STEM: Country Comparisons

International comparisons of science, technology, engineering and mathematics (STEM) education.

FINAL REPORT

PROJECT

2

SECURING
AUSTRALIA'S
FUTURE

A three-year research program funded by the Australian Research Council and conducted by the four Learned Academies through the Australian Council of Learned Academies for PMSEIC, through the Office of the Chief Scientist. Securing Australia's Future delivers research-based evidence and findings to support policy development in areas of importance to Australia's future.

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Contents

List of tables

List of figures

Project aims

A vibrant capacity in Science, Technology, Engineering and Mathematics (STEM) is pivotal to increasing our nation's productivity. Building on recent research commissioned by Australia's Chief Scientist to identify STEM skills shortages, this project will critically examine existing solutions to the STEM skills shortage in comparable countries and to ascertain which, if any, of those solutions could be usefully applied to the formation and maintenance of a STEM skills workforce and propose a set of options for increasing Australia's productivity and international competitiveness.

Securing Australia's Future, Project Two, STEM: Country Comparisons, aimed to address the following:

- Trends in STEM enrolments in all educational domains

- Access of STEM graduates to the labour market

- The perceived relevance of STEM to economic growth and well-being

- What are other countries doing to address declining STEM uptake and its impact on the workforce, and/or lifting national performance? Strategies, policies and programs used to enhance STEM at all levels of education, and judgments concerning the success of those programs

- Are measures put into effect in other countries and cultures successful and how has this been evaluated?

- Could and should such measures be applied in the Australian context, taking into account our cultural diversity?

- What are the implications of the application of culturally appropriate measures in Australia and will the policy framework need to be modified to accommodate them?

Executive summary

The essential mission of the STEM: Country Comparisons project is to discover what other countries are doing to develop participation and performance in the disciplines of science, technology, engineering and mathematics (STEM), and the take-up of STEM in the labour market and research system, and to draw out possible lessons and ideas for STEM policy and strategy in Australia. To this end, 23 specific reports were commissioned and completed by consultants from around the world. This has produced a body of current data of outstanding value. Most nations are closely focused on advancing STEM and some have evolved dynamic, potent and productive strategies. In world terms Australia is positioned not far below the top group but lacks the national urgency found in the United States, East Asia and much of Western Europe, and runs the risk of being left behind.

STEM disciplines have become important everywhere

STEM is a central preoccupation of policy makers across the world. In many countries discussion about STEM is advanced in terms of claims about shortages of high skill labour. However, the consultants' reports make it clear that nowhere are there conditions of general shortage. Though in many countries there are episodic shortages in particular fields, such as engineering and computing in Australia, in reality the STEM economic policy agenda is largely driven by the need to lift the general quality of the *supply* of human capital as well as enlarge the high-skill group capable in research, commercialisable innovation and effective response to technological change. STEM qualifications – in general science in all countries, and in engineering in some countries – prepare graduates for a broad range of occupations, including management. STEM plays a generic vocational role as well as enabling entry to specific occupations. As the United States consultants state:

STEM skills are not only needed in STEM occupations, but in other economic sectors as well. Given both the competitiveness of obtaining employment in some of the highly specialised STEM occupations, and the transferability of STEM competencies to other categories of occupations, it seems that part of the STEM workforce diverts into non-STEM – fulfilling demand in those fields, especially when wages offered are higher than in STEM occupations. Even in non-STEM fields, STEM degree holders earn more on average than non-STEM degree holders… Given this process of diversion and the economy as a whole demanding workers with STEM skills, a picture emerges of a shortage in the available workforce having STEM-related competencies.

More broadly still, governments want to lift the overall scientific literacy of their populations and to draw most students or all students into senior secondary school studies in STEM ('science for all'). Hence the centrality of STEM. The STEM disciplines are seen as essential for work and citizenship, while providing the cut through in global economic competition and social creativity. There is a close fit between the nations with leading and dynamic economies, and the nations with the strongest performing education and/or research science systems.

In the Organisation for Economic Co-operation and Development's (OECD's) Programme for International Student Assessment (PISA), which compares student achievement in mathematics and science at age 15, the nations/systems with the largest group of students at the top three proficiency levels are Shanghai in China, Singapore, Hong Kong SAR in China, Taiwan, Korea, Finland and Switzerland. These are also the systems with the smallest proportion of underperformers In PISA. It would seem that there is no need to choose between boosting high achievement and eliminating educational disadvantage.

Interestingly, these nations/systems are also exceptionally strong in research and development and are rapidly growing their scientific output. At the same time they have all experienced two decades of exceptional economic performance. It is unclear whether deep and wide intellectual formation precedes dynamic economic performance, or sustained economic growth is the foundation of stellar education and science. What is clear is that all three – science, universal learning, and economic dynamism and prosperity – *form a single inter-dependent system*.

Deepening *and* broadening STEM

Hence the goal of science (and mathematics) for all is not necessarily in conflict with the goal of enlarging and improving top-end STEM performance in secondary schooling and university research. For example, by growing the proportion of students who stay in STEM,

including women and low socio-economic status (SES) students, a nation expands the talent pool from which future STEM high achievers will be drawn. Many of the consultants' reports discuss this dual focus and the importance of reconciling the two objectives. Some note that when the senior secondary track in specialist science and mathematics is used as a privileged route for selection into high status university programs (often in non STEM fields), in school systems with a high degree of subject choice that allow students to opt out of STEM, this tends to both weaken overall participation in science and mathematics and narrow the size of the high achiever group. Arguably, this has been an outcome in Australia. Further, evidence can be found in the literature that 'science for all' types of programs provide a superior preparation for advanced STEM training.

A related problem is the shibboleth widespread in Australia, that the STEM disciplines are accessible only to students with 'talent' in science and mathematics. This contrasts with the notion prevalent in the high performance East Asian systems, that success in education and science is due less to talent than to hard work. The notion that educational outcomes are determined by pre-given talents, as if STEM was akin to an elite sporting contest, naturalises the social stratification of learning and undermines social inclusion by fostering a long 'tail' of low achievers. This contrasts with the position in those nations that perform strongest in the standardised international comparisons of student achievement, PISA and TIMSS (Trends in International Maths and Science Study). Whether their social and political cultures are egalitarian (the Nordic world) or hierarchical (as in Sinic East Asia) they expect high standards from all students.

In China, Russia and some European countries mathematics is compulsory until the end of school, and many higher education students continue with advanced mathematics. In most OECD nations the proportion of higher education students enrolled in engineering is significantly higher than in Australia, led by Finland, Korea and Germany. In part this is because these nations are strong in manufacturing, but many of their engineering graduates go on to work outside the profession.

Countries strong in STEM

While the countries strong in STEM are diverse in their economies, political and social cultures and their educational traditions, certain features recur in common. First, school teachers enjoy high esteem, are better paid and work within more meritocratic career structures than found elsewhere. An outstanding example is Finland, where all teachers have a Masters degree, teaching is harder to enter than most other professions, and the strongest teachers are paid to work in school districts serving poor families and students with the most learning difficulties. In China, STEM teachers receive salary increases not on the basis of seniority but via continuing professional development programs, specific to the discipline. To be promoted China's teachers must demonstrate an improving standard of work.

Second, these countries have an unbreakable commitment to disciplinary contents. They do not equate teaching with class management and credentialing alone. They focus on knowledge. STEM teachers are expected to be fully qualified in their discipline and to teach in that field and not others. This contrasts sharply with Australia. Professional development is primarily focused on the discipline rather than generic programs, which again contrasts with Australia.

Third, the 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 in STEM. The main South Korean program for building participation and achievement in STEM has incorporated the arts, to strengthen the focuses on creativity and design. The program is titled STEAM. These more student-centred approaches are being employed without diluting content. In Japan, where mandatory hours and standards in STEM were successively lowered for two decades and PISA performance declined, since 2008 there has been a return to stronger content requirements and less open choice.

Fourth, many of these countries have developed innovative policies to lift STEM participation among formerly excluded groups. Finland's focus on low achieving students has been mentioned. The consultants' report on the strategies used among first nations students in the Province of Saskatchewan suggest that the Canadian experience has lessons for indigenous STEM education in Australia.

Finally, STEM-strong countries have developed strategic national STEM policy frameworks which provide favourable conditions for a range of activities: centrally driven and funded programs, including curriculum reform and new teaching standards; world class university programs, the recruitment of foreign science talent and new doctoral cohorts; decentralised program initiatives and partnerships and engagement that link STEM activities in schools, vocational and higher education with industry, business and the professions. Often STEM programs are led or facilitated or informed by institutes, centres or other agencies that have been specifically created to progress and resource the shared national STEM agenda.

How is Australia travelling?

How does Australia's participation and performance in STEM compare with the STEM-strong countries and with the rest of the world? What are our strengths and weaknesses and where might we usefully gain from other nations' experiences?

The news is good but not great. Australia has travelled fairly well until now, but there are holes in capacity and performance. Further, many other countries are improving STEM provision, participation and performance more rapidly than us.

In the most recent (2009) PISA study, Australia ranked equal 7th of all nations/systems in science and equal 13th in mathematics. There has been a decline in Australia's relative position since PISA began. This is partly due to the entry of high performing Asian systems. The larger problem is that our average PISA mathematics score declined from 524 in 2003

to 514 in 2009. There was no significant change in science, but the average score for reading fell from 528 in the year 2000 to 515 in 2009. PISA focuses on the application of STEM knowledge. In TIMSS, which focuses more on content knowledge in STEM, Australia is a top 20 rather than top 10 performer. There has been no statistically significant decline in performance across the successive TIMSS assessments.

Perhaps the larger problem in Australia lies in the distribution of student achievement. Participants in both PISA and TIMSS are divided into groups according to their demonstrated proficiency. A benchmark performance level is set, below which students are thought to be at risk of having difficulty in participating work and life as productive citizens in the twenty-first century. In PISA, 16 per cent of Australian students fall below this point in terms of mathematical literacy, and 12 per cent in scientific literacy. In TIMSS testing of mathematics at year 4, 30 per cent of students fall below the specified benchmark. This proportion rises to 37 per cent by year 8. By contrast in science there is little change, from 29 per cent in year 4, to 30 per cent in year 8.

While only 3 per cent of Australian students in the highest SES quartile fall below the PISA international benchmark in scientific literacy, 22 per cent of students in the lowest SES quartile fail to reach it. The difference is more marked in mathematical literacy, at 4 per cent and 28 per cent respectively. Students from independent schools achieve higher raw scores than students from Catholic and government schools but there is not statistically significant difference once variation in students' SES backgrounds is taken into account.

Australia has a longer tail of under-performing students than nearest comparator Canada. In PISA mathematics non-indigenous students score on average 76 points higher than indigenous students, a gap equivalent to almost two years' schooling. More positively, migrant families do better in Australia than in most OECD countries. Young people born in Australia to immigrant parents are the highest achieving group in Australia. Many have East Asian cultural backgrounds.

Turning from performance data to participation data, in Australia the percentage of year 12 students enrolled in higher level STEM has been declining for decades. In 1992–2010 the proportion of year 12 students in biology fell from 35 to 24 per cent, in physics from 21 to 14 per cent. This period coincided with a broadening of the range of secondary subjects and a reduction in the role of prerequisites for university entrance into science-based programs, creating greater scope for student choice. University faculties want to attract the highest scoring students so as to maximise the university's market position, with decreasing regard for content-based preparation. There was a lesser decline in mathematics, from 77 per cent to 72 per cent, but most students were enrolled in elementary mathematics subjects. Only 10 per cent participated in advanced mathematics at year 12 level, with 20 per cent in intermediate mathematics. A growing proportion of high-achieving year 12 students participate in no mathematics program at all, particularly female students.

At tertiary stage in 2010, 29.9 per cent of Vocational Education and Training (VET) students were enrolled in STEM disciplines, mostly in sub-degree engineering and related technologies. In higher education 32.7 per cent of all higher education students were in STEM.

Commencing higher education domestic students in natural and physical sciences showed little change between 2002-2008 but there was 29 per cent growth from 2008 to 2010. Between 2002 and 2010 engineering commencements grew by 21 per cent. However, this was from a low base, as international comparisons show. In the average OECD country in 2010, 15.0 per cent of new entrants to tertiary education were in engineering, manufacturing and construction but in Australia it was only 8.7 per cent. While 4.4 per cent of new tertiary entrants across the OECD went into sciences compared to 6.6 per cent in Australia, 2.5 per cent were in mathematics compared to just 0.4 per cent in Australia. In both the average OECD country and Australia 4.3 per cent of tertiary entrants went into computing. In other words Australia is relatively strong in participation in the sciences but weak in mathematics and engineering. The

United Kingdom and New Zealand have a similar profile though the United Kingdom is stronger in mathematics. In the Westminster countries there is a common approach to engineering as more a professional than a generic degree (safeguarding the labour market and salary position of engineering graduates) in contrast with much of Europe and Asia.

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 – a low figure by international standards – in engineering. The combined total of 40 per cent was just above the OECD average and on par with Finland. But any growth there has been has been among international students: the number of commencing domestic PhD students in science and engineering in 2010 was below the 2004 level. This was in sharp contrast with the rapid growth of STEM doctorates in many other countries. For example between 2005 and 2010 in Canada there was 39 per cent growth in doctoral graduates in mathematics and statistics, 48 per cent in the physical sciences, 65 per cent in engineering, manufacturing and construction, and 134 per cent in life sciences.

There is severe gender imbalance in Australian tertiary enrolments in STEM, similar to patterns found in many countries, especially in engineering. In VET STEM in 2010, 25 per cent of students were women. In higher education the female share of STEM was 44 per cent, compared to 56 per cent in all disciplines. Once health sciences and nursing are taken out of the picture the imbalance looks more extreme. In information technology in higher education in 2010, 15 per cent of students were women; in engineering 14 per cent. In 2008, 37 per cent of all STEM doctoral degrees, with health included, were awarded to women. This was below Portugal and Israel but higher than in most other OECD nations. Gender imbalance is especially bad in South Korea and Japan.

There is a substantial decline in Australian students' commitment to science and mathematics between the middle primary years and the end of secondary school. The TIMSS data for 2011 show that 55 per cent of year 4 students 'like science'. Only 25 per cent say so in year 8. The international average also declines, but at a slower rate, from 53 to 35 per cent. Similarly Australian students' fondness for mathematics falls from 45 per cent (Year 4) to 16 per cent (Year 8).

Another concern is the capacity gaps in STEM teaching. We do not know how many mathematics and science teachers are trained each year, or what proportion 'leak' from teaching before they begin. What is clear is that supply is insufficient. There are instances of absolute shortage, especially in rural and remote communities, but the larger problem is teaching 'out of field'. A 2011 study by the Australian Council for Educational Research (ACER) found that in years 7-10 mathematics, only 62 per cent of teachers had two or more years' tertiary mathematics (the minimum required to teach mathematics in most countries). More than one third, 39 per cent, were teaching out of field, and 23 per cent had no tertiary mathematics at all. A May 2012 report from the Office of the Chief Scientist found that of teachers teaching years 11-12 mathematics, 12 per cent in metropolitan schools had no mathematics training at university level, and 16 per cent of those working in provincial towns. These problems are less likely to occur in high SES schools. Faced with staffing shortages 47 per cent of government school principals ask teachers to teach outside field, and 57 per cent of Catholic school principals, but only 14 per cent of independent school principals. Out of field teaching is unusual in the countries studied. Only in the United States, Brazil and Australia does it occur on a large scale and it appears to be worse in Australia than the United States.

Key findings

This report is grounded in 22 commissioned studies of educational policies and practices in relation to STEM around the world. The key findings were developed drawing on analysis of the commonalities across these reports and key points of difference or coincidence with the Australian situation, and on the knowledge vested in the Expert Working Group of critical contextual conditions in Australia, and of the literature on STEM participation. Though very few international policies and educational practices can be readily transferred into the Australian context, the STEM strategies and practices of other countries provide an informative window through which we can better make judgments about key features of Australian STEM practices, and provide many potentially useful ideas for developing STEM strategies in Australia. The main findings of the project are summarised in Sections 1-15 that follow. The findings highlight a number of STEM issues, emerging from the country reports and international comparisons, together with examination of STEM in Australia, that are key topics for discussion at the national level. This section of the report summarises these key findings and draws out potential implications concerning policy and practice in the Australian context. The finding numbers reflect the relevant section of the report. For evidence supporting each finding, and arguments concerning implications for Australian, see the relevant numbered sections of the Report.

STEM in society

Key Finding 5.1: Broadening STEM engagement and achievement

In all strong STEM comparator countries, broadening STEM engagement and achievement entails improving participation in the STEM disciplines through 'T' policies (i.e. learning in both breadth and depth) and covering the full spectrum of prior student achievement levels. In particular:

- Provision of at least some discipline-based STEM learning for all school students, up to and including students in senior secondary education.

- Improving the engagement and performance of students from groups currently under-represented in STEM, that on average perform relatively poorly in mathematics and science.

- Lifting the size and average achievements of the group of students engaged in intensive STEM learning in depth, in both schooling and higher education.

