Securing Australia's Future
By Simon Torok and Paul Holper, 208pp, CSIRO Publishing, 2017

4

Recharging education to power the nation

Australia lacks a sense of national urgency around STEM performance in contrast to some of our closest competitors.

Russell Tytler
co-author of SAF02 *STEM: Country Comparisons*

Golden thread

Australia must maintain its strong and broad foundations in education, including in science, technology, engineering and mathematics (STEM). We should nurture and challenge those who are enthusiastic in STEM, by better engaging primary and secondary school students, and supporting teachers. A major objective should be increasing participation in STEM by girls, those from lower socioeconomic backgrounds and Indigenous students. One immediate initiative would be a well-funded national STEM coordinating agency.

Key findings

Here are five key findings designed to improve education in general and to encourage Australian students to consider choosing STEM subjects and associated career choices:

1. The status of teachers in Australia needs to be lifted, they need ongoing support and training, and Australia needs to attract more science and mathematics teachers.
2. An innovative workforce relies on a strong education system that fosters academic skills across all disciplines, and analytic and social skills.

3. Mathematics and science experiences before the early middle years of schooling need to be positive and engaging. Mathematics could be made compulsory for everyone to the end of year 11 or even year 12.
4. Effective partnerships need to be fostered between civil and business organisations and education institutions that support innovation in school mathematics and science.
5. Australia would benefit from national coordination of approaches to improving participation in STEM.

Introduction

The Academy of Science asked a representative sample of Australians how long it takes for the Earth to go around the Sun. Almost a third said it takes a day. (The correct answer is that it takes a year to orbit the Sun. If it's any consolation, older Australians were more likely to give the wrong answer than younger ones.)

Innovation, science and research are critical to Australia's productivity and the securing of future industries.

This chapter explores how we can foster and enhance innovation, science and research through improvements to education in science, technology, engineering and mathematics and across the humanities, arts and social sciences.

We begin by looking at spending on education in Australia – which is acceptable by Organisation for Economic Co-operation and Development (OECD) standards – and how our school students fare in international assessments on science and maths literacy – acceptable, but declining.

Also declining is student participation in senior secondary science and maths. A growing number of high-achieving students, especially girls, study no maths at all in year 12. There is little surprise, then, that the Australian population has low scientific literacy. At tertiary level, Australia is well represented in the sciences but weak in mathematics and engineering. School participation in science and maths is declining at the very time when studies here and overseas are pointing to technology and innovation as vital to productivity growth.

Overall, the message is that Australian students are engaged in the STEM disciplines at levels comparable to those internationally, but we are not keeping pace with comparable countries that are lifting their performance.

We know this thanks to international comparisons undertaken by ACOLA's SAF02 *STEM: Country Comparisons* report panel. The researchers examined strategies, policies and programs used to enhance STEM at all levels of education and in the interface between education and work in over 20 countries. The interdisciplinary report examined solutions to the STEM skills shortage in comparable countries to determine which, if any, could be usefully applied in Australia to overcome similar shortages here.

Nations with leading and dynamic economies tend to be those with the strongest performing education and/or science research systems. These countries regard the STEM disciplines as essential for global economic positioning and social creativity.

There are five distinguishing characteristics of countries strong in STEM:

1. School teachers are held in high esteem, are well paid and are rewarded for performance and professional development.
2. Compared with Australia, STEM teachers are expected to be fully qualified in their discipline and to teach solely in that field.
3. The most successful countries have instituted active curriculum programs that make science and mathematics more engaging and practical.
4. Many of the successful countries have implemented innovative policies to lift STEM participation among formerly excluded groups, such as low-achieving and Indigenous students.
5. There are national STEM policy frameworks that support centrally driven and funded programs; world-class university courses; the recruitment of foreign science talent; and partnerships that link STEM activities in schools, vocational and higher education with industry, business and the professions. Frequently, there are agencies that have been specifically created to advance the national STEM agenda.

Despite the need for strong STEM foundations, many recent science and information technology graduates are failing to find full-time work. Some disciplines are in greater demand than others, such as IT and engineering. Demand for specific disciplines will vary in future, as the Australian workplace changes and new jobs emerge. A well-rounded education incorporating a range of disciplines will provide a strong basis for an ever-changing employment environment. Undoubtedly, STEM skills will continue to be needed, and relevant knowledge essential to engage in a technologically advanced society and contribute to decisions regarding the extent to which innovations should be implemented.

This chapter follows the discussion in Chapter 3 on the role of innovation and new technologies in lifting national productivity, sets the scene for how education must provide the foundation for our innovative farming, energy and urban industries of the future as described in Chapter 5, and provides context for our role in the Asian region as described in Chapter 2.

Achieving an innovative, flexible and creative workforce

Greater commercialisation of research doesn't happen spontaneously – it can only be led by STEM professionals who have not only technical skills and training but also business acumen, an understanding of how IP incentivises innovation, leadership and team management skills, cross-discipline skills and the creativity and motivation to drive the commercialisation process and closer ties between industry and the research sector.

– Professional Scientists Australia, quoted in SAF10 *Skills and Capabilities for Australian Enterprise Innovation*

Educational achievements and challenges

The Australian Bureau of Statistics reports that in 2015, 59 per cent of people aged 15 to 74 years had completed a non-school qualification. People aged over 55 years were less likely to have a non-school qualification than those aged 25 to 44 years. The proportion with a non-school qualification in both the 25 to 34 year age group and the 35 to 44 year age group was 73 per cent, compared with 58 per cent for people aged 55 to 64 years and 45 per cent for people aged 65 to 74 years. Of the 10.4 million people aged 15 to 74 years with a non-school qualification, almost one-third (29 per cent or 3 million) had a Bachelor degree.

However, the Standing Council on Tertiary Education Skills & Employment reported in 2012 that '44 per cent of Australia's working age population (around 6 million people) have literacy levels below … the level needed to meet the complex demands of work and life in modern economies'. Outside the labour force the figure is 70 per cent, which 'lend[s] weight to concerns about our ability to meet projected skills demands in coming years'. Furthermore, a large fraction of the Australian population has low scientific literacy.

> ***44 per cent of Australia's working age population (around 6 million people) have literacy levels below … the level needed to meet the complex demands of work and life in modern economies.***

This disturbing finding highlights the need for improvements in Australian education at primary and secondary level.