Key finding 5.2: STEM-specific tracking in secondary education

Many of Australia's comparator countries achieve strong participation in STEM through bifurcation at secondary school level between STEM and non-STEM tracks, and vocational tracks leading to significant STEM training. There may be benefits in significant discussion in Australia concerning the potential for, and the pros and cons of:

- Firm bifurcation between a comprehensive STEM track, and a non-STEM track, in the final two years of secondary education.

- Development of STEM-heavy technical and vocational schools and tertiary institutes, alongside academic secondary schools and universities (the latter also including some STEM).

Key finding 5.3: Compulsion vs choice in senior secondary mathematics and science education

There is a concerning trend in the senior secondary and undergraduate tertiary years in Australia away from the sciences and particularly away from advanced mathematics. There is a range of structural elements in the curriculum offerings of many of our comparators strong in STEM that offer possible models for consideration by Australia. Many of these countries have a more stringent approach to curriculum offerings, for instance requiring the study of mathematics to Year 11. An extension of mandatory STEM curricula in senior secondary schools has opportunity costs, by restricting student choice and engagement in non-STEM subjects of educational value. Nonetheless, there may be benefits in discussion among the states, territories, subject teacher associations, universities and relevant science and mathematics organisations about the pros and cons of possible reforms to senior secondary education certificate requirements, to enable one or more of the following:

- Including the study of mathematics (at any level from Essential Mathematics to Specialist Mathematics) up to the end of year 11 – making mathematics compulsory for everyone to the end of year 11.

- Including the study of mathematics (at any level from Essential Mathematics to Specialist Mathematics) up to the end of year 12 – making mathematics compulsory for everyone to the end of year 12.

- Including the study of mathematics for all to the end of year 12, with standards differentiated according to pathways. For all students, including those taking vocational pathways, the minimum curriculum level required would be equivalent to the Essential Mathematics course from the Australian Curriculum. For students to receive an Australian Tertiary Admission Rank (ATAR) and go to university, the minimum curriculum level required would be equivalent to the General Mathematics course from the Australian Curriculum.

- Including the study of at least one science subject up to the end of year 11 – making science compulsory for everyone to the end of year 11.

- Including the study of at least one science subject up to the end of year 12 – making science compulsory for everyone to the end of year 12.

Key Finding 5.4: STEM-specific prerequisites for higher education

In a number of high performing countries STEM subjects at upper secondary school level are strongly linked to university entrance. One way of lifting the level of 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, optimising preparation in the disciplines.

Key finding 5.5: Generic role of engineering degrees

Relative to our strong comparator countries Australia has low participation in tertiary engineering degrees. The participation of women in these degrees is also low.

5.5.1 Tertiary institutions and the professions in engineering and the technologies might consider ways and means of strengthening the generic role of engineering degrees in professional labour markets, broadening the pathways between the study of engineering and employment in fields beyond professional engineering, including business and government. Such an approach would have implications for program design, marketing and student counselling.

5.5.2 There is potential for strategies designed to make engineering more attractive as a generic degree, especially for young women.

Attitudes to STEM

Key finding 6.1: Building awareness of STEM disciplines and STEM-related occupations among young people

For most countries, initiatives targeted at student attitudes and identity were a significant part of the strategic mix. This included initiatives to increase awareness of the nature of STEM professions. Based on the consultants' reports, strategies and programs could be further developed and extended so as to encourage in students positive attitudes to study of mathematics and science, and to STEM-related work and careers. Such strategies would need to take into account the diversity of students' contexts, including their gender, ethnicity/cultural background, SES status and indigeneity. Such strategies could include:

- Awareness campaigns to enrich public understanding of career options in STEM and the nature of STEM work, and to alert young people to the range of possible future STEM lives and identities.

- Strategies at school level designed to involve families in mathematics and science learning and in building positive attitudes to STEM-related careers.

- Role models, in the form of student interaction with practicing STEM professionals, or web-based presentations of narratives of STEM professionals (such as those on the Academy of Technological Sciences and Engineering [ATSE] Science and Technology Education Leveraging Relevance [STELR] website).

- 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.

- The inclusion, in curriculum resources, of materials that speak to the identity needs of the diverse range of students. This includes girls (e.g. science material related to health, or the environment.), indigenous students (e.g. materials that embody respect for indigenous knowledge), and contextual science that relates to youth interests.

- The expansion of opportunities for families and the general public to engage positively with science and mathematics through events, exhibitions and other approaches.

- Enrichment programs whereby students are engaged in science or mathematics projects that entail linking to members of local communities.

Framing national STEM policy and strategy

Key finding 7.1: National STEM policy

A number of countries articulate through national policy a government commitment to STEM or a broader science and technology agenda. In these cases national policy establishes a framework for STEM-specific objectives and facilitates the implementation of coherent STEM-specific strategies and programs. National STEM policy tends to span more than one government ministry, and in many instances is supported by structures coordinating STEM or science and technology activity across jurisdictions and agencies. National STEM or science and technology policy is generally conceived in human capital terms.

A national STEM policy could provide a coherent framework for identifying and articulating STEM-specific strategies and programs spanning the school, VET, higher education and research and development sectors, and also relevant programs in relation to innovation, employment and industry development.

School curriculum and pedagogy

Key finding 8.1: Inquiry, reasoning, and creativity and design in STEM curricula

Many comparator countries with strong STEM agendas and results have a well-developed curriculum focus on innovation, creativity and reasoning, accompanied by a strong commitment to disciplinary knowledge. In relation to school curricula, teaching, learning and educational policy and organisation could usefully address elements such as:

- Strong disciplinary frameworks, noting that disciplinary thinking and disciplinary literacies are central to creative problem solving in STEM-related learning and work.

- At the core of learning, methods of problem solving, inquiry, critical thinking and creativity, all of which can enhance both students' attitudes to, and practical competencies, in STEM fields.

- Design tasks into school science and mathematics curricula, in order to support the development in students of problem solving skills, flexibility in thinking, and awareness of engineering design activities.

- Consideration of the inclusion of the visual and performing arts alongside strategies and programs designed to enhance the orthodox STEM-related disciplines, as in the successful STEAM policy in Korea.

- Development of assessment regimes that support the commitment to problem solving, inquiry-based approaches, critical thinking and creativity.

Key finding 8.2: Standardised tests of student achievement

A number of high performing STEM countries monitor achievement through standardised testing regimes. There was some evidence presented of negative effects of high accountability regimes in narrowing the curriculum and de-skilling teachers. At the other end of the standardisation-autonomy scale, most countries had instituted initiatives that supported local autonomy and contextual variation.

Standardised testing of student achievement in STEM is a useful way of mapping progress at systemic level and among sub-populations, and can be used to diagnose gaps and problems at macro and micro levels.

Teachers and teaching

Key finding 9.1: Career pathways for STEM teachers

STEM-strong comparator countries have in common the high status of teachers, and high entry level into the profession.

9.1.1 Strong STEM performing countries particularly in Asia have meritocratic career structures that recognise teaching excellence. Australia could develop a specific and integrated career pathway for mathematics and science teachers, one that would be common to all schools and based on teaching effectiveness, innovation and leadership closely tied to recognised continuous, discipline-based professional learning. The Australian Professional Standards for Teachers, developed by the Australian Institute for Teaching and School Leadership (AITSL), provide one possible basis for such an approach.

9.1.2 Higher degrees for teachers are a feature of some high performing countries such as Finland. Australia could consider the scheme put forward by the Academy of Science to attract PhD graduates in mathematics and science into a teaching career. The Academy has recommended that:

> … *enhanced career pathways be established to promote the recruitment of science PhD graduates into teaching. This would provide an alternative path for PhD scientists who wish to move out of research careers. It would also ensure that schools have science*

teachers who are not only passionate about science but are able to draw on their research skills and expertise to engage students in 'learning by doing' – an approach which has already been shown to increase student performance.

Key finding 9.2: STEM-specific salaries

There are a few examples of differential salaries or incentives for teachers in the STEM area to attract and retain science and mathematics teachers particularly in hard-to-staff schools.

9.2.1   One possible incentive strategy is to provide higher rates of pay for teachers of mathematics and science with honours or higher degrees.

9.2.2   Another possible incentive strategy is to provide bonus starting pay for mathematics and science teachers at schools in low SES schools and regional and remote schools, similar to the United Kingdom's 'golden welcome' scheme.

Key finding 9.3: Discipline-specific professional development in secondary education

A strong feature of some international jurisdictions is the development of an evidence based national approach to professional development of mathematics and science teachers. In high performing Asian countries in particular there is a strong tradition of school-based professional learning through collaborative planning.

9.3.1   One way to strengthen depth of content in STEM at school level is to engage secondary school-level science and mathematics teachers in sustained discipline-specific professional development programs, focused on pedagogical content knowledge and content knowledge that are not part of generic professional development programs common to all teachers.

9.3.2   Professional development for teachers of mathematics and science could support teachers in the implementation of the Australian Curriculum in Science, Mathematics and Technologies, and include, as key characteristics:

- an evidence-based approach

- use of international experience, and experience at state level

- a framework linking professional development with the acquisition of higher degrees in mathematics and science education, supported by financial incentives.

9.3.3   Consistent with the findings summarised in Sections 5 and 8, discipline-specific professional development could address methods of problem solving, inquiry-based approaches, critical thinking and creativity, and other methods designed to increase student learning and engagement with science and mathematics; and also take into account the diversity of the student population and the need to enhance inclusion and performance among students from social groups presently under-represented in STEM (see Section 5).

Key finding 9.4: 'Out of field' teaching

The incidence of 'out of field' teaching in science and mathematics is especially high in Australia by comparison with other countries. Arguably, this is a crucial weakness of Australian education, impairing both the breadth and depth of STEM learning, especially in government and Catholic schools. One possible strategy would be a national timetable for elimination of out of field teaching in STEM in Australia, coupled with monitoring of graduates from teacher training and rigorous discipline-specific professional development training programs, linked to monetary incentives and leading to a qualification, for teachers currently teaching 'out of field' in science and maths.

Key finding 9.5: Science and mathematics teaching in primary schools

There is a serious focus in all countries on the quality of mathematics and science education at the primary school level. Many countries mirror concern in Australia with the adequacy of current provision at this level.

The foundations of STEM competence are laid in early childhood and primary education. This suggests the need to lift the confidence and competence of primary teachers in the teaching of science and mathematics. One model would be a scheme akin to that of the United Kingdom, whereby trained specialist mathematics leaders have responsibility within their schools for overseeing mathematics teaching skills and approaches, and for developing the relevant learning resources.

Labour markets and STEM

Key finding 11.1: Specific and generic roles of STEM education and training in relation to the workplace

There is a lack of clear data in Australia concerning destinations of STEM graduates and the role of STEM training in a variety of professions. There is also lack of data on qualifications of teachers of STEM.

11.1.1   A key need is data concerning the destinations of STEM graduates (whether at the level of first degree, postgraduate coursework or postgraduate research) in the first 5-10 years after graduation, identifying the respective roles of STEM education and training in relation to:

- work specific to the STEM qualification

- work that is outside field but within STEM

- work in occupations with no specific STEM requirements that may nonetheless draw on STEM graduates' skills and knowledge in a more generic manner.

Such data gathering could also include:

- review and audit of occupations requiring STEM qualifications

- comparison of the labour market outcomes of STEM graduates by field, with those of non-STEM graduates

- factors that facilitate and limit the labour market mobility and flexibility of graduates with STEM qualifications, and employer take-up of STEM qualifications.

11.1.2   A comprehensive survey of secondary teachers in order to identify the number and full qualifications profiles of teachers of all STEM subjects at all year levels.

Girls and women

Key finding 12.1: Gender-based participation in STEM

Countries generally are grappling with the issue of under-representation of women and girls in STEM fields, and pursue a variety of gender equity policies and strategies to address this. In Australia, women's participation in STEM has not altered substantially over two decades, and there is a case to be made for re-invigorating the agenda on women in STEM. Comparator countries' initiatives could provide indications of ways forward. Measures designed to lift female participation in STEM, from first degrees to research functions, could include:

- System-wide targets designed to achieve an equitable percentage of women in STEM disciplines.

- Scholarships and fellowships specifically reserved for female students and researchers, in areas such as engineering where women are grossly under-represented. Such scholarships and fellowships would be largely provided by higher education institutions.

- Strategic reservation of funds for women to assist their study and establish themselves as researchers, and/or the allocation of greater points in funding selection processes to projects that include women researchers.

Key finding 12.2: Mentoring programs to encourage female participation in STEM

Mentoring programs in a number of countries have been positively evaluated as improving women's participation in STEM. Examples of mentoring programs include:

- Bringing together young women and successful female STEM professionals (including scientists, engineers, mathematicians and computing specialists) to provide authentic understanding of STEM careers, and access to female role models. Such contact with STEM professionals could start as early as primary level schooling and continue consistently through education and early career training.

- Peer to peer support between high school and primary students, or between tertiary and upper secondary students, through activities and science shows.

- Systematic linkages between professors in STEM fields, and doctoral students or post-doctoral level women in STEM fields.

Key finding 12.3: Gender-related elements in school curricula and pedagogies in STEM disciplines

Gender-related elements in school curricula and pedagogies in STEM disciplines are a feature of some countries' initiatives that are well supported in the literature. Strategies could include:

- Curriculum design and professional development that could generate greater teacher awareness about encouraging girls to consider STEM pathways.

- Content, pedagogy and resources suited to the learning styles and preferences of girls as well as boys.

- An increased focus on inquiry based science teaching, integrated; mathematics throughout the curriculum.

- Engaging science experiences from an early age.

Key findings 12.4 and 12.5

Further strategies for increasing women's participation in STEM, successfully pursued by a number of comparator countries, include career counselling and flexible workplace arrangements. These suggest the following options for Australia:

Key finding 12.4: Course and career counselling designed to encourage female participation in STEM

Counselling services and promotional materials in relation to STEM pathways designed to effectively encourage young women to follow STEM pathways.

Key finding 12.5: Women in the STEM-related workplace

Facilitating female participation in STEM-related fields of work, including issues such as maternity pay and provision for paternity pay and leave, flexible working hours, child care provision, and support for family mobility.

STEM and indigenous students

Key finding 13.1: National approach to STEM teaching and learning for indigenous students

The Canadian indigenous STEM education experience presents a strong case for pursuing 'culturally responsive teaching' involving the recognition of indigenous knowledge as part of the study of science, and the active involvement of indigenous elders in framing the curriculum and teacher professional development. On the basis of this report, advancing STEM teaching and learning for Australian indigenous students needs wide discussion, including approaches to curriculum and pedagogy in STEM that would more strongly engage indigenous students with STEM subjects at school, in higher education, and into professional STEM pathways. Such approaches could entail, among other elements:

- Recognition of indigenous Australian knowledge in science and mathematics curricula, providing that this draws on systematic research into indigenous Australian perspectives, as well as appropriate international examples such as those from Canada, the United States and New Zealand;

- Involvement of indigenous elders in this research, and in the ensuing development of curriculum and teacher professional learning support;

- Compilation of recent and existing educational programs and practices and support structures, which have proved effective in Australia.

Key finding 13.2: Programs and activities designed to facilitate indigenous students' learning and work in STEM-related disciplines

The experience of Canada, the United States and New Zealand point to common findings concerning the characteristics of programs successful in attracting and retaining indigenous students in tertiary STEM pathways. Programs and activities designed 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;

- 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;

- Higher education institutional structures and activities including specialist societies, mentors, and career counselling;

- Curriculum initiatives and professional learning for higher education teaching staff.

Key finding 13.3: Professional development regarding STEM and indigenous students

The Canadian report in particular makes clear the critical role of professional development in successfully engaging indigenous students in school science and mathematics. Professional development regarding STEM and indigenous students could include:

- Recognition and respect for indigenous ways of knowing; and

- Culturally responsive teaching, whereby students from indigenous backgrounds are supported in engaging effectively with scientific thinking and practices; and also

- Programs and activities designed to facilitate indigenous students' learning and work in STEM-related disciplines.

Partnerships and enrichment activities

Key finding 14.1: STEM Partnerships

Successful partnership initiatives in a number of STEM-strong countries demonstrate the important role of partnerships in supporting innovation in school mathematics and science. While partnership activities are common in Australia, clear understandings of their nature and their effects is often lacking. An approach to STEM partnerships could include:

- Developing an understanding of the scale, scope and variety of STEM-related partnership and enrichment initiatives in Australia – many of which are localised in nature – and of their nature, aims, and effectiveness.

- Coordinating the sharing of details about the relevant initiatives, and develop advice for science organisations, business and industry, and school authorities, concerning how best to manage these to good effect.

National STEM coordination

Key finding 15.1: Possible forms and activities in relation to national STEM coordination

There are many examples of potent policy and coordination regimes in our comparator countries, that express the urgency with which national STEM agendas are being pursued, and the benefits of coherence across STEM related areas. National coordination could make a significant contribution to the enhancement of STEM provision and participation in Australia, as it already does in many other countries.

Areas of activity in which national coordination might add value to STEM provision and participation include:

- The compilation of data concerning participation and performance in STEM education.

- The generation and dissemination of knowledge concerning effective, evidence based approaches to engagement with quality learning in STEM fields, drawing on international and Australian experience, and on the relevant research literature.

- Coordination and networking of policies, strategies and programs designed to enhance approaches to STEM-related teaching and learning in schools, consistent with the Australian Curriculum, including the coordination of resource development and dissemination across the States and Territories.

- Coordination and networking of policies, strategies and programs designed to enhance approaches to STEM-related teaching and learning in tertiary education, including outreach and placement activities in partnership with schools and with industry.

- Coordination of principles and approaches to professional development in relation to STEM teaching, and support structures for teachers of mathematics and science, designed to build the capacity and status of the profession and to support improvements in student learning.

- Coordination of approaches to the enhancement of knowledge and advice regarding STEM pathways, courses and careers.

- Coordination of approaches to partnership and mentoring designed to support STEM education in schools and tertiary institutions.

- Coordination of policy and program development in relation to the participation in STEM of students from under-represented groups, including girls and women (particularly in relation to engineering), low SES students and disadvantaged school communities, including regional, rural and remote communities, and indigenous communities.

- Coordination of approaches to enhancing public, student and employer perceptions of the potential contributions of STEM, and better understanding of STEM in education, work and careers.

Key finding 15.2: Possible coordination structures

In the key comparator countries there are a variety of structural approaches to national coordination of STEM initiatives. Australia could productively learn from these. Approaches could take a number of possible forms, not all mutually exclusive, including for example:

- a specially constituted national STEM body (i.e. an agency or centre) reporting to an appropriate government office or department

- an advisory body with State and Territory government representation

- an advisory body with broad representation of peak stakeholder groups including industry, STEM educator and research bodies, and education systems.

The key aspects of such a body or bodies needing considered discussion are the national overview that would be required, the capacity to establish working groups to deal with distinct issues, and the capacity to commission research and to focus resources.

1 Introduction

Building on recent research commissioned by Australia's Chief Scientist to investigate the health of Australian science and identify STEM skills shortages and capacity constraints, the *STEM: Country Comparisons* project critically examined approaches to STEM capacity building in countries and regions across the world. The project set out to consider whether any of these solutions could be usefully applied to STEM provision in Australian education and the formation and maintenance of a STEM-skilled workforce. Drawing on the policy interventions and programs implemented in other countries, with due regard to issues of translation into the Australian context, this report articulates key findings and their implications for increasing Australia's productivity and international competitiveness by nurturing scientific literacy and fostering capacity and performance in STEM.

In doing so the report pays due regard both to immediate issues and problems, such as teaching capacity in the STEM disciplines, and issues of longer-term development. It uses a global overview of STEM strategies and programs, while at the same time making key findings relevant to national and local conditions.

It was proposed by the authors of this report at the outset of the project, and subsequently endorsed at the first meeting of the project's Expert

Working Group that the project would primarily focus on STEM in terms of human learning, knowledge and skills ('human capital'), and their applications in work. It was not primarily focused on the research, development and innovation system, except in relation to the training of knowledge workers, though it was recognised that aspects of the research and development system were part of the institutional framework and policy conditions in which STEM development occurs.

The project investigated all levels of education except early childhood learning, with particular emphasis on the senior secondary and tertiary years, including doctoral education. Tertiary (and in some systems, secondary) education included both academic education (e.g. universities) and technical/vocational training, and the interface of each with employers, occupations/professions, the workplace and other education sectors.

Special attention was given to the participation of girls and women, and students from social groups under-represented in STEM learning or STEM-related work (e.g. students from poor families, students from migrant communities in some countries). Indigenous participation in STEM was the subject of separate reports in Canada and the United States and was included in some national reports from other systems, where relevant.

As the project aims suggest, the primary interest of the project was in strategies, policies and programs used to enhance STEM at all levels of education and in the education/work interface. This includes comparator countries' systems of measuring and monitoring STEM activity and progress towards policy goals. The project was particularly interested in success and/or failure of these strategies, policies and programs, and the factors that have affected each. The

emphasis on policy and strategy meant that the main focus was on (primarily) national and provincial government programs dealing with STEM. Nevertheless, strategies and programs developed by education institutions and some non-government organisations were also considered to be relevant (e.g. foundations in the United States), and the potential of joint industry-education bodies was seen as significant, especially given that Australia and other English-speaking nations have favoured such strategies. In the outcome, however, most of the data collected and summarised by the consultants related to government policies and programs, or derived from standard official statistics on educational institutions.

Definition of STEM

STEM is defined within this project as learning and/or work in the fields of science, technology, engineering and mathematics, including preliminary learning at school prior to entry into the specific disciplines. The reports commissioned for this project revealed that the discipline grouping, and the term itself, are not used uniformly in international educational policy or practice. For example, in Australia, health professions, agriculture, environment and related fields, and computing, are all typically included within the official ambit of STEM, and appear in some of the tables in this report. The inclusion of agriculture is common but not uniform throughout the world. Practical health fields, such as medicine, are included in some countries, including Argentina, China, Israel, New Zealand, and the United States. In East Asia and in Russia, however, STEM normally excludes health professions. Finland includes geography. Some countries include psychology. Tertiary level analysis in New Zealand includes architecture, veterinary and environmental studies.

In much discussion of STEM both in Australia and in other jurisdictions, it appears that science, engineering and related technologies, and mathematics, are seen as a de facto core. Medicine and health sciences, as noted, are marginal to this core or are not always included.

This core notion of STEM poses problems for policy in Australia because compared to some comparator countries (e.g. Finland, Korea), Australia has a large workforce in health services and a small workforce in manufacturing and the engineering professions. Nevertheless, it can be argued that mathematics and the basic sciences are foundational to all science-based work, including health and other applied life sciences. At school the foundational preparatory practice of STEM – in the form of the science and mathematics disciplines – remain relevant whether STEM is conceived broadly or narrowly. Most of this report is focused on schooling. Discussion of tertiary education and workforce issues is largely focused on science, mathematics and engineering.

At the same time, science, technology, engineering and mathematics – not to mention the many specific disciplines within these broad fields, especially in natural sciences, and more so if the health and agricultural professions are added to the mix – constitutes a heterogeneous cluster. The dynamics, issues and problems of participation, performance and usage are not identical for each discipline, especially in the workforce. There is an artificiality in combining all these fields in a single noun. We recognise that where statements are made that cover the whole cluster, it is essential the generalisation applies to each part.

At the outset we note also that learning in the STEM disciplines is not entirely sui generis within educational curricula. Educationally, the development of and performance in the STEM disciplines is not independent of success in other disciplines, as is discussed further in Section 5. Nor should other disciplines be seen as 'less worthy' or 'less important', or 'less valuable' educationally or vocationally, than are the STEM disciplines. The key findings presented in this report imply the need both a broader take-up of science and mathematics, and a larger cohort engaged in intensive or 'deep' STEM-related learning. In upper secondary and in tertiary education, students make subject choices and more study of STEM means less study of non-STEM disciplines. There are inevitable opportunity costs. Nevertheless, over a whole education and career the best outcomes are likely to be derived from a balanced and plural approach to disciplinary learning. We

do not advocate – and nor does the international experience favour – students studying narrowly specialised programs that wholly exclude non-STEM disciplines such as the humanities.

For example, rather than STEM-focused final year secondary school students limiting their program to science, mathematics and compulsory English, given the point about the value of breadth and balance, it might be better if those STEM-intensive students did one less STEM-related subject and an additional subject in the humanities and social sciences such as a foreign language or history. In other words, one way to go might be for most students to do somewhat more STEM than before, and a minority of students to do a little less STEM than before (for more discussion of the different curriculum and tracking options see Section 5).

Methodology

Country, regional and special interest reports

Country and regional reports

The project commissioned consultants to provide STEM: Country / Regional Reports including, but not limited to the following:

- Attitudes towards STEM, and the priority given to STEM, in families, the community/media, government, educational institutions, employers and professional bodies.

- The perceived relevance of STEM to economic growth and well-being.

- Current patterns of STEM provision in schooling, including STEM in primary education, and its influence on later participation in STEM; enrolments in STEM disciplines in secondary education; STEM provision, and participation, in tertiary (university and non university) education; and trends since 2005 in those secondary and tertiary enrolments.

- The role of STEM disciplines in both general education and vocational and occupationally-specific programs in education and training.

- Student uptake of STEM programs and factors affecting student performance and motivation.

- Access of STEM graduates to the labour markets, and labour market take-up of STEM knowledge and skills.

- Strategies, policies and programs used to enhance STEM at all levels of education, and judgment concerning the success of those programs.

Special interest reports

The project also commissioned special interest reports in relation to key issues including indigenous students and STEM in Canada and the United States, the policies and data of international agencies in relation to STEM and STEM-related performance in education, STEM and student identity, and STEM-related graduates in the Australian labour market.

The full list of country, regional and special interest reports is set out in Table 1.

National Workshop, 21 February 2013

The *STEM: Country Comparisons National Workshop* was held on 21 February 2013, at the Australian National University in Canberra. The National Workshop focused on international STEM provision and take-up, strategies for enhancing STEM, and the implications for Australia. Attendees included Expert Working Group members and 45 people from a diverse range of organisations, including ACOLA and the Office of the Chief Scientist, CSIRO, Questacon, the ACER, the Australian Research Council (ARC), the Australian Bureau of Statistics (ABS), the Australian National Centre for the Public Awareness of Science, the Australian Government (DEEWR, DIICCSRTE, Australian Workforce and Productivity Agency) and State and Territory government (Tasmania, ACT, South Australia departments and Skills Tasmania). The National Workshop was also attended by people from the university sector (including a number of individual universities and the Regional Universities Network) and associations (Australian Secondary Principals Association, Science and Technology Australia, Australian Association

Table 1: Country, regional and special interest reports on STEM commissioned for this project

Report	Authors	Title
China	Yuan Gao, University of Melbourne	Report on China's STEM System
Taiwan	Yuan Gao, University of Melbourne	Report on Taiwan: STEM (Science, Technology, Engineering and Mathematics)
Japan	Mayumi Ishikawa, Shota Fujii, Ashlyn Moehle, Osaka University	STEM Country Comparisons: Japan
Singapore	Noraini Idris, Mohd Fadhil Daud, Chew Cheng Meng, Leong Kwan Eu, Ahmad Dzohir Ariffin @ Maarof, University of Malaya	Country Report Singapore STEM
Korea	Jae-Eun Jon, Korea University and Hae-In Chung, University of Minnesota	STEM Report – Republic of Korea
United States	Adam Maltese, Indiana University; Florin Lung and Geoff Potvin, Clemson University; Craig Hochbein, University of Louisville	STEM Education in the United States
Canada	Julian Weinrib and Glen Jones, University of Toronto	Canada's Approach to Science, Technology, Engineering and Mathematics (STEM): Context, Policy, Strategy and Programs
Western Europe Regional Report (including Belgium, Denmark, Germany, the Netherlands, Norway, Sweden, Switzerland)	Ian Dobson, University of Ballarat	… a critical examination of existing solutions to the STEM skills shortage in comparable [European] countries
Finland	Ian Dobson, University of Ballarat	… a critical examination of existing solutions to the STEM skills shortage in comparable [European] countries: Finland Country Report
France	Elodie de Oliveira, OECD and Kelly Roberts, University of Melbourne	Literature Review: STEM Education in France
United Kingdom	Anthony Tomei, Emily Dawson and Justin Dillon, King's College London	A study of Science, Technology, Engineering and Mathematics education in the United Kingdom
New Zealand	Cathy Buntting and Alister Jones, University of Waikato; Liz McKinley and Mark Gan, University of Auckland	STEM initiatives and issues in New Zealand
Russia	Anna Smolentseva, National Research University – Higher School of Economics, Moscow	Science, Technology, Engineering and Mathematics: Issues of Educational Policy in Russia
Brazil	Hugo Horta, Technical University of Lisbon	Education in Brazil: Access, quality and STEM
Portugal	Hugo Horta, Technical University of Lisbon	STEM education in Portugal: Education, policies and labor market
Argentina	Cynthia Fernandez Roich, University of Melbourne	Study of Science, Technology, Engineering and Mathematics (STEM) and STEM-related issues in Argentina
Israel	Gili Drori and Avida Netivi, The Hebrew University of Jerusalem	STEM in Israel: The Educational Foundation of 'Start-Up Nation'
United States Indigenous	Sharon S. Nelson-Barber Pacific Resources for Education and Learning (PREL)	US Indigenous STEM Report

Report	Authors	Title
Canada Indigenous	Glen Aikenhead, University of Saskatchewan	Science, Technology, Engineering and Mathematics Education and Related Employment for Indigenous Students and Citizens of Saskatchewan
South Africa	Michael Kahn, Stellenbosch University	Science, Technology, Engineering and Mathematics (STEM) in South Africa
Australian Labour Market	Josh Healy, Kostas Mavromaras, Rong Zhu, Flinders University	The STEM Labour Market in Australia
Literature Review: Student Identity	Marilyn Cole, Deakin University	Literature review update: Student identity in relation to Science, Technology, Engineering and Mathematics subject choices and career aspirations
International Agencies	Kelly Roberts, University of Melbourne	Literature Review – A selection of the work of international organizations on STEM education and STEM-related issues
Australia	Brigid Freeman, University of Melbourne	Science, Technology, Engineering and Mathematics (STEM) in Australia: Practice, policy and programs

of Mathematics Teachers, Australian Science Teachers Association, Australasian Science Education Research Association).

Key themes emerging from the National Workshop included international comparisons and Australia's performance in that context, the large proportion of mathematics teachers teaching out-of-field (one class in every three), the 'long tail' of STEM underperformance, the need to support 'STEM for all' as generic preparation whilst also supporting the 'STEM elite', the question of compulsory mathematics or science participation, the foundational role of mathematics to everyday life, career structures/ladders and professional development requirements and opportunities for Australia's mathematics and science teachers, indigenous participation in STEM, and the need for more information about STEM labour market needs.

This Report

This report provides an outline of STEM provision and participation in Australia (Section 2) that serves as the base of comparison with other country systems. Section 2 also draws attention to existing issues and problems in Australia's STEM effort. Section 3 provides a general introduction to the international comparisons used in this report, reflecting on the broad

differences between the systems discussed in the report, which are grouped into four main regional sets: the English-speaking countries, Western Europe, East Asia and Singapore, and emerging and developing countries. Section 3 also reflects on the relevance of international comparisons to Australia, and on the potential for and limits of policy borrowing and policy transfer across borders. Section 4 then looks at STEM policy issues from the point of view of international agencies such as the OECD and the World Bank, and uses data from the PISA and TIMSS to compare Australian participation in, and performance in relation to, the STEM disciplines, with those of other countries. Australian students display a strong performance overall but we are not improving rapidly as are some other nations and there is some faltering in mathematics.

The report then moves into substantive discussion of relevant issues in Australia through the lens of international comparison. Each succeeding section of the report focuses on a particular aspect of STEM provision and participation, reflecting on the contents of the reports from the consultants, and then discusses possible changes in Australian policies, strategies and professional practices. Section 5 looks at the overall structuring of the STEM disciplines within education and the economy. It considers difficult and ambiguous issues such as the extent to which STEM functions as general education

and as vocationally-targeted education; the relationship between broadening the take-up of STEM and strengthening the nation's high-end STEM performance; whether STEM-specific tracks should be developed in academic and/or vocational secondary education; the desirability or otherwise of compulsory STEM subjects in senior secondary education; the use of STEM prerequisites at the gateway to university; and the potential for engineering to function as a generic vocational degree. Section 6 looks at public, government, family and student attitudes to STEM and strategies for building awareness of STEM learning and STEM careers. Many governments around the world are pursuing such strategies at present. Section 7 looks at the approach taken by governments in framing overall policy on STEM. Australia does not have a STEM policy framework and the report considers possible forms of such a policy framework, and the potential benefits, limits and obstacles.

Section 8 (Curriculum and pedagogy) and Section 9 (Teachers and teaching) look at possible changes in teaching and learning in Australia, designed to enhance participation and performance in relation to STEM, in the light of the many recent initiatives taken around the world. These sections discuss the use in school programs of greater emphases on creativity, problem solving, inquiry-focused methods and critical thinking; possible career pathways and special salary arrangements for teachers of science and mathematics; the enhancement of discipline-specific professional development; and what to do about the very high incidence of teachers in STEM classrooms in Australia who are teaching outside the field in which they were trained. Few other countries have this problem.

Section 10 discusses the strategies used in other countries to build high-end research performance and doctoral student numbers in the STEM disciplines. It notes that the policies on building 'World-Class Universities' that are now widespread in East Asia and in Western Europe have no counterpart in Australia. Section 11 looks at the findings of the consultants' reports, and the commissioned report on Australia, in relation to STEM disciplines in the graduate labour markets. It notes that with a small number of exceptions, the country reports suggest that there is insufficient research on the labour market take-up of STEM

qualifications, knowledge and skills; and in many policy jurisdictions there is ambiguity about the economic role of STEM. While it is widely assumed that the STEM disciplines directly create economic value through the labour process, and the value equation is most effective when the mix of specific vocational skills in STEM is matched closely with employer requirements, in fact many STEM graduates use their STEM education and training as general rather than specific preparation for work. There is evidence of recurring shortages of STEM-qualified labour in engineering but on the whole labour market data do not strongly support a demand-driven argument for growing participation in specific STEM disciplines. However, this does not obviate the potential benefits, at work and in society, of more widely distributed STEM knowledge and skills, and of better high-end preparation in STEM.