Interdisciplinary skills

In a 2016 report entitled *Promising Practices for Strengthening the Regional STEM Workforce Development Ecosystem*, the US National Academies of Sciences, Engineering and Medicine stated that:

> *Employers are increasingly focusing on the skills and abilities new hires possess, rather than the specific field in which an individual has obtained a degree or credential. While there is a need for STEM graduates who will work as professional research and development scientists and engineers (so-called STEM narrow skills), there is a growing need for individuals who apply STEM knowledge and skills in technologically sophisticated occupations that require a facility with STEM concepts, but not necessarily a bachelor's degree (so-called STEM broad skills). There is also a growing need for students with a breadth of skills outside of their core STEM discipline, including skills that are perhaps best developed through a well-rounded liberal education that includes STEM courses, humanities courses, and experiences in the arts. These include problem solving, critical thinking, teamwork and collaboration, communication, and creativity.*

The attributes most often identified as requirements for an innovative workforce are:

- basic reading, writing and numeracy skills;
- information and communications technologies;
- academic skills (including qualifications in science, technology, engineering and mathematics, and in humanities, arts and social sciences);
- analytical skills (including problem solving, critical and creative thinking, ability to learn and manage complexity);
- social skills (including the ability to work in teams, communication, and receptiveness to new ideas); and
- management and leadership skills (including the ability to form and lead teams, negotiation, coordination and ethics).

The value of teamwork

The Council for the Humanities, Arts and Social Sciences (CHASS) commissioned work to explore the relationships between the humanities, arts and social sciences (HASS) and the science, technology, engineering and medical (STEM) sectors. In the resulting report, researchers identified several ingredients to maximise the success of cross-sector collaborations. The most important ingredient turned out to be the characteristics of people on the collaborative team. The report quoted an interviewee with experience in cross-sector collaboration:

> *Those groups of people have worked best when there have been great skills in working in a group. Great interpersonal skills – this depends on the group – inclusive or exclusive (hierarchy). Also, the willingness of people to reflect on their part in the project. The communication – bringing those [skills] together with some of the other skills.*
>
> *Being prepared to let things evolve – go in a direction you may not have initially thought of – that is hard but often you get to the best outcomes.*
>
> *Being prepared to try anything once and if something doesn't work – so what? It didn't work. I think it needs to be about being adventurous.*

Future innovation depends on students gaining both STEM and HASS skills, including analytical and creative thinking, the ability to communicate ideas and work in teams.
(Source: Monkey Business Images/Shutterstock)

Australian enterprises – and education and government institutions concerned with innovation – need to move beyond a focus on technical skills alone and consider what other sets of skills will be needed for successful innovation in the future. Technical skills are necessary, but not sufficient for continued and successful enterprise innovation.

Research shows that innovative businesses need staff with a range of skills. STEM as well as business skills are important. STEM skills were more strongly associated with businesses that innovate with products and processes, while business skills were linked with companies that undertake process, organisational and marketing innovations.

Innovation now depends on 'bundles' of skills that are provided by people having broader skills (technical and non-technical), by people endowed with diverse sets of skills working in teams, and by organisations working in alliances and networks that bring together different skills and experiences across different types of innovation, and different activities in the innovation cycle.

The Australian Bureau of Statistics's Business Characteristics Survey found that skill shortages were the most significant barrier to innovation among innovation businesses. A quarter of all businesses active in innovation reported that skills shortages were a significant barrier to innovation.

There is an argument for broadening the skills of STEM trained and qualified employees, including managers and business leaders. Business will need to take on some of this responsibility, but educational institutions also have a role to play.

There is a need to emphasise broad relational and problem-solving skills that are applicable across all disciplines. For tertiary education, this may require new curriculum developments that build skills mixing by:

- integrating management subjects in non-business degrees, and embedding technical programs in business and arts degrees;
- providing internship opportunities, and practical application within academic programs;
- creating opportunities to complete practical certificate-level programs while completing a degree program;
- developing industry-based and 'translational' PhD programs that enable students to apply research in solving industry problems and developing products and services that can be taken to commercialisation.

More direct involvement with enterprise workplaces during their studies will help tertiary students develop a more holistic understanding of the skills needed for innovation.

There is always choice in the development and adoption of new technologies, and education relating to technological change is essential to facilitating adoption. Education and training – even from an early age – that focuses on problem-based learning and critical thinking is more likely to create a workforce that is better adaptable to new technologies and more likely to benefit from restructuring caused by technological change. While much of this chapter examines STEM education and its application, Australia will benefit immeasurably from a rigorous approach in schools and universities to humanities, arts and social sciences, and to their active application in the workforce and in helping make decisions about the adoption of new technology.

Science, technology, engineering and mathematics education: a national report card

> *STEM education is almost universally recognised as important. A key problem for Australia lies in the distribution of student achievement with a long tail of underperforming students when compared to our major competitors.*
>
> – Russell Tytler, co-author of SAF02 *STEM: Country Comparisons*

In 2015, there were over 3.7 million students enrolled across more than 9400 schools in Australia. Government schools were responsible for 65 per cent of all students.

Under the Australian Constitution, states and territories have responsibility for education, although the Commonwealth also contributes funds to school and tertiary education. The OECD estimates that Australia's 2011 government expenditure on school and non-tertiary post-school level education (3.5 per cent of GDP) matched the OECD country average.

Total spending on school and non-tertiary post-school education was 4.1 per cent of GDP compared to the OECD country average of 3.9 per cent, reflecting high investment in Australia's large private school sectors.

Student performance in science and mathematics

Australia's school student science and mathematics performance is declining in some instances, and remaining static in others. The 2012 study by the Program for International Student Assessment (PISA) ranked Australia 16th in science and 19th in mathematics.

Scientific literacy

> *Australia's average score in the PISA 2012 scientific literacy assessment was significantly higher than the OECD average.*

Australia's average score in the PISA 2012 scientific literacy assessment was significantly higher than the OECD average. Thirteen per cent of Australian students were low performers in scientific literacy compared to 18 per cent of students across the OECD. We were outperformed by China, Singapore, Japan, Finland, Estonia and Korea – for example, just 2 per cent of students in China were low performers.

The performances of Australian girls and boys in scientific literacy were similar, while across OECD countries boys performed slightly better than girls. Australia's average score in scientific literacy did not change significantly between PISA 2006 and PISA 2012.

Mathematical literacy

Australia's score in the PISA 2012 mathematical literacy assessment was significantly higher than the OECD average. We were outperformed by 16 countries, including China, Singapore, Korea, Japan, Liechtenstein, Switzerland, the Netherlands, Estonia, Finland, Canada, Poland, Belgium and Germany.