Section 12 considers the under-representation of girls and women in certain STEM-related fields of study and work, especially engineering and computing, and what might be done to better utilise the potential of girls and women. Female under-representation is a world-wide problem but there is significant statistical variation between country systems, and some have been more successful than others in improving gender balance. The section discusses possible policies and strategies, in the light of international experience. Section 13 considers STEM and indigenous students in Australia, in the light of both the disappointing national performance, and the experiences of indigenous students in Canada (more advanced in its approach than Australia), the United States and New Zealand. Section 14 provides an account of various approaches around the world to partnerships between educational institutions, business and industry designed to enhance STEM provision and participation, and to other forms of community outreach in relation to STEM.

The final Section 15 considers the potential in Australia for upgraded national coordination in relation to STEM, and the kinds of activities that a national body or structure might pursue. Most of the countries considered in this study have more extensive coordination arrangements than currently apply in Australia.

2 | STEM in Australia

Australian Government focus on school education, and science and innovation

School education, and science and innovation are national priorities for the Australian Government. The *National Plan for School Improvement* (Australian Government, 2012) pledges access to a high-quality, high-equity education for every Australian school student, regardless of where they live, where they attend school or their personal circumstances. *Transforming Australia's Higher Education System* (Australian Government, 2009), the government's response to the Bradley review of Australia's higher education system (*Review of Australian Higher Education: Final Report*, Bradley et al, 2008), commits to higher education expansion as a driver for Australia's knowledge-based economy. *Powering Ideas An Innovation Agenda for the 21st Century* (Australian Government, 2009), the government's response to the Cutler review of Australia's science and innovation sector (*Venturous Australia building strength in innovation,* Cutler & Company, 2008*)*, undertakes to enhance science and innovation, including research and development.

Table 2: Schooling in Australia, 2010

Schools	
Total number of schools	9,468
Primary schools	6,357
Secondary schools	1,409
Combined schools	1,286
Special schools (for students with disability)	416

Schools by sector	Government		Catholic		Independent	
Total number of schools	6,743		1,708		1,017	
Primary schools	4,879	72%	1,230	72%	248	24%
Secondary schools	1,034	15%	303	18%	72	7%
Combined schools	498	7%	148	9%	640	63%
Special schools	332	5%	27	2%	57	6%

Students		
Total number of full-time equivalent students	3.5 million	
Number and percentage attending government schools	2.3 million	66%
Number and percentage attending Catholic schools	713,289	20%
Number and percentage attending independent schools	491,233	14%

Source: Reproduced from ABS 2011, *Schools, Australia 2010,* cat. No. 4221.0, cited in Gonski et al., 2012, *Review of Funding for Schooling – Final Report*, p. 4.

Key structural elements of the education, and science and innovation agendas at the federal level include the Prime Minister's Science, Engineering and Innovation Council (PMSEIC), the Office of the Chief Scientist, the Department of Education, Employment and Workplace Relations (DEEWR) and the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE). In releasing the *Health of Australian Science* (Office of the Chief Scientist, 2012a), the Chief Scientist, Professor Ian Chubb placed STEM firmly on the national agenda. The Office of the Chief Scientist has recently established the position of National Mathematics and Science Education and Industry Adviser (February 2013). The Adviser will champion the role of mathematics, science and statistics across education and industry, and work with these sectors to develop and provide policy advice to government through the Chief Scientist.

Australia's school education system

In 2010 there were 9,468 schools in Australia, including 6,357 primary schools, 1,409 secondary schools, 1,286 combined primary and secondary schools and 416 special schools for students with disability. Most government and Catholic schools were primary schools (72 per cent), whereas most independent schools were combined primary and secondary schools (63 per cent) (Gonski et al, 2011).

Australia's schools enrolled 3.5 million full-time equivalent students. The majority of school students (66 per cent) were enrolled in government schools, with the remainder enrolled in Catholic systemic and non-systemic schools (20 per cent), and independent schools (14 per cent). The number of school students has grown over the last decade, with greater growth recorded in independent schools (14 per cent) than Catholic schools (6 per cent) or government schools (2 per cent) (ABS, 2011, cited in Gonski et al, 2011).

Under the Australian Constitution, States and Territories have responsibility for education, although all levels of government fund school and tertiary education. The OECD estimates that Australia's 2009 government expenditure on school and non-tertiary post-school level education (3.8 per cent of GDP) was the same as the OECD country average. Total spending on school and non-tertiary post-school education was 4.2 per cent of GDP compared to the OECD country average of 4.0 per cent, reflecting what is by international standards a relatively high private investment in Australia's relatively large private school sectors.

Australian Curriculum

The Australian Curriculum, led by the Australian Curriculum, Assessment and Reporting Authority (ACARA) is progressively being developed and introduced from foundation (kindergarten) to senior secondary level in all States and Territories, across all school systems. The Australian Curriculum defines learning areas, specifies general capabilities and establishes cross-curriculum priorities. The Foundation to Year 10 (F-10) Australian Curriculum includes the learning areas of Mathematics and Science, general capabilities in Numeracy and Information and Communication Technology, and cross-cultural priorities (Indigenous histories and cultures, Asia and Australia's engagement with Asia, and Sustainability). Sustainability will encompass the organising ideas of Systems, World View and Futures, and be embedded in the various learning areas. F-10 Australian Curriculum has been published, and States and Territories have agreed to the phased introduction of this curriculum over the next few years.

The Senior Secondary Australian Curriculum includes the learning areas of Mathematics (Essential Mathematics, General Mathematics, Mathematical Methods, Specialist Mathematics) and Science (Biology, Chemistry, Physics, and Earth and Environmental science). The Senior Secondary Australian Curriculum for Mathematics and Science has been published, and negotiations with the States and Territories are progressing to

determine the extent to which the curriculum will be implemented. States and Territories are responsible for determining senior secondary certification requirements, which mandate which curriculum elements are required for certification purposes. The Australian Curriculum: Technologies is under development. The *Australian Curriculum Implementation Survey* (ACARA 2012) reports on the state and territory implementation plans to introduce the F-10 Australian Curriculum, noting the phase-in period 2011-2014.

Overall educational achievement

The upper secondary graduation rate for Australians under the age of 25 is higher than the OECD average in general programs (70 per cent versus 49 per cent) and lower than the OECD average in pre-vocational and vocational programs (23 per cent versus 35 per cent). These graduation rates should be interpreted carefully as they represent the estimated percentage of people from a certain age cohort that is expected to graduate at some point during their lifetimes, and the estimate is sensitive to changes in the duration of the programs; and they include international students, which artificially boosts the apparent graduation rate.

The Standing Council on Tertiary Education Skills & Employment reported in the *National Foundation Skills Strategy for Adults* (SCOTESE, 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. This equates to 40 per cent of employed Australians, 60 per cent of unemployed Australians and 70 per cent of those outside the labour force. … (which) lend(s) weight to concerns about our ability to meet projected skills demands in coming years' (ibid., p.2). These findings raise questions about the scientific literacy of a large part of the Australian population.

The educational attainment of 25-64 year old Australians in 2010 is presented in Table 3. Up to 73 per cent of the Australian population aged 25-64 years had completed at least upper secondary level education or more. This figure is up to 85

Table 3: Educational attainment of Australians aged 25-64 years in 2010

	At least upper secondary	Tertiary type a and advanced research programs
Australia	73%	27%
OECD Average	74%	22%

Source: OECD 2012, *Education at a Glance 2012: OECD Indicators,* OECD Publishing, Paris.

per cent among those aged 25-34 years, above the OECD average of 82 per cent for this group. As many as 27 per cent of Australians aged 25-64 years have attained tertiary type A (bachelor or other undergraduate level program) and advanced research programs, clearly above the OECD average of 22 per cent. Among Australians aged 25-34 years, 34 per cent had attained the levels of bachelor or advanced research programs in 2010.

School student performance

Literacy and numeracy

The *Review of Funding for Schooling* found with respect to educational attainment generally that:

> … on average, students from low socioeconomic backgrounds, Indigenous students, students with disability, students from remote and very remote areas, and to variable degrees LBOTE students: are more likely to be considered developmentally vulnerable at school entry, have lower performance on assessments throughout schooling, with the gap getting larger in the later years of schooling, have lower Year 12 and equivalent attainment rates (Gonski et al, 2011, p.28).

In terms of literacy and numeracy specifically, the 2012 National Assessment Program – Literacy and Numeracy (NAPLAN) results (ACARA, 2012) reveal persistent differences in students' literacy and numeracy achievement between States and Territories and significant underperformance in some jurisdictions relative to the national average, particularly in the Northern Territory. The results also reveal lower mean literacy and numeracy scale scores for indigenous students (particularly remote and very remote indigenous students) and students based in remote and very remote locations.

These findings are confirmed in other research. The Australian National Audit Office reported in the review of the *National Partnership Agreement on Literacy and Numeracy* (Gonski et al, 2011, p.28) that a large percentage of indigenous students are at or below the national minimum standards for reading and numeracy achievement. In 2011, the percentage increased as students progressed through years 3-9, with 60.9 per cent of year 9 Indigenous students in 2011 at or below the national minimum standard for reading and numeracy achievement, compared to 22.2 per cent of non-Indigenous year 9 students.

Mathematics and science

Results emerging from international assessment programs, including the TIMSS and PISA suggest that Australia's school student science and mathematics performance is declining in some instances, and remaining static in others. For more discussion of Australia's performance in comparative context see Section 4. (These results will be discussed only briefly here).

In science, Australia's performance appears to have held steady. However, the 2009 PISA results reveal a decline over time in mathematical literacy and are of particular concern. Thomson et al. suggest that 'the average mathematical literacy performance of Australia declined significantly (by 10 score points) between PISA 2003 and PISA 2009, while there was no significant change in the OECD average over this time' (2010, p.vii).

In terms of variations in performance in PISA, there is significant disparity between the States and Territories. With respect to mathematics literacy achievement, students in Western Australia and the Australian Capital Territory consistently achieve the highest raw mean scores, and students in Tasmania and the Northern Territory consistently record the

lowest raw mean scores. Males on average scored significantly higher than females, and non-indigenous students on average scored significantly higher than indigenous students, by 76 points, or equivalent to almost two years of schooling (ibid, p.viii). Students from independent schools achieved significantly higher average raw scores than students from Catholic and government schools, and students in Catholic schools significantly outperformed those in the government schools. However, once differences in students' SES backgrounds were taken into account, there were no statistically significant differences in the average score by school sector. Students from metropolitan schools significantly outperformed students from provincial and remote schools, and students from high SES backgrounds on average significantly outperformed students from low SES backgrounds. In many instances these disparities were large: 'the performance gap between students of the same age from different backgrounds can be equivalent to up to three years of schooling. This gap places an unacceptable proportion of 15-year-old students at risk of not achieving significant levels sufficient for them to effectively participate in the 21st century workforce and to contribute to Australia as productive citizens' (ibid, p.xiv). In reflecting on these performance gaps, the *Review of Funding for Schooling* stated that:

> The absolute decline in performance as measured by PISA in reading and mathematical literacy is evident at all levels of achievement. Australia's weak performance in reading and mathematics compared to Canada (a similar

country) and Singapore (our nearest Asian neighbour participating in PISA) illustrates a serious cause for concern and suggests significant educational reform is needed to address the competitive disadvantage our children face (Gonski et al, 2011, p.211).

School student participation in mathematics and science

In 2009, 52 per cent of the total cohort of all year 12 students were enrolled in science subjects (Goodrum et al, 2012), including biology (49,681 or 24.1 per cent of the total year 12 cohort), chemistry (35,867 or 17.4 per cent) and physics (29,532 or 14.3 per cent) (noting that a small number of students enrol in more than one science course). Geology and earth science enrolled the lowest proportion of year 12 students (2,201 or 1.1 per cent; these disciplines are not offered in many schools). In comparison, 148,097 (72 per cent of the total cohort) of all year 12 students were enrolled in mathematics (National School Statistics Collection, ABS cited in Office of the Chief Scientist, 2012a, p.24). The majority of these enrolments were in elementary mathematics, compared with advanced mathematics (10.1 per cent) and intermediate mathematics (19.6 per cent) (Barrington, 2011).

Participation in senior secondary science and mathematics has been declining for decades. For example, the period 1992 – 2010 saw a decline in year 12 school science and mathematics participation rates, including a marginal decline in mathematics (from 76.6 per cent to 71.6 per cent),

Table 4: Student enrolments in year 12 science subjects, Australia 2009

Subject	Students enrolled (Number)	Proportion of cohort
Mathematics	148,097	71.7%
Biology	49,681	24.1%
Chemistry	35,867	17.4%
Physics	29,532	14.3%
Geology and Earth science	2,201	1.1%
Other science	16,655	8.1%

Source: Reproduced from Office of the Chief Scientist 2012a, *Health of Australian Science*, Australian Government, p. 24.

Figure 1: Year 12 science participation as a percentage of the year 12 cohort in Australian schools, 1976 to 2007
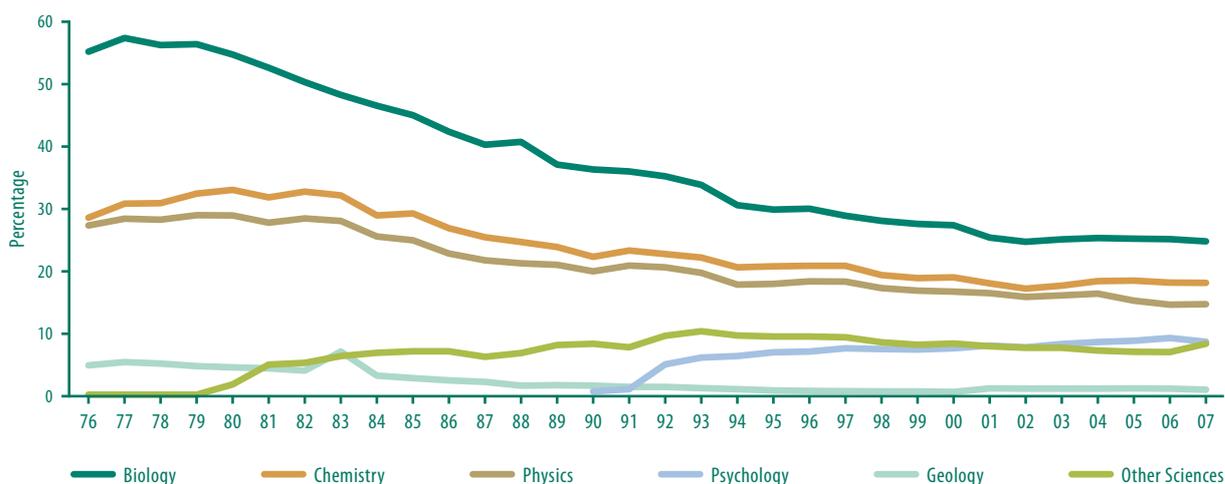
a larger proportional decline in both biology (from 35.3 per cent to 24.0 per cent) and physics (from 20.8 per cent to 14.2 per cent), and decline also in chemistry (from 22.9 per cent to 17.2 per cent) (Office of the Chief Scientist 2012a, p.43). This decline has been attributed to the increased range of year 12 course offerings (Lyons & Quinn, 2010) and a decline in the 'perceived utility value' of physics and chemistry, in particular (Office of the Chief Scientist 2012a, p.53).

It is important to note that while the proportions of the year 12 cohort enrolled in these science subjects has declined significantly, trends in the absolute number of enrolled students in the STEM disciplines are less clear-cut. Between the mid 1970s and 2010 the absolute number of students rose, peaking in the early 1990s and has declined since, in part because of relaxed university prerequisite requirements. The absolute number of STEM students at year 12 is currently at a level similar to the mid 1970s. Regardless of these fluctuations in absolute numbers, it appears that Australia has been unsuccessful in developing a momentum for 'science and maths for all' in year 12. Though the proportion of the age cohort finishing year 12 has increased substantially, it is likely that those students who in former years would not have completed school have enrolled in year 12 science subjects and advanced mathematics at a more modest rate than other students.

In relation to mathematics, the National Committee for the Mathematical Sciences reported that the spread of achievement in years leading up to year 12 is wide and growing, with 'extensive underachievement and small numbers reaching advanced levels' (National Committee for the Mathematical Sciences 2006, cited in Broadbridge & Henderson, 2008, p.17). This reduces the number of students eligible to progress to advanced school-level mathematics. In terms of year 12 mathematics, for the period 1995-2010, participation in elementary mathematics increased (from 37 per cent to 50 per cent), while participation in both intermediate and advanced mathematics decreased (from 27.2 to 19.6 per cent, and 14.to 10.1 per cent, respectively) (AMSI, 2012a). Intermediate and advanced mathematics (calculus-based subjects) are prerequisites for many university STEM-discipline courses, so decreased participation in these subjects in year 12 has significant implications for the pipeline to university STEM-disciplines.

In NSW, Mack and Walsh (2013) identify a decline in the proportion of students undertaking at least one mathematics and one science subject in the HSC. In 2001 some 19.7 per cent of boys and 16.8 per cent of girls from the corresponding year 8 cohort went on to study a mathematics/science combination in the HSC. However, in 2011 only 18.6 per cent of boys and 13.8 per cent of girls went

Table 5: Tertiary education provider type profile, 2010

Provider type	VET		Higher education		Total	
	('000)	per cent	('000)	per cent	('000)	per cent
Equivalent full-time students						
Dual-sector universities	53.8	8.2%	87.0	10.1%	140.8	9.3%
TAFE institutes	464.5	70.8%	2.5	0.3%	467.0	30.8%
Public universities	2.0	0.3%	716.5	83.2%	718.5	47.4%
Other providers	135.5	20.7%	55.5	6.4%	191.0	12.6%
Total	655.8	100.0%	861.5	100.0%	1 517.3	100.0%
Students						
Dual-sector universities	104.4	5.8%	118.6	9.9%		
TAFE institutes	1 182.9	65.8%	3.5	0.3%		
Public universities	4.5	0.2%	992.3	83.2%		
Other providers	491.2	27.3%	78.3	6.6%	Not provided	
Students attending various providers	16.0	0.9%	-	-		
Total	1 799.0	100.0%	1 192.7	100.0%		

A dash (-) represents a true zero figure, with no data reported in this category.

Sources: Data on vocational education and training were derived from the National VET Provider Collection. Data on higher education were derived from the Higher Education Statistics Collection.

Source: NCVER 2012, *Tertiary education and training in Australia 2010*, Department of Industry, Innovation, Science, Research and Tertiary Education, viewed 19 March 2013, http://www.ncver.edu.au/publications/2489.html.

on to study mathematics/science in the HSC' (ibid, p.1). It should be noted the cohort size increased in this period. Furthermore, the report notes the high proportions of high achieving (ATAR-eligible) students who do not participate in any mathematics programs in year 12, particularly girls.

Broadbridge and Henderson note that in entry to higher education, within the context of increasing competition for discerning high achieving students, there have been 'many cases (of) the lowering of entry prerequisites for courses' (2008, p.11). With respect to engineering programs in particular, Broadbridge and Henderson found that 'many respondents … attributed the decline in mathematical ability to a lowering of entry standards to engineering degree programs; the majority of universities have removed the higher level secondary school mathematics prerequisite' (ibid, p.14).

Tertiary participation in the STEM disciplines

It is not always recognised that in tertiary education, students enrol in STEM disciplines in both Vocational Education and Training (VET), and higher education. In 2010, the VET sector catered for 1,799,000 students (655,800 effective full time [EFT] students). Of that group 70.8 per cent were enrolled in TAFE Institutes, 8.2 per cent were in dual-sector universities, 0.3 per cent were in public universities and other training providers housed 20.7 per cent. The higher education sector catered for 1,192,700 students (861,500 EFT), enrolled in public universities (83.2 per cent), dual-sector universities (10.1 per cent), TAFE institutes (0.3 per cent), and other training providers (6.4 per cent).

In 2010, the VET sector enrolled students in programs spanning Australian Qualification Framework (AQF) levels 1-8, meaning from Certificate 1 to Graduate Certificate or Graduate Diploma, and also some students in non-AQF

programs. The higher education sector enrolled students in programs spanning AQF levels 5–10, that is, from Diploma to Doctoral degree. In terms of AQF programs, the largest group of VET students were enrolled in Certificate Level III programs (34.3 per cent), whereas the majority of higher education students were enrolled in Bachelor degree Pass and Honours programs (73.6 per cent).

Table 6: Equivalent full-time domestic and international students by sector of education and selected course characteristics, 2010

	Vet		Higher education		Total	
	('000)	per cent	('000)	per cent	('000)	per cent
Qualification level						
AQF qualifications						
Doctoral degree	-	-	35.2	4.1%	35.2	2.3%
Master's degree	-	-	109.6	12.7%	109.6	7.2%
Graduate certificate or graduate diploma	0.4	0.1%	34.7	4.0%	35.2	2.3%
Bachelor degree (Pass and Honours)	1.2	0.2%	634.2	73.6%	635.4	41.9%
Advanced diploma	27.0	4.1%	3.7	0.4%	30.7	2.0%
Associate degree	0.1	0.0%	6.6	0.8%	6.7	0.4%
Diploma	113.2	17.3%	17.3	2.0%	130.6	8.6%
Certificate IV	114.8	17.5%	-	-	114.8	7.6%
Certificate III	225.2	34.3%	-	-	225.2	14.8%
Certificate I or II	116.1	17.7%	-	-	116.1	7.6%
AQF sub-total	598.1	91.2%	841.3	97.7%	1,439.4	94.9%
Non-AQF qualifications						
Other recognised courses	42.6	6.5%	10.2	1.2%	52.8	3.5%
Non-award courses	8.4	1.3%	8.4	1.0%	16.9	1.1%
Subject only – no qualification	6.7	1.0%	-	-	6.7	0.4%
Cross-provider programs	-	-	1.5	0.2%	1.5	0.1%
Non-AQF sub-total	57.7	8.8%	20.2	2.3%	77.9	5.1%
Field of education						
Natural and physical sciences	4.6	0.7%	62.4	7.2%	67.0	4.4%
Information technology	17.4	2.7%	33.9	3.9%	51.3	3.4%
Engineering and related technologies	110.6	16.9%	65.6	7.6%	176.2	11.6%
Architecture and building	47.4	7.2%	21.4	2.5%	68.8	4.5%
Agriculture, environmental and related studies	31.2	4.8%	12.5	1.5%	43.8	2.9%
Health	31.2	4.8%	126.8	14.7%	158.0	10.4%
Education	15.5	2.4%	74.6	8.7%	90.1	5.9%
Management and commerce	133.9	20.4%	228.6	26.5%	362.5	23.9%
Society and culture	103.0	15.7%	160.3	18.6%	263.3	17.4%
Creative arts	32.6	5.0%	61.9	7.2%	94.5	6.2%
Food, hospitality and personal services	49.5	7.5%	0.8	0.1%	50.2	3.3%
Mixed field programs	72.4	11.0%	4.1	0.5%	76.5	5.0%
Not applicable	6.7	1.0%	8.4	1.0%	15.1	1.0%
Total	655.8	100.0%	861.5	100.0%	1,517.3	100.0%
International status						
International*	38.3	5.8%	252.6	29.3%	290.9	19.2%
Domestic	617.5	94.2%	608.9	70.7%	1,226.4	80.8%

*NCVER 2012 defines 'International students' are 'those with a temporary entry permit or student visa or those who reside outside Australia during the unit of study. The number of international students is derived for the VET sector, based on students with at least one unit with an international full-fee-paying funding source' (p. 28).

A dash (-) represents a true zero figure, with no data reported in this category.

Sources: Data on vocational education and training were derived from the National VET Provider Collection. Data on higher education were derived from the Higher Education Statistics Collection.

Source: NCVER 2012, *Tertiary education and training in Australia 2010*, Department of Industry, Innovation, Science, Research and Tertiary Education, viewed 19 March 2013, http://www.ncver.edu.au/publications/2489.html.

In terms of the field of education, 195,000 effective full-time VET students were enrolled in STEM disciplines (natural and physical sciences, information technology, engineering and related technologies, agriculture environmental and related studies), representing 29.9 per cent of all VET EFT enrolments. Over half of these enrolments were in the engineering and related

Table 7: Equivalent full-time domestic and international students by sector of education and selected course characteristics for all students, males, females, aged 24 years and under, 2010

	All students		Males		Females		Aged 24 years and under	
	VET	Higher education	VET	Higher education	VET	Higher education	VET	Higher education
Qualification level								
AQF qualifications								
Doctoral degree	-	4.1%	-	4.6%	-	3.7%	-	0.8%
Master's degree	-	12.7%	-	13.7%	-	12.0%	-	7.0%
Graduate certificate or graduate diploma	0.1%	4.0%	0.1%	3.6%	0.1%	4.4%	0.0%	1.6%
Bachelor degree (Pass and Honours)	0.2%	73.6%	0.1%	71.9%	0.2%	75.0%	0.2%	84.6%
Advanced diploma	4.1%	0.4%	4.5%	0.5%	3.8%	0.4%	4.5%	0.5%
Associate degree	0.0%	0.8%	0.0%	1.1%	0.0%	0.5%	0.0%	0.7%
Diploma	17.3%	2.0%	13.1%	2.4%	21.6%	1.7%	14.8%	2.5%
Certificate IV	17.5%	-	15.8%	-	19.2%	-	12.9%	-
Certificate III	34.3%	-	38.6%	-	30.0%	-	38.9%	-
Certificate I or II	17.7%	-	18.7%	-	16.7%	-	21.0%	-
AQF sub-total	91.2%	97.7%	90.9%	97.7%	91.5%	97.6%	92.4%	97.6%
Non-AQF qualifications								
Other recognised courses	6.5%	1.2%	6.8%	1.1%	6.2%	1.3%	5.7%	1.1%
Non-award courses	1.3%	1.0%	1.4%	1.0%	1.1%	1.0%	1.6%	1.1%
Subject only – no qualification	1.0%	-	0.8%	-	1.2%	-	0.3%	-
Cross-provider programs	-	0.2%	-	0.2%	-	0.2%	-	0.2%
Non-AQF sub-total	8.8%	2.3%	9.1%	2.3%	8.5%	2.4%	7.6%	2.4%
Field of education								
Natural and physical sciences	0.7%	7.2%	0.5%	7.7%	0.9%	6.9%	0.7%	7.8%
Information technology	2.7%	3.9%	4.3%	7.2%	1.0%	1.3%	3.3%	3.9%
Engineering and related technologies	16.9%	7.6%	30.5%	14.3%	2.8%	2.3%	19.0%	8.4%
Architecture and building	7.2%	2.5%	13.1%	3.3%	1.2%	1.8%	10.1%	2.7%
Agriculture, environmental and related studies	4.8%	1.5%	6.8%	1.6%	2.6%	1.4%	4.0%	1.3%
Health	4.8%	14.7%	2.2%	9.3%	7.4%	19.1%	3.6%	13.5%
Education	2.4%	8.7%	1.8%	4.8%	2.9%	11.8%	0.6%	7.3%
Management and commerce	20.4%	26.5%	13.8%	29.3%	27.2%	24.3%	19.9%	28.3%
Society and culture	15.7%	18.6%	7.8%	15.0%	23.8%	21.5%	12.0%	17.2%
Creative arts	5.0%	7.2%	4.0%	6.2%	6.0%	8.0%	6.5%	8.1%
Food, hospitality and personal services	7.5%	0.1%	5.0%	0.1%	10.1%	0.1%	10.1%	0.1%
Mixed field programs	11.0%	0.5%	9.2%	0.4%	13.0%	0.5%	9.9%	0.4%
Not applicable	1.0%	1.0%	0.8%	1.0%	1.2%	1.0%	0.3%	1.1%
Total (per cent)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total ('000)	655.8	861.5	331.8	383.9	322.7	477.6	321.8	623.8

A dash (-) represents a true zero figure, with no data reported in this category.

Sources: Data on vocational education and training were derived from the National VET Provider Collection. Data on higher education were derived from the Higher Education Statistics Collection.

Source: NCVER 2012, *Tertiary education and training in Australia 2010*, Department of Industry, Innovation, Science, Research and Tertiary Education, viewed 19 March 2013, http://www.ncver.edu.au/publications/2489.html.

Figure 2: Commencing domestic bachelor's (pass and graduate entry) enrolments: science-related fields of education
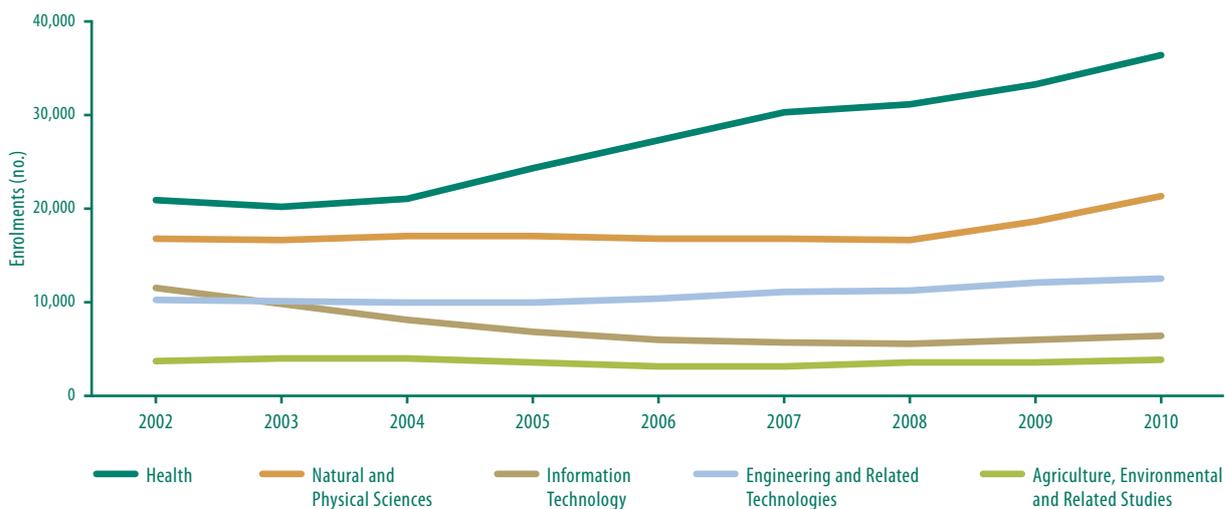
technologies field of education. 349,000 EFT higher education students were enrolled in STEM disciplines, representing 32.7 per cent of all higher education enrolments. Over a third of these enrolments were in the health field of education. In total, 496,300 EFT VET and higher education students were enrolled in STEM disciplines in 2010, representing a total of 32.7 per cent of all enrolments.

In terms of international higher education students, the Office of the Chief Scientist reported (2012a) that: 'The proportion of international students varies widely across narrower fields of education: Information Technology and Engineering had the largest international student components, at 68 and 43 per cent respectively; Natural and Physical Sciences and Agriculture and Environmental Sciences had the smallest at 22 and 20 per cent respectively' (p. 27).

In terms of gender representation, while more females enrolled in VET (322,700) than males (331,800) in 2010, many more males than females enrolled in STEM disciplines (44,300 males versus 14,700 females). Similarly in the higher education sector, more females were enrolled overall than males (477,600 versus 383,900), but females were under-represented in STEM disciplines in the higher education sector (40,100 males versus 31,000 females). For more discussion see Section 12.

Note that the inclusion of the health field of education, which enrols 19,100 females, considerably decreases the gender disparity in STEM disciplines. The greatest disparities in higher education discipline enrolments are in information technology (7,200 males, 1,300 females) and engineering (14,300 males, 2,300 females).

University STEM participation over time

For the period 2002-2010, commencing domestic undergraduate enrolments increased overall by 23.6 per cent. However, there was much variation by field of education. In terms of undergraduate participation in STEM, commencing enrolments in health increased significantly (by 73.0 per cent) to represent 17.9 per cent of all commencing undergraduate enrolments[1]. Commencing enrolments in natural and physical sciences remained flat for the period 2002-2007 then grew by 29 per cent in 2008-2010, to represent 10.5 per cent of all commencing undergraduate enrolments in 2010 (Office of the Chief Scientist, 2012a).

Commencing enrolments in engineering increased by 21 per cent from a low base,

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1 The overall decline in STEM-discipline enrolments would be higher if nursing had not been made a university degree level program.

representing growth in student numbers from approximately 10,000 to 12,400. Engineering represented 6.1 per cent of all commencing undergraduate enrolments. Enrolments in information technology decreased by approximately 50 per cent, to represent 3 per cent of all commencing domestic undergraduate enrolments in 2010. Enrolments in agriculture and environment decreased from a low base of 4 per cent, to represent just 1.7 per cent of all commencing domestic undergraduate enrolments (ibid.). Commencing international undergraduate enrolments increased more than domestic enrolments.