Australian boys achieved an average score in mathematics significantly higher than that for girls. This difference is equivalent to about one-third of a school year.

Between PISA 2003 and PISA 2012, mean mathematical literacy performance dropped significantly in 13 countries including Australia, while the OECD average performance held steady. Our performance in mathematics is concerning: Australian top, average and low-performing students all recorded significant declines between 2003 and 2012. The performance of girls fell more than that of boys.

The gap between our lowest and highest performing students is wider than the OECD average for each of mathematical, scientific and reading literacy.

Our performance in mathematics is concerning: Australian top, average and low-performing students all recorded significant declines between 2003 and 2012.

School science and maths continues to fall out of favour

Participation in senior secondary science and mathematics has been declining for decades.

Participation in senior secondary science and mathematics has been declining for decades (Fig. 4.1). From 1992 to 2012 the proportion of year 12 students studying biology fell from 35 to 25 per cent, chemistry from 23 to 18 per cent and physics from 21 to 14 per cent.

There was a lesser decline in mathematics but most students were enrolled in elementary mathematics subjects. Only 10 per cent participated in advanced mathematics at year 12 level. A growing proportion of high-achieving year 12 students, particularly girls, study no maths at all.

Intermediate and advanced mathematics (calculus-based subjects) are prerequisites for many university STEM-discipline courses, so decreased participation in these subjects in year 12 means fewer students can progress to university STEM disciplines. Coincidently, increased competition among universities for high-achieving students has led to the lowering of entry prerequisites for courses. Many commentators attribute the decline in mathematical ability to a lowering of entry standards for engineering degree programs; the majority of universities have removed the higher level secondary school mathematics prerequisite.

Tertiary participation: strong in sciences, weak in maths and engineering

From 2002 to 2008, the number of domestic students commencing higher education in natural and physical sciences was fairly constant. However, numbers grew by 29 per cent from 2008 to 2010. The largest increase in science-related enrolments was in health, which experienced a 73 per cent rise from 2002 to 2010, helped by nursing being made a university degree program.

From 2002 to 2010 engineering commencements grew by 21 per cent, albeit from a low base. In Australia in 2010, fewer than 9 per cent of new tertiary education students were in engineering, manufacturing and construction, compared with 15 per cent in the average OECD country. The comparison is more stark in mathematics: 0.4 per cent of Australian new tertiary entrants chose the subject, compared with the OECD country average of 2.5 per cent. During the same period, undergraduate enrolments in information technology halved, and agriculture and environment enrolments more than halved.

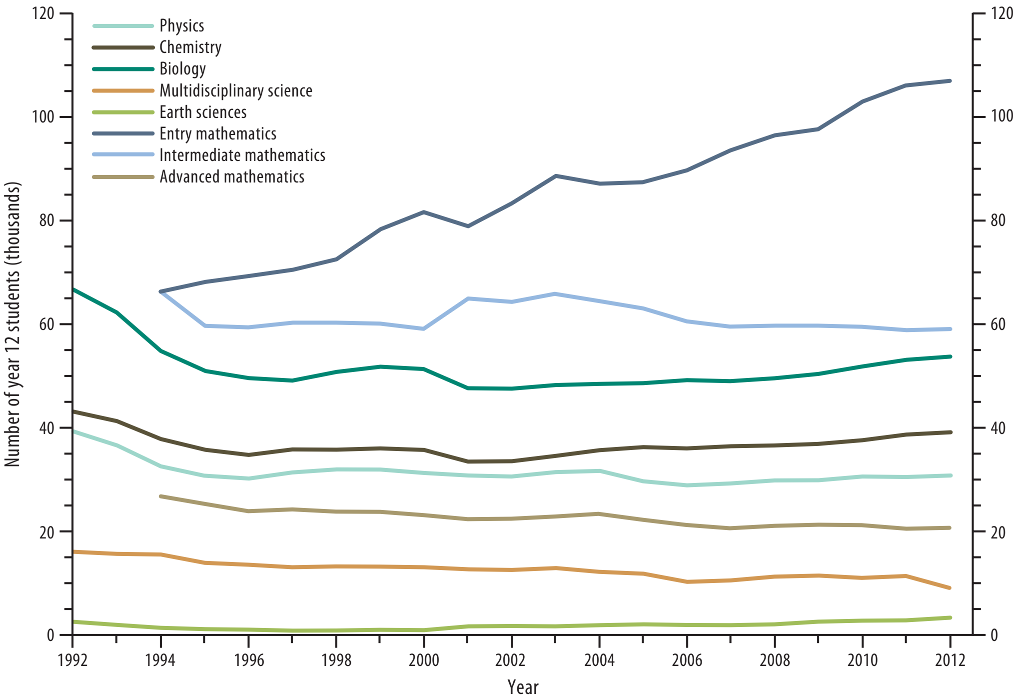

Fig. 4.1. Australian participation rates for science and maths subjects, 1992–2012. Modified with permission from Kennedy J, Lyons T, Quinn F (2014) The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science* **60**(2), 34–46.

In other words, Australia is relatively strong in participation in the sciences but weak in mathematics and engineering.

The 2011 Australian Census showed that employment rates are high among all STEM-qualified people (81 per cent), and that unemployment remains low (less than 4 per cent). From 2007 to 2011, the number of employed people across the Australian economy grew by 8.1 per cent, while the top eight STEM occupations grew by an average of 11.1 per cent. The strongest growth in employment among STEM occupations was in design, engineering, science and transport and information and communications technology.

In most countries the role of STEM is larger at doctoral level than first degrees. In Australia, 26 per cent of PhDs awarded in 2008 were in science, with 14 per cent – low by international standards – in engineering. International students are responsible for any growth: the number of Australian students commencing a PhD in science and engineering in 2010 was below the 2004 level. By contrast, many countries are experiencing rapid growth in STEM doctorates.

Tertiary enrolments in STEM continue to be dominated by men, as happens in many countries, especially in engineering. In 2010, just 25 per cent of Vocational Education and Training STEM students were women. In higher education, 44 per cent of STEM students were women, compared to 56 per cent in all disciplines. If you remove health sciences and nursing, the imbalance becomes more extreme.

Participation rates of Australian students in the STEM disciplines are good on the international scale and provide something of a competitive advantage. However, Australia needs to undertake significant improvement in order to keep pace with comparable countries that are lifting their performance.