Higher degrees by research

Over 2002-2010, commencing domestic higher degree by research enrolments remained fairly static, with some variation by field of education. In STEM higher degrees by research, commencing enrolments in natural and physical sciences fell from a high of 1,700 in 2004 to recover partly between 2008-2010, reaching 1,600 students in 2010. Commencing enrolments in health grew by 21 per cent over 2002-2010 to reach about 1,400. Commencing enrolments in engineering and related technologies declined for several years then returned to the 2002 level of about 1,000. In commencing enrolments in agriculture, environmental and related studies, numbers

Figure 3: Domestic commencing HDR enrolments: science-related
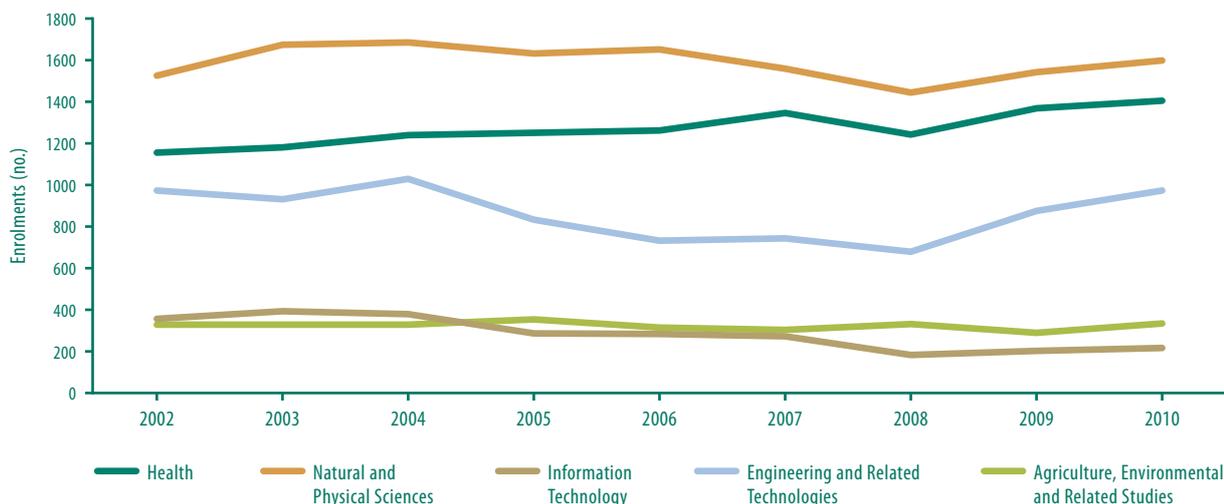
Source: Office of the Chief Scientist 2012a, *Health of Australian Science*, Australian Government, p. 75.

Figure 4: Proportion of domestic commencing undergraduate enrolments, by gender: science-related fields
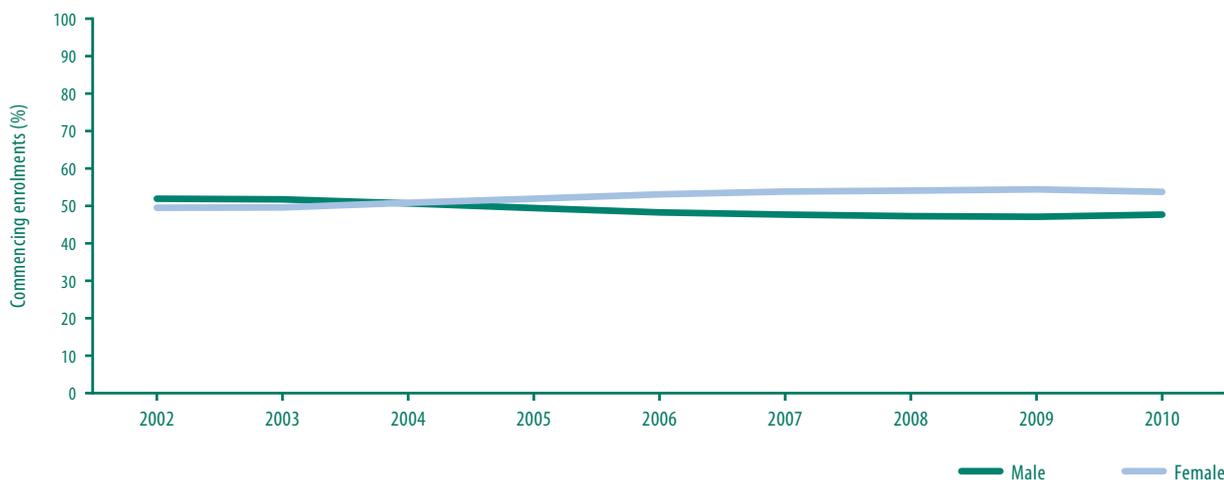
Source: Office of the Chief Scientist 2012a, *Health of Australian Science*, Australian Government, p. 72.

Figure 5: Number of student completions (domestic and international): science-related fields of education, by course level, 2010
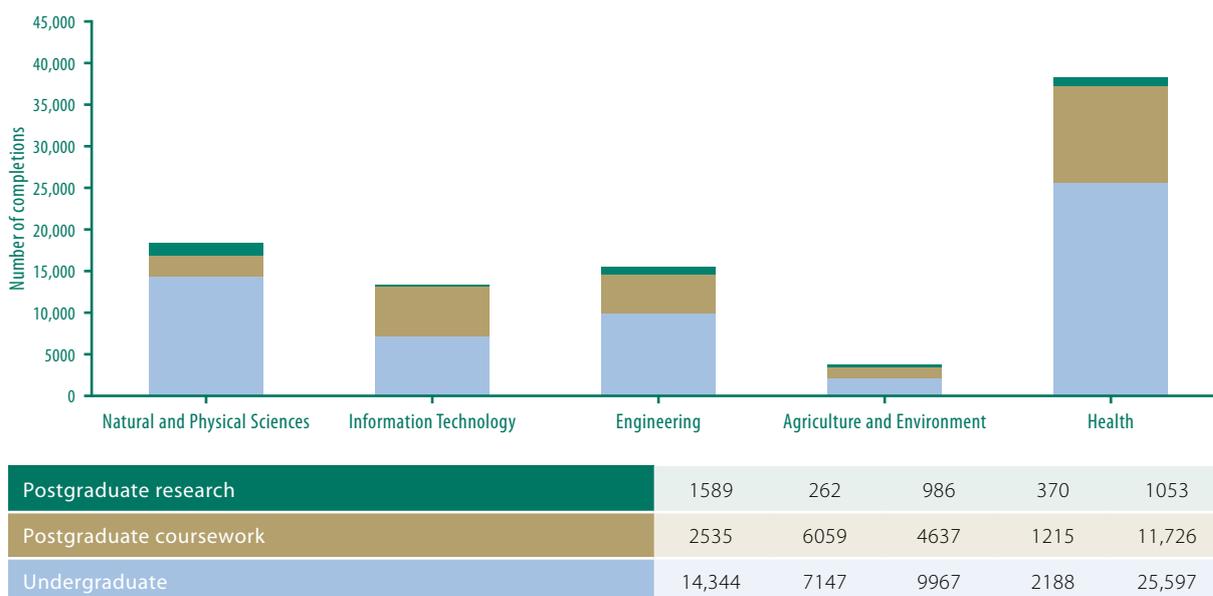
	Natural and Physical Sciences	Information Technology	Engineering	Agriculture and Environment	Health
Postgraduate research	1589	262	986	370	1053
Postgraduate coursework	2535	6059	4637	1215	11,726
Undergraduate	14,344	7147	9967	2188	25,597

Source: Office of the Chief Scientist 2012a, *Health of Australian Science*, Australian Government, p. 26.

remained steady at approximately 350; and enrolments in information technology declined from 370 to 230 (Dobson, 2012).

Domestic higher degree by research completions increased for the period 2002-2010. However the *Health of Australian Science* report suggests some caution is taken in interpreting this data.

Gender balance of university enrolments

In 2010, women's share of commencing domestic students in the science-related disciplines was almost equal to women's share of all commencing enrolments: 54.0 per cent of starting enrolments in the combined group of agriculture and environment, engineering, health, information technology, and natural and physical sciences, compared to 55.6 per cent of all commencing enrolments.

However, domestic women students' representation in undergraduate commencing enrolments varies considerably by field. Women are about 80 per cent of commencers in health and slightly more than half in agriculture and environment, and the natural and physical sciences. But in engineering and related technologies (20 per cent) and information

technology (14 per cent) they are poorly represented (Office of the Chief Scientist 2012a). Women's under-representation in engineering and in information technology is longstanding and for the most part worldwide. As noted, Section 12 explores this issue in more detail.

In 2010, there were approximately 285,000 course completions in all fields of education and at all levels (undergraduate and postgraduate), for domestic and international students together[2]. Of these course completions, approximately 90,000 were in science-related fields of education, representing 32 per cent of all completions. The largest numbers completing were in health (approximately 38,000), and the lowest in agriculture and environmental sciences (approximately 3,800). The largest number of higher degree by research student completions was in the natural and physical sciences (1,589). Indicative completion rates for undergraduate students varied, with the highest recorded in health (73 per cent) and natural and physical sciences (69 per cent). There were lower indicative completion rates in engineering (58 per cent), agriculture and environment (56 per

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2   Domestic students comprised 69 per cent of all completions in science-related fields of education in 2010 (Office of the Chief Scientist 2012a).

cent) and information technology (50 per cent). Completion rates for higher degree by research students in science-related fields of education were generally higher than the average for all fields, with the exception of information technology (Office of the Chief Scientist, 2012a).

In terms of both patterns of STEM enrolments and patterns of completions, there are continued disparities between students from different groups, in rates of participation and achievement. There are disparities between States and Territories; and between students from government, Catholic and independent schools. Indigenous, students with disability, students in remote and very remote locations, and students from low socio-economic status [SES] background are all under-represented. Where these disadvantages compound, particularly for indigenous students living in remote and very remote locations, young Australians are at much higher than average risk of under-achievement in standardised tests of STEM-related knowledge and skills, and of under-enrolment in STEM disciplines in post-compulsory education and training. As noted, girls and women are under-represented in the STEM fields of education of engineering and information technology. All these disparities are longstanding.

Teacher supply

Australia's schools are staffed by over 300,000 teachers. The *Staff in Australia's Schools* (SiAS) survey identified a small number of unfilled specialist area teaching positions including science (10 positions overall), computing (110) and technology (70), in almost all cases at a rate of one position unfilled per school, where a vacancy was identified. There were no reported unfilled numeracy positions (McKenzie et al, 2011). However, there were sizable shortages noted for Generalist Primary teacher positions (610) (ibid, p.108). DEEWR's *Skills Shortage List Australia 2011-12* (current as at June, 2012) identified national skills shortages for the education professionals classification of Early Childhood (Pre-primary School) Teacher (DEEWR, 2012a). DEEWR also notes that 'secondary school teacher positions in the fields of senior

mathematics and science attract relatively few suitable applicants' (ibid, p.23).

There is variation at the State and Territory level: recruitment difficulties have been recorded in New South Wales for secondary school teachers in some locations (DEEWR, 2012b), Queensland for primary school teachers in regional areas (DEEWR, 2012c), Tasmania for mathematics and science teachers (DEEWR, 2012d) and the Northern Territory for primary school and secondary school in mathematics and IT, particularly in remote locations (DEEWR, 2012e). Schools located in regional and remote areas, or indigenous communities, and schools with a low socioeconomic advantage experience more difficulty filling teaching vacancies.

Secondary school principals identified larger numbers of unfilled teaching positions including 400 in mathematics (390 positions in mathematics; 10 in statistics), 190 in science (chemistry – 80; physics – 50; science: general – 50 and biology – 10) and 310 in technology (computing – 30; information technology – 130; and wood or metal technology – 120). In many instances individual schools reported vacancies of more than one unfilled teacher in the nominated specialty, indicating that some secondary schools in particular experience difficulty recruiting teaching staff. In total, there were some 900 unfilled mathematics, science and technology positions identified in 2011 (McKenzie et al, 2011). Teacher skills shortages, particularly with respect to secondary qualified science and mathematics teachers, have been identified as a key element of the 'crisis in science education' (Tytler, 2007).

We note that data on absolute shortages do not tell the whole story of teaching capacity in the STEM disciplines, and are misleading if relied on as the sole source of information. This is because of the widespread practice in Australia of staffing classes in mathematics and science (especially senior secondary physical sciences) with teachers untrained or under-trained in the disciplines concerned. McKenzie and colleagues note that where there are unfilled positions, secondary school principals report the implementation of strategies including 'requiring teachers to teach outside their field of expertise' (42.2 per

cent), 'recruit(ing) retired teachers on short-term contracts' (25.1 per cent), and 'recruit(ing) teachers not fully qualified in subject areas with acute shortages' (23.0 per cent).

The incidence of teaching out of field for mathematics and science in Australia, especially in regional and rural areas, is of grave concern. We note that there are socially regressive variations between school systems, with more secondary school principals from government (72.9 per cent) than Catholic (67 per cent) or independent schools (49.3 per cent) resorting to a range of strategies to deal with staffing shortages (McKenzie et al. 2011). In other words, where there are labour market shortages in specialist science, mathematics and technology secondary school teaching positions, government and Catholic schools in particular are resorting to the use of under-qualified or unqualified replacement staff, in terms of disciplinary qualifications. Teaching outside field is a serious weakness in Australian schooling. It is discussed in more detail, in relation to mathematics, in Section 9.

The Australian Mathematical Sciences Institute suggest with respect to issues of teacher supply, that 'the ageing secondary teacher population and falling graduation rates indicate an endemic problem' (AMSI 2012a, p.2).

In addition, there are serious concerns with respect to primary school teachers' level of science and mathematics training, and some teachers' confidence and capacity to deliver lessons in these areas. The Australian Mathematical Sciences Institute has called on the government to ensure teachers are 'mathematically prepared', and has indicated that 'a concerted and immediate effort by governments, the teaching profession and the universities is required to guarantee the supply of suitably qualified mathematics teachers' (AMSI 2012b, n.p.).

STEM and the labour markets

There is discussion of labour market-related issues in Section 11 of the report. This part of Section 2 merely establishes basic facts about the situation in Australia.

The Australian Workforce and Productivity Agency Discussion Paper *Future focus: Australia's skills and workforce development needs* (AWPA, 2012) having examined the skills and workforce development needs arising from four proposed scenarios (long boom, smart recovery, terms of trade shock, ring of fire) reported that 'skills shortages in some areas and industries threaten wage inflation and risk growth-constraining monetary tightening' (ibid., p.1). Further, the report states that 'the demand for higher levels of skill is a reality … (and) this can be expected to continue into the future in response to technology-induced change, structural adjustment, a progressive shift to service-based industries, and Australia's changing demographics' (ibid, p.1).

The primary data used in this Section are derived from the ABS Census data, which are divided into three ASCED codes: natural and physical sciences (NPS), information technology (IT) and engineering and related technologies (ERT). It should be noted that the category of natural and physical sciences is very broad, covering the gamut of mathematics, physics, chemistry, biochemistry and geology to laboratory technology. The category of information technology is relatively focused.

The Census data on employment are gathered on the basis of the respondent's highest qualification. This leads to under-reporting of STEM qualifications, in particular by school teachers. For example, a respondent who completed a first degree in a STEM field and then completes a postgraduate qualification in education will not be captured in this employment category.

According to the Census there are 651,000 STEM-qualified people in Australia (in 2011), including those holding Bachelor Degree level or higher qualifications in natural and physical sciences (232,000; 40 per cent), information technology (161,000; 36 per cent) and engineering related technologies (257,000; 25 per cent). The STEM group – here excluding health sciences – represents approximately 20 per cent of the Australian population with a Bachelor Degree or higher qualification. The under-reporting mentioned above is more likely to influence the reported figures for

natural and physical sciences graduates because information technology and engineering graduates are less likely to become school teachers.

The STEM-qualified population is more male-dominated (72 per cent male) than the tertiary-qualified Australian population as a whole (45 per cent). However, secondary teaching in Australia is female-dominated, especially in the biological sciences. If the STEM educated but under-reported female secondary teachers were included in the NPS category of STEM graduates, the percentage of male graduates would decrease. The under-reporting of NPS graduates probably exaggerates the extent of male domination of the STEM-qualified population in Australia.

Employment rates are high among all STEM-qualified people (81 per cent), and the unemployment rate is low (less than 4 per cent). From 2007 to 2011, the total growth across all occupations nationally was 8.1 per cent; the top eight STEM occupations exceeded the national rate, growing by 11.1 per cent on average. There are marked differences in labour market participation patterns between males and females, with female STEM graduates more likely to be employed part time: 23 per cent, compared to 10 per cent for males. Rates of return are broadly similar to those of other graduates, and among the STEM-qualified group are highest for computing/information technology graduates.

There is great diversity in the occupational destinations of STEM graduates. A significant occupational 'bunching' occurs at a broad level, with eight occupations taking 75 per cent of employed STEM graduates (design, engineering, science and transport professionals; ICT professionals; specialist managers; business, human resource and marketing professionals; engineering, ICT and science technicians; education professionals; office managers and program administrators; hospitality, retail and service managers). Between 2007 and 2011 the strongest growth in employment among the STEM occupations was for design, engineering, science and transport professionals (24.7 per cent) and for ICT professionals (13.8 per cent). In this period, both headcount and total hours of employment of STEM graduates grew more quickly than the national average. Full-time average weekly earnings remained above the national average, but generally grew at a slower rate.

It appears that there are skills shortages for at least some classifications of engineers. In the period under discussion, civil, mining, mechanical and electrical engineering generally had low vacancy fill rates and there were few suitable applicants per vacancy (see Section 11 for more detail).

There are concerns regarding the Australian university academic staffing profile as the academic workforce ages, the proportion of tenured staff positions decrease, casualisation increases, employment conditions exacerbate recruitment difficulties, and global competition and mobility increases. These concerns affect the capacity of the university sector to enhance scientific literacy, educate STEM undergraduate and higher degree by research students, and undertake STEM-related research.