Australia needs to undertake significant improvement in order to keep pace with comparable countries that are lifting their performance.

Strong STEM push overseas

A useful way of assessing Australia's performance in education and ways in which we can improve is to compare efforts and results here with those overseas. ACOLA's SAF02 *STEM: Country Comparisons* report panel examined strategies, policies and programs used to enhance science, technology, engineering and mathematics at all levels of education. The countries, regions and groups studied were Argentina, Belgium, Brazil, Canada, Canada indigenous, China, Denmark, Finland, France, Germany, Israel, Japan, Korea, The Netherlands, New Zealand, Norway, Portugal, Russia, Singapore, South Africa, Sweden, Switzerland, Taiwan, United Kingdom, United States, and United States indigenous.

The many overseas countries examined were preoccupied with the level of STEM participation in senior secondary school.

The governments of the many overseas countries examined were preoccupied with the level of STEM participation in senior secondary school, and the level of achievement in the STEM-related disciplines in both secondary and higher education. These governments strive to build high-end STEM skills, linked to research and development, and industry innovation.

The view is that achieving quantity and quality in STEM competencies lifts economic performance. Most government action is directed at lifting STEM take-up in schools, via curriculum, pedagogy, student motivation and teaching. The approach is understandable as schooling is subject to direct government regulation and responsibility, while universities are more autonomous and largely beyond governmental reach.

Many countries view STEM-related education as fostering broad-based scientific literacy. STEM disciplines lift the general level of understanding of science and technology, and disseminate quantitative, reasoning and problem-solving skills of a high order across the economy.

Curiously, despite the widespread assumption and expectation that STEM contributes strongly to productivity and innovation in the workplace, little genuine effort is made to establish whether, and to what extent, these expected benefits of STEM are manifest in the economy. Policy focuses largely on the supply side, on tuning the education system to turn out more STEM students, with demand for such skills expected to appear spontaneously.

PricewaterhouseCoopers assessed the importance of STEM subjects in a 2015 publication, describing technology and innovation as 'the solution to our workforce and growth challenge'. PricewaterhouseCoopers reported that 75 per cent of fast-growing occupations in Australia require STEM skills and that moving 1 per cent of the workforce into STEM roles would add $57.4 billion to our gross domestic product.

There is a strong link between cognitive ability levels in the population – as measured by tests of scientific, mathematical and reading literacy – and long-term economic growth and competitive advantage, as well as overall wellbeing. Economic modelling has consistently identified a relationship between direct measures of cognitive skills and long-term economic development.

In trying to apply lessons from overseas, we could focus on nations that have much in common with Australia, such as English-speaking countries and the affluent countries of north-western Europe. But that's not where the strong performances are in education and in STEM more generally. It is countries with quite different languages, histories and cultures from our own, such as Finland and East Asian nations such as Korea, Taiwan and China that are the star performers. Other standouts are Singapore and Hong Kong. These are the places to learn from, where there are successful programs that are lifting STEM performance in schools and in research. Finland has exceptional STEM indicators in all domains including school performance, the proportion of doctoral enrolments, teaching and the workforce.

'Science for all' is the international mantra. Many countries pursue this aspiration through changes to the junior and middle secondary curriculum, and an increasing focus on science-specific education in primary schools.

There are strong arguments for making mathematics a compulsory subject at high secondary school year levels.

There are strong arguments for making mathematics a compulsory subject at high secondary school year levels. Higher order mathematics such as statistical modelling is increasingly useful in a broad range of areas. A goal of science for all also requires stronger mathematical skills.

In China, maths is compulsory until the end of school. Long-term planning abounds, with a broad governmental consensus about the importance of science, technology, research and STEM. There are strong programs to lift international rankings of the top science universities. Policy focuses on quantitative benchmarks, achieves them and moves the standard to a higher level. There are comprehensive programs of reform in every schooling system with a common movement towards more student-centred, inquiry-based and problem-solving learning and an emphasis on creativity.

Careers in research and development and technology management draw high-achieving STEM students. Where do we find the largest number of top performers in PISA? In mathematics it's the Shanghai region of China, Singapore, Hong Kong and Taiwan. The places with the largest group of students in the top three proficiency levels are Shanghai, Singapore, Hong Kong, Taiwan, Korea, Finland and Switzerland. Interestingly, these are also the systems with the smallest proportion of underperformers. These countries are lifting student achievement across the entire population.

The notion of science for all accompanies an emphasis, in nearly all countries, on fostering high-end STEM achievement: increasing the size of the high-performing cohort, retaining more bright students in STEM, lifting the level of performance of top students, and fostering research and world-class universities.

The United Kingdom Treasury Ten-Year review says:

> *[T]he Government's overall ambitions are to achieve a step change in: the quality of science teachers and lecturers in every school, college and university; the results for students studying science at GCSE level; the numbers choosing SET subjects in post-16 education and in higher education; and the proportion of better qualified students pursuing R&D careers.*

High-performing Asian countries often feature specialist science and mathematics schools providing elite education.

Wealthy country students have lowest interest in science

Worryingly, students in the wealthiest countries – who coincidently achieve high scores on international mathematics and science texts – tend to have the least interest in science. Just 25 per cent of girls and 40 per cent of boys in Norway, for example, agree they like science better than most other school subjects. Eighty per cent of students in Uganda like science better than most other school subjects. (There are no comparable figures for Australia.)

The findings highlight the challenges in post-industrial societies such as Australia of engaging students in science.

Encouraging and improving STEM teaching

STEM strong countries have a strong focus on teachers and teaching with teachers held in high esteem and expected to teach in their qualified field and not others.

– Lesley Johnson, University of Technology Sydney and Griffith University

We saw in the previous section the international moves towards inquiry-based and problem-solving education. Australia has a long-standing commitment to these and to scientific and mathematical literacy. Our educators have been at the forefront of these ideas internationally. However, many schools and teachers adhere to traditional teaching approaches. This situation is reinforced by assessment that entails testing of concepts at low levels of reasoning and problem solving.

The situation is often worsened, particularly in mathematics, by the number of out-of-field teachers. The solution lies in dedicated teacher professional development that supports significant changes in the teaching of mathematics and science.

We certainly don't have enough mathematics and science teachers. There are shortages, especially in rural and remote communities. However, a larger problem is where teachers take classes for which they have little, or even no, university training. Our ageing secondary teacher population exacerbates the problem. The status of teachers in Australia needs to be lifted, and entry into the teaching profession should be more competitive.

There are a few overseas examples of differential salaries or incentives to attract and retain science and maths teachers, particularly in hard-to-staff schools. One option is to provide higher pay for teachers with Honours or higher degrees. Another strategy is to provide bonus starting pay for maths and science teachers in low socioeconomic status schools and regional and remote schools. The United Kingdom does this with its 'golden welcome' scheme. In high-performing Asian countries in particular there is a strong tradition of school-based professional learning through collaborative planning.

Discipline-specific professional development in Australia could address methods of problem-solving, inquiry-based approaches, critical thinking and creativity, and other ways of increasing student learning and engagement with science and mathematics.

Australian primary schools include only a small proportion of teachers with major studies in science or mathematics, compared to our major comparator countries. An enthusiastic and knowledgeable primary school science or mathematics teacher can increase the quality of the curriculum and pedagogy.

Australia needs to increase its numbers of mathematics and science teachers to decrease out-of-field teaching. (Source: Iakov Filimonov/Shutterstock)

We need to improve the confidence and competence of primary teachers in the teaching of science and mathematics. The United Kingdom offers a promising model. There, trained specialist mathematics leaders are responsible in their schools for overseeing mathematics teaching skills and approaches, and for developing learning resources.

There is far too much teaching 'out of field' for mathematics and science in Australia, especially in regional and rural areas. We need to quickly attract more qualified teachers into the profession. It is unacceptable to have our primary school children taught by staff without the requisite knowledge and skills.

Too few women in STEM

The main issue in Australia is the lack of women between entry and senior levels in STEM fields. Changing this situation is about local actions at all levels.

– Nalini Joshi, co-chair of Science in Australia Gender Equity program

The proportion of women employed in STEM fields in Australia is too low. Women and girls are under-represented in STEM fields throughout their education and careers. Under-representation of women in science and other STEM fields is problematic for several reasons. When the gender balance in STEM matches the gender balance in the real world, the STEM research is more likely to be productive and relevant. Women can boost the quality of STEM research; diversity leads to creativity and reduces bias. Additionally, greater participation by women yields a larger talent pool from which to source the best and brightest.

Student attitudes and career ambitions at secondary school level are critical in determining engagement in tertiary level science courses. Almost three-quarters of students who studied two science subjects in their final year of secondary school continued on to study science-related areas at university. Young women are less positive about STEM study.

In New South Wales, the participation of girls in at least one mathematics and one science subject after year 10 has been declining since 2001. Between 2001 and 2011, the proportion of girls who elected to study no mathematics whatsoever after year 10 tripled from 7.5 per cent to 21.5 per cent. The corresponding proportion of boys also tripled but from a much lower base level, from 3.1 per cent to 9.8 per cent.

At tertiary level in Australia, men outnumber women in mathematics, statistics, sciences (particularly physics), engineering, manufacturing, construction and computing. Women outnumber men in the study of health, welfare, education, humanities, arts, agriculture, life sciences, services, social sciences, business and law. There are similar patterns internationally.

Not only is female participation in STEM education and employment low, but the attrition rate is high, with women leaving science and other related disciplines in disproportionate numbers at each stage of the career cycle. This happens most at the post-doctoral level.

Lifting STEM participation by women

Countries are pursuing a variety of gender equity policies and strategies to address the under-representation of women and girls in STEM fields. In Australia, a good start would be system-wide targets to lift numbers.

Changes should begin with schools and with teacher training. Primary school children need to be engaged from an early age in science experiences. Most children thoroughly enjoy being actively involved in experiments and technology. This engagement logically leads to an increased focus on inquiry-based science teaching, with mathematics integrated throughout the curriculum.

Curriculum design and professional development can generate greater teacher awareness about encouraging girls to consider STEM pathways. The design should include content, pedagogy and resources suited to the learning styles and preferences of girls as well as boys.

Mentoring programs lift female participation. A sound model is to bring together young women and successful female STEM professionals to provide understanding of STEM careers, and access to female role models. Such contact with STEM professionals could start as early as primary school and continue through education and early career training.

Allocation of targeted funding will help, such as scholarships and fellowships specifically reserved for female students and researchers, in areas such as engineering where women are grossly under-represented. There is merit in reserving funds for women to assist their study and establish themselves as researchers, and allocating greater points in funding selection processes to projects that include women researchers.

In 2015, the Australian Academy of Science and the Australian Academy of Technology and Engineering established a program of activities designed to improve gender equity and diversity in STEM and in medicine. Science in Australia Gender Equity (SAGE) is funded by the Australian Government and involves 40 universities, research institutes and organisations. A pilot project requires participants to collect, analyse and present data on gender equity policies and practices in relevant departments, as well as identify gaps and opportunities for improvement.

Lifting Indigenous engagement in STEM

While there have been some improvements over the past decade, the gap between Indigenous and non-Indigenous educational outcomes remains unacceptably large.

– Geoff Masters, Chief Executive, Australian Council for Educational Research

What lessons can we take from overseas to increase the involvement of Indigenous Australians in STEM, and in education generally? Australia has many educational support structures for Indigenous people.