Policies, strategies and programs

Commonwealth government reports and policy statements have specifically focused on elements of the education, and science and innovation agendas relevant to science, technology, engineering and mathematics. With respect to schooling and teaching quality, the *Melbourne Declaration on Educational Goals for Young Australians* commits all Australian governments to quality schooling, including knowledge in mathematics and science (physics, chemistry and biology). The *Measurement Framework for Schooling in Australia*, NAPLAN, NAP-SL and NAP-ICT package represents a framework for the collection of data regarding mathematical and science performance, scientific literacy and ICT literacy. These Australian assessment regimes are additional to the PISA and TIMSS initiatives.

There have been a number of inquiries into teaching and teacher education. The Council of Australian Government (COAG) *National Partnership Agreement on Improving Teacher Quality* supported the development of the *Australian Professional Standards for Teachers* by the Australian

Institute for Teaching and School Leadership (AITSL), national accreditation of pre-service teacher training courses, national consistency in graduate teacher registration (AITSL Proficient Standards), performance management systems and professional development.

In response to the *Review of Funding for Schooling: Final Report* (Gonski report) the Australian government has announced the *National Plan for School Improvement*. A key theme of the plan is Quality Teaching, which involves reforms aimed at ensuring Australia has the best possible teachers and that they are adequately supported. Announced reforms include: increasing entry requirements for school leavers and mature-aged teaching degree applicants; increasing the length of pre-service practicum requirements; improvements to teacher performance management; higher quality professional development and greater school autonomy including in staff selection and employment. Government reviews have recognised the issues facing declining student engagement with, and participation in, school science and mathematics, and recommended a range of policy interventions to address declining performance and general science literacy. This includes improving primary school science through a focus on literacy education, establishing partnerships between industry and education, installing contemporary science equipment, and providing careers education and transition support.

In terms of participation in higher education, reviews have recommended strategies to address disparities faced by particular cohorts, for example the Bradley review's targets for increasing participation of students from low SES backgrounds. The Cutler review made recommendations relevant to STEM research and development and industry innovation. With respect to both school and university education, addressing the inequities for indigenous Australians is a key government priority. The COAG *National Foundation Skills Strategy for Adults* highlights skill development needs for adults, including the skills of English language, literacy and numeracy which are seen as precursors for scientific literacy. The Australian Workforce and Productivity Agency is exploring a range of strategies to increase the skill level of Australia's workforce, including scientific literacy and capacity to transition to higher education.

Commonwealth, State and Territory governments have produced a number of policies, strategies and review reports related, directly and indirectly, to STEM. This includes documentation focused on early childhood, vocational education and training, existing workforce skills development, research and development, and innovation. Policy interventions to support STEM and scientific literacy address teaching quality, curriculum, curriculum resources, school and university education and research infrastructure, work integrated learning (e.g. internships and work placements), career and subject selection advice, post-school transitions, cross-sectoral partnerships (education, industry, government) including the *School Business Community Partnership Brokers Program*, existing workforce development, targeted immigration, research capabilities, business development, commercialisation, community engagement and accountability.

Despite the plethora of government policies and reviews focused on education, and science and innovation and the relatively recent emergence of the STEM agenda in Australia, the 'pipeline' is decreasing and there are serious questions about performance in the foundation skills of literacy and numeracy, and the enabling sciences, mathematics and scientific literacy. Participation in university undergraduate and higher degree by research programs in STEM-disciplines is only marginally increasing, largely due to increases in the health disciplines. There are challenges facing Australia's research and development and innovation sector, and there are some labour market shortages in STEM-occupations, principally engineering. If workforce levels of numeracy and scientific literacy were higher it is likely that productivity would advance. A coherent STEM policy framework spanning all Commonwealth, State and Territory governments, education systems and industry, including strategies in early childhood, school, VET, higher education and research and development, could go some way to addressing these challenges. That matter is discussed further in Section 7.

3 | What country comparisons can tell us

In this project, when seeking to identify useful lessons and ideas for Australia, in the approaches taken by other countries, we did not commission reports from every possible national system. We focused on those domains where useful ideas were most likely to be identified: countries most similar to our own, in relation to the nation overall or particular populations such as indigenous students, and countries that are high performers in relation to STEM. Broadly, the reports commissioned for this project that were nation-specific fall into five main groups:

- English-speaking countries with whom we share many common features in government, society, the economy and education: the United Kingdom, the United States, Canada and New Zealand.

- Europe, including the Western Europe regional report plus specific country reports on France, Portugal, Finland and Russia. We focused mostly on the STEM-strong countries rather than covering every jurisdiction in Europe.

- The emerging and emerged players in East and Southeast Asia which share a Post-Confucian heritage and are exceptionally dynamic in STEM: China, South Korea, Japan, Taiwan and Singapore.
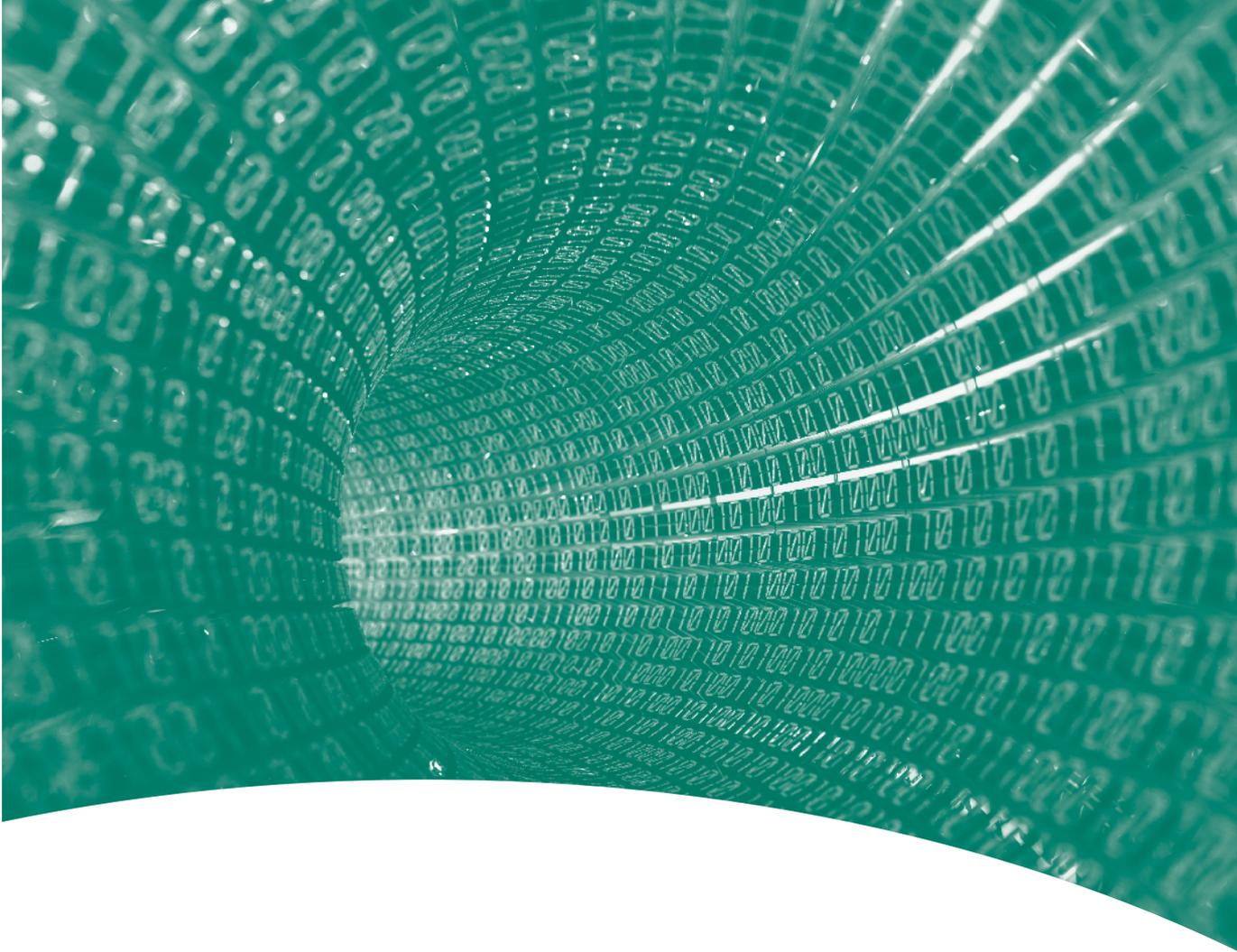
- Emerging economies and education systems: South Africa, Brazil and Argentina.

- Countries with a particular interest in indigenous policy issues: Specific reports on indigenous students and STEM in Canada and the United States, plus content in the country reports from New Zealand and Brazil, and related issues in the report from South Africa.

The country and regional reports reveal an almost universal governmental preoccupation 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. In most nations with active official policy there is also active public discussion. There is a widespread interest in building high-end STEM skills, linked to research and development, and industry innovation. It is assumed in most national jurisdictions that the quantity and quality of STEM competences

affects economic performance – though in most nations there is less programmatic focus on the links between education in STEM, and the take-up of STEM skills in the labour markets, than the assumption suggests. Most efforts of government, and most of the focus of media and public attention, are in relation to schools. Most of the reports discuss issues of curriculum, pedagogy, student motivation, and teaching. Consequently this summary report is rich in those areas. In the consultants' work there is less focus on universities than on schools, and almost no discussion of the parallel set of higher education issues in relation to curriculum, pedagogy, student motivation, and teaching. Thus these issues in higher education are scarcely touched on in this report, though they are important.

There is little discussion of the labour market and industry settings, which remain something of a 'black box' everywhere. There is also surprisingly

little policy and public focus – in most countries, including Australia – on technical education, where the STEM factor is strong. The exceptions are the minority of countries which maintain high quality vocational or technical secondary institutions and/or tertiary level institutions.

In large part the dominance of emphasis on schooling is because schooling is subject to direct government regulation and responsibility, while universities are more autonomous, technical institutes in most systems lack adequate status, and the economic utilisation of STEM, on which the rationale for STEM policy (ostensibly) pivots, are largely beyond governmental reach and public scrutiny. Command economies such as that of the former Soviet Union used to directly run the production side of the economy, including the allocation of graduates to work. The government of China still exercises greater interest in the education-to-labour relation than do most governments. Nevertheless, the overall trend is for governments to withdraw from directing the take-up of graduate labour except in their own organisations. It is ironic that much of the official rhetoric about STEM turns on its assumed contribution to productivity and innovation in the workplace, yet 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, and (it seems) expects demand to spontaneously appear and to make effective use of graduate skills, despite the obvious limitations of a strategy of relying on a supply-side approach alone.

The preoccupation with the quantity and quality of STEM is often, though not always, linked to national results in comparative international tests of school student achievement in STEM domains. In some countries there are widespread concerns about declining proportion – or numbers – of students in the STEM disciplines. In some countries there are also concerns about shortages of STEM skills in the labour markets, especially engineering-related skills. Sometimes the STEM policy agenda is driven by an argument about shortages that inhibit economic capacity; sometimes more by arguments about lifting performance to meet the challenges of modernisation and/or international competitiveness.

The fact that there is an almost universal preoccupation with STEM-related issues in education and the economy, and the fact that examination of government strategies and programs reveals many points of not just overlap and similarity, but commonality, does not mean the issues are 'the same' everywhere. Still less does it mean that programs and practices in one jurisdiction can be transplanted into another with the same or similar effects. Programs, policies and professional practices in relation to STEM are nested in 'thick' and complex social, economic and policy contexts. Common trends around the world are articulated everywhere through national political cultures and local histories and conventions, and STEM policies must be consonant with the national and local contexts in order to gain purchase. Each individual program initiative plays out in specific ways. Policy borrowing not only requires much translation and adaptation, it is a case-by-case matter. Nonetheless, governments everywhere watch other government initiatives closely. There is much parallelism and convergence in STEM, as in other education policy.

All else being equal, policies and practices that have developed in settings relatively similar to Australia are more likely to provide useful pointers for Australia, than policies and programs from elsewhere. Where political, educational and business organisations are broadly similar to our own, there tends to be greater ease of policy transfer and adaptation. Where families, students and educational professionals share similar assumptions and behaviours to those of their Australian counterparts, programs that work elsewhere are more likely to work here. Thus in this project we looked especially closely at nations where we have obvious commonalities: the English-speaking countries, and to a lesser extent, the affluent countries of Northwestern Europe closest to the United Kingdom. But this does not mean that only these closer comparator countries can have something to teach us in Australia. Some of the strongest recent performers – in education in general, and in STEM educational achievement and STEM-led dynamism in the

economy in particular – are countries with quite different languages, histories and cultures to our own, such as Finland in Europe, and East Asian nations such as Korea, Taiwan and China. Other standouts include education systems where Eastern and Western heritage are combined, such as Singapore and Hong Kong SAR in China. It is in these nations that programs to lift STEM performance appear to be bearing the most fruit at present, in both schooling and in research science. We need to better understand what drives and sustains their improvement.

In the consultants' reports it is noticeable that the presentation of STEM-related issues differs in terms of the five groupings outlined above. STEM issues are nested in rather different narratives in each case. These narratives colour the kinds of strategies and programs employed, at least to some extent.

In the English-speaking countries, with the exception of Canada, there is widespread talk of a STEM 'crisis'. This is underpinned by quantitative indicators that show a declining relative (or even absolute) performance in international comparisons of achievement and a lower rank than the nation believes it should occupy; and/or declines in participation in STEM subjects at school. There are some inventive programs related to STEM, especially in the United Kingdom and United States. However, for the most part the talk of crisis does not appear to secure a consensus about programs able to lift performance in a sustained way. Certainly the outcomes of comparative tests over time suggest that a clear dynamic of improvement is missing, in contrast with, say, Korea. Nevertheless, it is interesting to note that when there *are* measured improvements, as in the United States PISA performance in science, little attention is given to this. The narrative about decline seems to be deeply entrenched. In the United States, Australia and New Zealand, there is more debate about the quality of teachers than in the STEM-strong countries, and with some exceptions the status of teachers is not as high. There is also a faltering of universal achievement – the 'tail' of STEM low achievers is longer in the English-speaking countries than in much of Western Europe and East Asia, though again Canada is an exception,

and the United States and United Kingdom have longer 'tails' than Australia. In research the English speaking countries still enjoy a global advantage but are concerned that some other countries exhibit faster improvement. Australia and New Zealand do not perform as strongly in science as the United States, United Kingdom and Canada.

In the reports of the consultants from English-speaking countries there is some critique of the orthodox STEM policy drivers. The United Kingdom report refers to 'somewhat hysterical' reactions to PISA results. The United States report raises the question of the extent of STEM worker shortages. It also mounts an argument that STEM graduates are very useful in workplaces generally, and that raising universal STEM competencies has a positive economic effect outside of specific occupations. In the English speaking countries, though, the arguments about specific STEM skills (whether in terms of shortage, or in terms of high performers) mostly seem in a tradeoff with the argument for general STEM literacy across the population. The former arguments seem to have more purchase than the latter.

Western Europe includes many countries where an emphasis on STEM has long been part of the framing of national policy on education and industry, though some countries refer to crisis or under-performance. Several countries perform exceptionally well in research science given their size, including Switzerland, Sweden, Finland and the Netherlands. The European Commission has been centrally focused on STEM policy since the 1990s. STEM is especially significant in advanced manufacturing nations such as Germany, where engineering is a large presence. Finland has exceptional STEM indicators in all domains including school performance, the proportion of doctoral enrolments, the level of the STEM qualifications required at work, including teaching, and the weight of the research and development workforce within the economy. Not everyone is on the STEM reform bandwagon: Russia inherited from the Soviet era what was then an advanced culture of science and technology, including special science schools and competitions, and there is strong content knowledge in schooling as measured by TIMSS, but the education system is less effective in

PISA, which compared to TIMSS places greater emphasis on applications of knowledge rather than content. However, Russia is not at this stage so enthusiastic about reforms to emphasise inquiry based and problem-solving processes, and enhance creativity, preoccupations in many other systems. There is little momentum in the STEM discussion or interest in other countries' performance. In contrast, in France, there are concerns about declining participation in secondary school and tertiary STEM, notwithstanding the fact that France looks relatively strong in terms of STEM at university level, and science careers are more prestigious in French society than in the English-speaking world. As in other nations, it seems there is always room for a 'there should be more STEM' argument regardless of the actual level of STEM competences. This indicates the power of the core economic narrative about the contribution of STEM to economic innovation, growth and competitiveness. In that respect STEM draws on near universal perceptions of the centrality of science and technology. These themes are especially obvious in policy and public cultures in Western Europe.