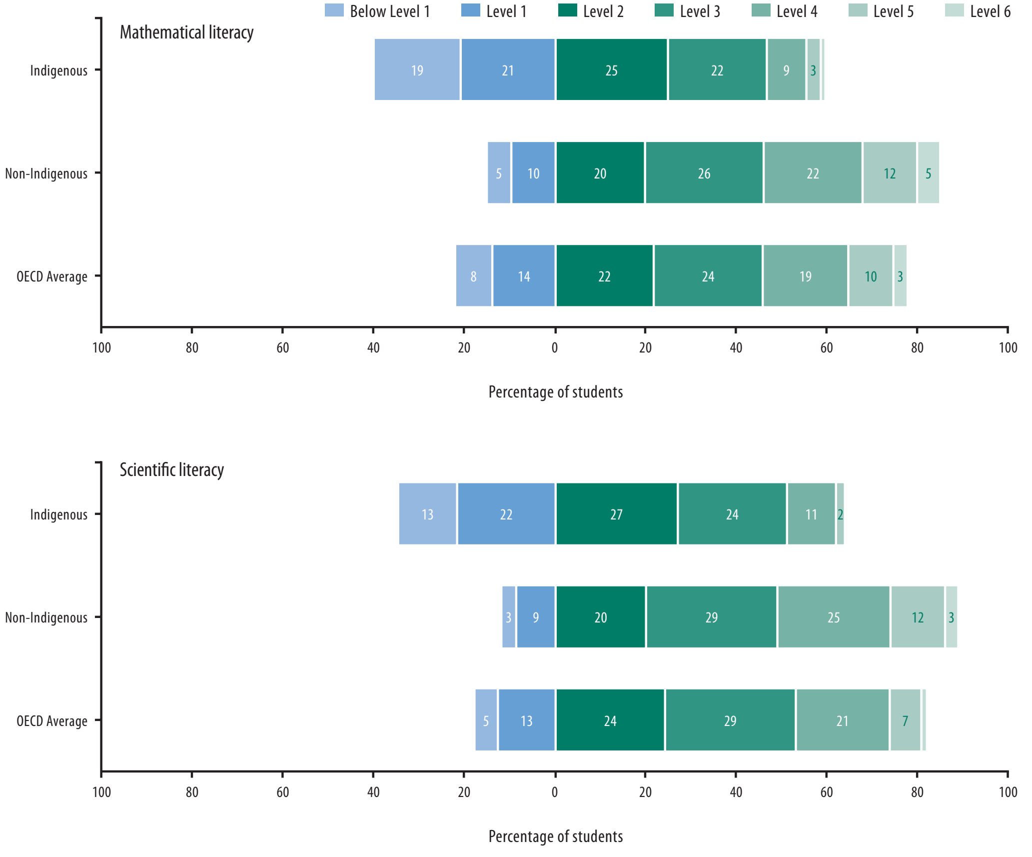

Fig. 4.2. There is a significant level of disadvantage for Indigenous Australians in mathematical and in scientific literacy, with 62 per cent of Indigenous children in Level 4 working at Level 2 or below (13 per cent have virtually no competency) compared with 3 per cent of non-Indigenous children. (Source: Thomson S, Hillman K, Wernert N, Schmid M, Buckley S, Munene A (2012) *Monitoring Australian Year 4 Student Achievement Internationally: TIMSS and PIRLS 2011*. Australian Council for Educational Research, Melbourne.

Overseas studies identify two culture-related issues that act against Indigenous participation in STEM. First, there is a mismatch between cultural beliefs about the world and science and mathematics curriculum beliefs and teaching approaches. Second, Indigenous students often have problems in dealing with institutional cultures, particularly at university level. The disadvantage that Indigenous students face in scientific literacy is shown in Figure 4.2.

Australia can learn from Canadian experiences in indigenous STEM education. There, 'culturally responsive teaching' involves the recognition of indigenous knowledge as part of the study of science. We can recognise Indigenous Australian knowledge in science and mathematics curricula, involving Indigenous elders, and in the ensuing development of curriculum and teacher professional learning support.

Programs and activities to facilitate Indigenous students' learning and work in STEM-related disciplines could include courses facilitating the transitions between schooling and tertiary education, and between education and work; outreach activities between tertiary education and schools; and working with industry to establish processes for engaging Indigenous students and graduates into the workforce, including local work placements that draw on STEM education and training.

Scholarships leading to university and/or employment would help, as would specialist societies, mentors and career counselling in tertiary education institutions. Professional development could include recognition and respect for Indigenous ways of knowing; culturally responsive teaching, in which students from Indigenous backgrounds are supported in engaging effectively with scientific thinking and practices; and programs that facilitate Indigenous students' learning and work in STEM-related disciplines.

Partnering and enriching

I love seeing threw [sic] the microscope and I saw algae and it moved.

– Year 1 boy, during Scientists in Schools lesson on microbiology

There are numerous international examples of informal support for STEM education, including partnerships between civil and business organisations and education institutions; and a plethora of enrichment programs.

While partnership activities, especially local ones, are common in Australia, often there is no clear understanding of their nature and their effects. Developing such an understanding would be helpful, as would sharing of details about the relevant initiatives. The next step would be to develop advice for science organisations, business and industry and school authorities regarding how best to develop and manage partnerships.

Learning experiences outside the classroom include National Science Week, camps, science centres, museums, zoos, planetaria, aquaria, botanical gardens, science parks, science fairs, historic parks, and performing arts and science centres. There are science awards and competitions such as Olympiads in physics, mathematics, chemistry, geoscience and engineering. These activities are often aimed at high-achieving school students. Real-world science activities include 'Meet the Scientist', excursions and work experience.

Again there is a lack of coordination and oversight of these programs. There is strong anecdotal support, but little clarity about their impact on students. Often the programs have not been formally assessed.

Science by Doing, the Australian Academy of Science's comprehensive online science program, is available free to all Australian students and teachers (https://www.sciencebydoing.edu.au).

A particularly successful example of support for school teaching and learning of science is the Academy of Science's 'Primary Connections' project for primary schools, and its 'Science by Doing' online science program for years 7 to 10. The Scientists and Mathematicians in Schools program, run by CSIRO, has been very positively evaluated.

The Australian Academy of Technology and Engineering runs STELR, a hands-on, inquiry-based, in-curriculum program designed for year 9 or year 10 students, on the theme of global warming and renewable energy.

National STEM coordination

> *STEM strong countries were all found to share a focus on curriculum reform to make STEM engaging; a strong commitment to learning and achievement for all; guided by a national STEM policy framework.*
>
> – ACOLA media release

The country comparisons suggest possibilities for productive approaches to improving participation and performance in STEM at many levels, relating to teaching and teacher education, curriculum and pedagogy at primary through tertiary levels, public perceptions, and participation by particular groups including girls and women, low socioeconomic status communities and Indigenous communities.

Individual programs and activities can themselves be valuable, but to maximise the benefits for Australia we need national level coordination. Almost all countries studied feature a single coordinating process or agency. There is a strong case to be made in

Australia for coordination at national level of the various aspects of STEM participation. National coordination would bring coherence, enhance the status of STEM, and draw on significant Australian expertise. It might even succeed in developing approaches that would operate beyond election cycles.

There is a strong case to be made in Australia for coordination at national level of the various aspects of STEM participation.

In Australia, STEM policy in schools is vested in the states. The Office of the Chief Scientist appointed a science and maths education and industry advisor to oversee coordination across the country. However, compared to the situation in similar countries, where significant structures including centres are common, the level of input of advice and the capacity to commission studies and generate resources seems limited.

Coordination could be via a specially constituted national STEM agency or centre reporting to an appropriate government office or department. Options include an advisory body with state and territory government representation, and an advisory body with broad representation of peak stakeholder groups including industry, STEM educator and research bodies, and education systems.

Useful tasks for the coordinating agency include compiling data on participation and performance in STEM education, and coordinating approaches to STEM-related teaching and learning in tertiary education, including outreach and placement activities in partnership with schools and with industry.

In fact, the agency could play a pivotal role in Australian STEM education by seeking to implement all the suggestions in this chapter.

Lessons for Australia and STEM

By doing a science or engineering degree, [students] are going to learn a way of thinking and understanding of the world around them that I think will serve them very well, whether they go into science or business or politics or the public service.

– Alan Finkel, Chief Scientist for Australia

Overseas experience shows that Australia should aim to increase the pool of students undertaking STEM subjects, and nurture and challenge those who are enthusiastic. We need effective remedial programs, especially in mathematics. We need more of our high-achieving year 11 and 12 STEM students to continue with these disciplines in higher education.

If Australia is to produce a strong STEM educated population, we need to pay serious attention to students who are currently performing poorly in this area, including those from low socioeconomic backgrounds and Indigenous students. Our increasingly fragmented education system with the concentration of STEM students in wealthy suburb public schools and in private schools is at odds with overseas approaches that feature wide community participation with STEM for all students.

The Australian education system maximises the choice of subject offerings. In Victoria, for example, students can choose from more than 100 subjects for their final years of secondary school education. There has been a relaxing of prerequisites for tertiary education, allowing students to delay career choices. The disadvantage is that students can choose 'easy options' and shy away from challenging subjects such as science and mathematics.

We can learn from some other countries' more stringent approaches to STEM education. It is likely that the increased range of choices in Australian schooling, the reduced role of science and mathematics prerequisites for university entrance (and the corresponding greater emphasis on aggregate score rather than subjects completed), and thus the ease of opting out of harder STEM subjects, are associated with fewer students taking STEM subjects and fewer students tackling the most challenging subjects.

One way to increase the proportion of students doing STEM, while not compromising the rigour of the STEM subjects, is to introduce mandatory mathematics and/or science to either year 11 or 12. Such an approach would need a commitment to providing enjoyable and rewarding learning experiences in the middle years of secondary education.

In several high-performing countries, STEM subjects at upper secondary school level are strongly linked to university entrance. One way of encouraging the study of STEM in both senior secondary and higher education would be the reintroduction of more comprehensive prerequisite requirements for university programs requiring advanced STEM knowledge.

One way of encouraging the study of STEM in both senior secondary and higher education would be the reintroduction of more comprehensive prerequisite requirements for university programs requiring advanced STEM knowledge.

In 2016, for example, the four public Western Australian universities offered an incentive to students to study advanced maths at school – a 10 per cent bonus on their score in this subject. Professor Arshad Omari, Deputy Vice-Chancellor at Edith Cowan University, explained the initiative to *The Australian*: 'Maths is a bugbear for all universities. We all want students to have had better exposure to maths before they get to university. On top of that, we all know the jobs of the future will revolve around being numerate.'

One way to improve STEM adoption is to have some STEM skills incorporated into a range of apparently non-STEM subjects. The opposite applies as well. Science subjects can consider the ethics of various technological advances, such as biotechnology.

Overseas comparisons lead to some options for structural change in Australia that could develop further the reach and educational effects of the STEM disciplines and increase their social and economic contributions to Australia:

1. STEM tracking: separating students into STEM streams early in their secondary education may lift achievements in these fields and attract more students. Many of Australia's comparator countries achieve strong participation in STEM through separation at secondary school level between STEM and non-STEM tracks, and vocational tracks leading to significant STEM training.
2. Academic and technical-vocational institutions: the development of a group of STEM-intensive schools and tertiary institutes.
3. An integrated secondary curriculum: a less specialised and more integrated upper secondary curriculum, in which all students would pursue mathematics, science and humanities. This would strengthen 'science for all', and it may broaden the intellectual formation of high achievers.
4. Mandatory STEM in years 11 and 12.

These changes don't all have to occur together; they can be considered independently. Indeed, the first and third are contradictory.

School student interest in science and maths declines with age

Over half of Australian year 4 students say they like science. Only a quarter say so in year 8. Almost half of those year 4 students profess fondness for mathematics; by year 8 just 16 per cent enjoy the subject. The trend of declining attitudes to mathematics and science with age, from primary through the secondary school years, happens overseas too.

Any initiatives designed to encourage STEM participation need to be broad and focus on primary and secondary schools. The primary and lower secondary years are crucial in determining students' intentions to continue or not with STEM-related subjects and careers. Student experience and developing intentions through these years are strongly indicative of their eventual choices.

The implications are clear – if we are to encourage students to consider the possibility of STEM subjects and eventual career choice, or even to encourage them to engage productively in the future with science and mathematics, then their mathematics and science experiences before the early middle years of schooling need to be positive and engaging, and they need to be made aware of the range of people and activities comprising STEM work in society.

Personal identity: a powerful way of engaging students

Better understanding students' identities – how they perceive themselves; their experiences, relationships and aspirations – is a powerful way of examining the factors affecting student commitment to STEM. It's also a good way of studying the issues associated with Indigenous people learning science, and also the experiences of other minority groups, low socioeconomic status students, and girls.

Identity helps to determine strategies needed to support a broader cohort of students engaging with, and valuing, science and mathematics.

Encouraging STEM participation from an identity perspective entails:

- emphasising role models, whereby students are introduced to people working in and enthusiastic about STEM, with whom they can relate;
- curriculum diversity to cater for many students, so that STEM ideas and practices are seen as sufficiently varied to allow for individual commitments;
- the inclusion of values in the curriculum, so that technological objectivity and determinism (the belief that people have no real ability to make choices or control what happens) is not seen as defining of STEM – instead, students see that social good and personal values can be associated with STEM ideas and practices;
- inclusion of career information and images as part of the school curriculum, so that students have identity models to work with, offering a range of possible identity futures; and
- teaching that takes on and values science ideas, as critical in learning science.

Building student awareness of STEM disciplines and occupations

Many countries run programs aimed at student attitudes and identity, including initiatives to increase awareness of the nature of STEM professions. Australia could do similar work to encourage positive attitudes to study of mathematics and science, and to STEM-related work and careers.

US seventh grade student drawings of a 'scientist' before (left) and after (right) a student visit to a scientific research laboratory. (Source: European Communities (2008) *Mapping the Maze: Getting More Women to the Top in Research*. Scientific Culture and Gender Issues, Directorate of Science, Economy and Society, European Commission, Brussels. Document Number: EUR 23311 EN, p. 13)

Such strategies could include:

- awareness campaigns to enrich public understanding of career options in STEM and the nature of STEM work;
- school programs that involve families in maths and science learning and in building positive attitudes to STEM-related careers;
- role models, in the form of student interaction with practising STEM professionals, or web-based presentations of narratives of STEM professionals;
- career advice that includes images of people working in STEM-related careers, delivered through information workshops for careers teachers and mathematics and science teachers;
- the inclusion in curriculum resources of images of people working in STEM-related careers; and
- the inclusion in curriculum resources of materials that meet the identity needs of the diverse range of students.

Learning, not teaching

All of the advanced industrial countries comparable to Australia favour similar kinds of curriculum reform, shifting from a heavy content focus in science and a rules-based approach to maths, towards inquiry, problem solving, creativity and critical skills.

Countries are establishing pedagogies that are student-centred and inquiry-based.

All these countries are establishing pedagogies that are student-centred and inquiry-based, with support for a variety of student competencies. High-performing Asian countries such as China are incorporating inquiry-based, creativity-focused, student-centred learning with reforms supported by textbook revision, teaching resource material preparation, and professional development for teachers.

Many countries in Western Europe have embraced inquiry-based education, particularly with the sciences, and learning which involves real-world contexts.

Findings for the future

Based on the research and evidence presented in the relevant ACOLA Securing Australia's Future reports, there are several actions that we could implement to encourage Australian students to consider choosing STEM subjects and associated career choices.

A sound start would be national coordination of approaches to improving participation in STEM.

These actions include making students' experiences in mathematics and science more positive and engaging, including highlighting the many applications of these subjects in society. There is a variety of partnerships between schools and external agencies including business that could help support this link between the classroom and the workplace.

Implementing these changes – and additional findings presented in the reports – will help make Australia more competitive, contribute to innovation and help us cope with technological change in the coming decades.

The SAF program addressed STEM education needs, challenges and solutions throughout several reports, particularly SAF02 *STEM: Country Comparisons*. Given the consistent findings about the integral place of the humanities, arts and social sciences (HASS) disciplines to Australia's innovation future, there is a need to better understand the types of skills and knowledge delivered by education in HASS, and the opportunities and challenges facing these disciplines, including the contribution they have to make to improving Australia's literacy levels.

Engaging with the world

If we are going to negotiate future challenges, and make the most of any opportunities that might come our way in the Asian Century, we want to give our children the best education to do so.

– Ross Tapsell, Australian National University

We are operating in a truly global economy. As highlighted in Chapter 2, for example, the rise of Asia will have large implications for Australia through the 21st century. Successive Australian governments have made Australia's relationship with Asia a policy priority since at least the 1990s, and Australia's economic prosperity is increasingly driven by two-way trade with the region, which now accounts for 55 per cent of total trade with the world.

There are several ways of strengthening relationships with our neighbours. Taking advantage of language, research and cultural capabilities will provide the basis for deep, long-term engagement that will return social, economic and political benefits to Australia and its partners in the region. Improving cultural literacy will bring many benefits to Australia.

While English may have the status of a world language, being monolingual in English is insufficient for deep engagement internationally. Bilingual or plurilingual capability is the norm in most parts of the world.

Foreign language learning has a significant positive effect on knowledge and perception of another country. A 2013 Newspoll survey of Australian attitudes towards Indonesia found that those who have studied the Indonesian language have a higher level of awareness and understanding of the country, have more positive perceptions of Indonesia, are more likely to think Australia and Indonesia have things in common, and are more supportive of increased links between the two countries.

STEM is a central preoccupation of policy makers across the world. Many Asian countries are strong in these fields and aspire to be stronger. Most successful countries have instituted active programs of reform in curriculum and pedagogy that are focused on making science and mathematics more engaging and practical, through problem-based and inquiry-based learning, and emphases on creativity and critical thinking. These themes also run through the best Australian classrooms. Perhaps here is a further opportunity for engagement with Asia: smart STEM engagement.

The power of language

The importance of language – and language differences – is often underestimated, especially in a largely single-language, English-speaking country such as Australia. Efforts over recent decades to promote Asian languages have not been particularly successful. Levels of interest have remained low. Of the 70 000 students enrolled in the NSW Higher School Certificate in 2014, only 2.2 per cent studied Japanese, 1.3 per cent studied Chinese and 0.3 per cent studied Indonesian (see Chapter 2).

Diversity Council Australia's nationally representative survey of 2000 Australian workers uncovered the following: one in three has no or very little understanding of Asian languages or culture; two out of three have no or very little operational knowledge of how to manage in Asian business contexts; and just one in 20 is fluent enough in an Asian language to comfortably communicate on complex business matters with colleagues or clients.

A significant increase in uptake of foreign language learning will be difficult to achieve in Australia. We need to stimulate demand for language learning, especially of Asian languages. Options include integration into the curriculum, an example of which is the International Baccalaureate where language study is mandatory as part of the program's commitment to multilingualism. While such integration offers the possibility for students to learn a language more thoroughly, sufficient resources would need to be allocated across both primary and secondary school programs.

Language study in senior secondary school could be made compulsory for university entrance, or be made a requirement for some university courses. Alternatively, tertiary admission scores could include a bonus for studying an overseas language in year 12. Learning a language could also be made compulsory at university regardless of the course followed, similar to practices at US universities.

Conclusion

Australia is unique in many ways, including our natural resources. To maximise our many advantages we need to make use of a wide range of skills. Our approach will necessarily be different from that undertaken by countries with fewer resources. We should learn from other countries' approaches, including to STEM education, but success will not come from simply emulating them. But we do need to approach and plan for our future every bit as seriously as our competitors.

This chapter on revitalising education draws on key ACOLA reports (SAF02 *STEM: Country Comparisons*; SAF03 *Smart Engagement with Asia: Leveraging Language, Research and Culture*; SAF04 *The Role of Science, Research and Technology in Lifting Australian Productivity*; SAF10 *Skills and Capabilities for Australian Enterprise Innovation*; SAF11 *Australia's Diaspora Advantage*) as well as incorporating cross-cutting themes that appear in the other ACOLA reports.