In East Asia and Singapore the language about STEM is more confident. There is an almost universal recognition in the home about the importance of education (Marginson, 2011) and STEM has been placed in a superior position. The position of STEM in secondary schooling and higher education is unquestionable. China has compulsory mathematics until the end of school. Long-term planning approaches are dominant and there is a broad and deep social and governmental consensus about the importance of science, technology, research and STEM. There are strong programs to lift the top science universities on the global scale, in every one of these systems. 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. In the last Korea stands out, with its inclusion of the Arts in its STEAM program. There are concerns in both Korea and Japan about the need to encourage more bright students to stay with science and mathematics: here the concern intersects with that of many other countries. In the Post-Confucian societies teachers are respected, and STEM classes are taught by discipline-qualified teachers teaching in the fields in which they were trained. While there is less debate about the quality of teachers

than in English-speaking countries (except perhaps in Japan), there is much emphasis on lifting teacher quality, which is built into the promotion-oriented professional development system in China. There is a largely seamless movement between STEM for all and programs focused on higher achievers and research, though particular techniques designed to isolate high STEM achievers, such as special schools or scholarship allocations, play into fraught debates about competitive systems and outcomes and can be controversial. STEM is generally (as it is everywhere) associated with high achieving academic tracking. Perhaps the association is strongest in East Asia. There are relatively strong systems of technical schools in some systems, including Singapore and Taiwan. Taiwan also has technical universities. There is much talk about the need to lift national effort and performance, coupled with a focus on trends in performance; but the Anglo-American preoccupations with 'crisis', decline, and seemingly intractable capacity weaknesses, are absent in these countries, except that Japan is focused on declining participation and relative performance in STEM.

For countries in the process of developing an industrial base, and/or with low levels of education participation and teacher supply such as Brazil and South Africa, STEM participation is framed in terms of improving participation in basic education, and putting in place a qualified teaching workforce. Issues of socio-economic equity and building human capital in previously excluded populations have greatest resonance in these nations, where participation in good quality upper secondary and tertiary education (indeed, participation in the modern economy) is by no means universal; there are social groups whose members are largely excluded; and science and research systems are down the development curves. This is not a description of Australian economy and society. However, it does describe the position of many indigenous Australians. There, solving the problem of STEM capacity and performance is a sub-set of the larger problem of designing more effective educational programs and resources. This is not to say STEM-related indigenous education should 'wait' until the larger problems of indigenous participation in education and society have been effectively addressed.

The consultants' reports on STEM in indigenous education contexts indicate common themes across the group. Indigenous STEM issues in part are understood in terms of the disadvantages of low SES and remote locality, and in part in terms of cross-cultural encounter. Inventive curricula and pedagogies are needed, as the reports from Canada and the United States suggest.

4

An international view of STEM in Australia

International organisations have a unique comparative perspective that highlights global recognition of the importance of the STEM disciplines, and can usefully inform Australia's national STEM agenda. The international organisations that give significant attention to STEM issues include the Organization for Economic Cooperation and Development (OECD), the World Bank, United Nations Science, Education and Cultural Organization (UNESCO), the European Union (EU), and the International Association of the Evaluation of Educational Achievement (IEA). A full discussion of data, findings and policy recommendations of international organisations in relation to STEM education is provided in the consultants' report on the work of international organisations.

Interest in STEM education: An economic imperative

The interest of international organisations in both education and the labour market in STEM fields is closely tied to an overall

economic agenda. This is based on research that connects cognitive ability levels in the population, as measured by tests of scientific, mathematical and reading literacy, to long-term economic growth and competitive advantage. In this argument, economic growth signifies the overall wellbeing of the population and not simply the wealth of the economy.

Economic modelling has consistently identified a 'relationship between direct measures of cognitive skills and long-term economic development' (OECD, 2010a; Barro, 2001; Sianesi & Reenen, 2003; and Krueger & Lindahl, 2001). Educational attainment falls short as a proxy for human capital, as it measures only quantity, not quality. The OECD argues that this relationship is 'particularly incomplete and potentially misleading … for comparing the impacts of human capital on the economies of different countries' (OECD 2010a, p.13), because

it implies that there is similarity in the outcomes of a year of schooling between countries and that formal schooling is the only source of learning. Instead, the international evidence reveals that educational quality, as measured by tests of cognitive skills primarily in science and mathematics, is both a more accurate predictor of, and a more potent influence on, economic outcomes (Hanushek & Woessmann, 2009; Hanushek & Woessmann, 2008; OECD 2010a; Sianesi & Reenen, 2003; Hanushek & Kimko, 2000). A recent study (Hanushek & Woessmann, 2012) again confirms this overall conclusion. Their model has now grown to encompass a particularly large base of evidence. It includes the results of international tests conducted over many decades by both the IEA and the OECD. Modelling undertaken by the OECD on results generated in its own standardised global testing program has similarly demonstrated that

'differences in cognitive skills' explain 'a majority of the historic differences in economic growth rates across OECD countries' (OECD 2010a, p.10).

International organisations emphasise the economic imperative as a justification for their interest in STEM education. The OECD explains its interest in declining numbers of students studying STEM fields, and in correcting gender imbalances in STEM participation, in these terms. A report from the OECD Global Science Forum notes that 'the economy is increasingly driven by complex knowledge and advanced cognitive skills' and claims this to be the driver of OECD and ministerial interest in the area (OECD 2006, p.3). The report described women not currently involved in STEM fields as a 'resource' (ibid.). UNESCO (2007, p.45) similarly uses this terminology, referring to women and minorities under-represented in STEM fields as a 'resource' or 'pool of talent' that is necessary for achieving development goals. The EU has a similar view, expressing concern about declines in participation in STEM fields due to the 'strategic importance' of 'innovation and knowledge in science and technology' for the maintenance of 'economic growth' (European Communities 2008, p.16). The same research described the under-representation of women, attrition in particular, as essentially the under-utilization of available and qualified human capital. Furthermore, the European Commission (EC) (ibid.) advocates urgent action in order to boost quality and international competitiveness in innovation. Again these are primarily economic concerns.

The OECD's flagship international testing program expresses its goal as the measurement of 'cumulative yield' from the quantitative examination of educational outcomes (OECD, 2010b, p.11 & OECD 2006, p.9). UNESCO notes the importance of engineering education for the economy by describing it as a 'foundation for the development of society' (2010, p.337). Without a thriving engineering profession, it claims, development, production and economic growth would suffer. The reasoning is that engineering drives innovation, and in turn, innovation drives the economy through the exploitation of new markets.

Focus on the link between economic development and high-end skills may seem an obvious concern for international organisations like OECD whose work is anchored to the wealthier, more developed countries. However, organisations whose main concern is developing countries, such as the World Bank, are similarly preoccupied with the economic benefits of STEM-related performance. For example, UNESCO claims that excellence in STEM 'plays an important role in promoting long-term economic growth, and in building a base for a science-based knowledge society' (ibid, p.27), as well as in establishing a sustainable development trajectory within developing economies. In relation to women in science, the report explains that any discrimination reducing the engagement of women limits growth and the reduction of poverty in developing countries (UNESCO, 2007). In 2010, UNESCO also refers to the role of science and technology capacity as being 'critical drivers for achieving sustainable development and gaining access to the knowledge economy and society' (p.7). The outcomes of this are both societal improvement and economic growth.

Policy research and recommendations

International organisations have undertaken research and policy work in a variety of areas related to education in STEM fields in countries around the world. Much of this work refers to declining interest and participation in STEM study, and the need to make changes that attract more students to the related disciplines, particularly women and other under-represented groups. Research in international organisations has also focused on the training of engineers to meet labour market demands. In addition, the international organisations have discussed the use of STEM education to promote sustainable development and to improve levels of financial literacy.

The most significant role of international organisations in relation to STEM education is the comparative measurement of participation and performance.

Participation in STEM fields of education

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

A lack of comparable data at upper secondary level

School level engagement in the study of STEM fields is key to ongoing pathways through higher education and into the STEM labour market. However, there is a distinct lack of standardised international data collated to illustrate upper secondary level participation in STEM fields of study.

As noted in Section 4, in Australia 52 per cent of year 12 students in 2009 were enrolled in science subjects (Goodrum et al, 2012), and 72 per cent took some level of mathematics study, including 14 per cent in intermediate level mathematics, and 7 per cent in advanced mathematics (Office of the Chief Scientist, 2012a; and Barrington, 2011).

Consultant reports commissioned for this project provide specific national data from a selection of comparable countries. In Canada national statistics are not collated but the education system of each province provides enrolment data in STEM disciplines. In 2010-11 between 42 per cent and 50 per cent of year 12 students were enrolled in mathematics, varying by province. Physics and chemistry attracted between 14 and 40 per cent of enrolled students, depending on the province. The United States is another useful comparator. Unlike Australia or Canada, the United States nationally counts the proportion of high school graduates who have completed mathematics and science courses at some point throughout their secondary studies. On this measure, more than 75 per cent of graduates in 2009 had undertaken at least basic level mathematics, 90 per cent biology, 75 per cent chemistry, and less than 40 per cent physics. Basic secondary school mathematics topics, such

as algebra and geometry, had been covered by more than two thirds of all students. More tertiary directed topics, such as probability and calculus, had been undertaken by less than 10 per cent of United States secondary school graduates in 2009.

In some countries students are required to study mathematics until the end of school, including Brazil, China, Israel, Finland and Taiwan. However, each has a unique curriculum structure and mandates mathematics study quite differently. While participation in mathematics to year 12 is at or above 90 per cent, national performance levels significantly diverge between these countries. Finland, along with selected educational regions of China, top international tests of students' mathematical and scientific abilities, while students from Brazil and Israel reach comparatively low proficiency levels.

Finland is an important comparator given its successful education system. In 2011, 14 per cent of Finnish matriculation candidates undertook advanced mathematics, 19 per cent basic level mathematics, 7 per cent each of biology and physics, and 6 per cent chemistry. These figures provide a good example of the difficulty with direct comparison. The curriculum is arranged differently in Australia and Finland, there are more Finnish than Australian students engaged in academically oriented programs at this level, and more students overall complete secondary school in Finland (93 per cent, compared with 70 per cent of Australian students).

First degree tertiary participation in STEM fields

In Australia the proportion of first degree students enrolled in STEM disciplines is comparatively low. Fewer Australian students are enrolled in STEM fields overall than in other comparable countries, below key comparators such as Finland, Korea and Germany.

The overall STEM shortfall is attributable primarily to low participation in engineering and mathematics study, rather than in the sciences. If enrolments in these two discipline areas are not included, the Australian figures climb well above the OECD and European averages. Of the countries presented above, only New Zealand

Table 8: The distribution of tertiary new entrants by field of education in 2010 for Australia, a selection of comparable countries, and the OECD and E21 averages

Country	Engineering, manufacturing and construction	Sciences	Mathematics and statistics	Computing	Other
Finland	25.4%	3.4%	1.2%	4.3%	65.7%
Israel	25.3%	4.7%	0.9%	2.8%	66.3%
Korea	23.8%	4.0%	0.7%	2.9%	68.6%
Germany	15.7%	5.6%	2.5%	3.8%	72.4%
OECD Average	15.0%	4.4%	1.0%	4.3%	75.3%
EU21 Average	14.9%	4.3%	1.0%	4.3%	77.7%
United Kingdom	8.2%	8.3%	1.7%	4.1%	78.0%
New Zealand	6.4%	6.9%	2.5%	6.3%	78.8%
Denmark	11.9%	2.1%	1.2%	5.9%	80.0%
Australia	8.7%	6.6%	0.4%	4.3%	82.2%
Argentina	8.0%	3.3%	1.7%	4.8%	83.2%
Japan	14.6%	2.2%	-	-	-

Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators,* OECD Publishing, Paris.

Table 9: The distribution of international tertiary new entrants by field of education in 2010 for Australia, and a selection of comparable countries

Country	Engineering, manufacturing and construction	Sciences	Mathematics and statistics	Computing	Other
Sweden	34.51%	8.60%	1.90%	6.73%	48.26%
Finland	31.72%	3.67%	0.46%	7.03%	57.13%
Germany	21.58%	7.05%	1.93%	7.30%	62.14%
United States	18.42%	8.77%	2.08%	6.64%	64.09%
Canada	15.75%	7.75%	2.74%	4.94%	68.82%
Denmark	19.27%	1.71%	2.06%	6.54%	70.42%
United Kingdom	14.88%	5.73%	1.78%	6.14%	71.46%
New Zealand	6.99%	6.91%	2.45%	9.79%	73.87%
Australia	11.08%	3.48%	0.47%	7.65%	77.33%
Japan	14.98%	1.21%	0.00%	0.00%	83.81%

Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators,* OECD Publishing, Paris.

and the United Kingdom reach a higher level of participation in science and computing than does Australia. Participation in engineering at tertiary level is particularly strong in Finland, Israel and Korea, such that when this discipline is removed, these countries fall below OECD and European average participation to less than 9 per cent of tertiary new entrants. The comparable figure in Australia is more than 11 per cent. Even Denmark, with STEM participation at first degree level only just above that of Australia, attracts a proportionately greater number of students to engineering study.

Australia is a key global destination for education, hosting a considerable number of international students. It is not a key STEM destination. Given the significant numbers of international students

who remain in the country on completion and apply for residence or citizenship, the disciplinary choices of these students are pertinent to the enhancement of STEM fields. The majority of international students (55 per cent) in Australia choose study programs in the fields of social science, business and law, while less than a quarter (23 per cent) undertake STEM studies.

In contrast, Sweden, Finland, Germany and the United States are key STEM destinations, with Canada, Denmark, the United Kingdom and the New Zealand also attracting a greater proportion of their international students to these fields than does Australia. Engineering again experiences a particular shortfall in Australia compared to other countries, with only 11 per cent of international students participating studying in this field. As

many as 35 per cent of all international tertiary students in Sweden, and 32 per cent in Finland are enrolled in engineering, manufacturing and construction related programs.

There is no consistent pattern of participation in STEM study at tertiary level through time. The consultants' reports indicate variation by country and by specific discipline or sub-discipline. Some countries, such as Finland, have had difficulty producing longitudinal data as a result of structural and governance changes in higher education in recent years.

STEM higher degree participation

In comparative terms Australia has stronger participation of students in STEM doctoral degrees. A higher proportion of doctoral degrees than first degrees are in science and engineering fields: 40 per cent of all doctorate degrees awarded in 2008 in Australia were in these two fields, just above the OECD average and on par with Denmark and Finland. Other countries with higher doctoral participation include France, Canada, New Zealand and the United Kingdom.

Australia attracts students to science fields at doctoral level in higher numbers than in engineering. Twenty-six percent of doctorates are awarded in science, with only 14 per cent in engineering. In contrast, key Asian countries China, Japan and Korea focus doctoral training on engineering. Australia, however, is not alone.

New Zealand, Germany and the United States also have higher proportions of doctoral degrees awarded in science than in engineering.

In Australia 37 per cent of doctorate degrees in science and engineering fields were awarded to women in 2008. Australia is significantly behind only Portugal and Israel on this measure. In both these countries, close to half of their doctoral completions in science and engineering are women. Women are most under-represented in Japan and Korea, amongst the countries shown.

Performance in STEM fields of education

Two international organisations use large scale standardised testing programs to measure school level educational achievement on a comparative basis.

The OECD has developed PISA. This has grown since 2000 to encompass more than 74 member and non-member countries and economies in its fifth cycle in 2012. The participant countries account for more than 90 per cent of the world's economy. The most recent data available are from the fourth cycle of PISA testing conducted in 2009. Questions used in the test are designed to capture the learning of 15 year-olds by measuring the application of curriculum knowledge to real world problems.

Figure 6: Percentage of all awarded doctoral degrees from science and engineering fields in 2009
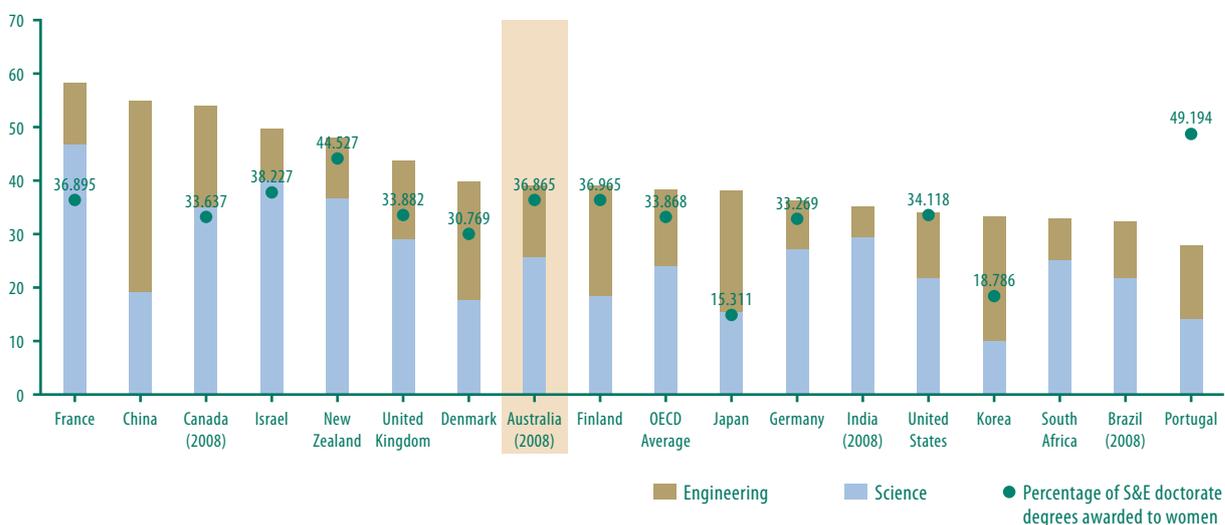
Source: OECD 2011, *Science, Technology and Industry Scoreboard 2011*, OECD Publishing, Paris.

The second international test is TIMSS, which has been conducted every four years since 1995 by the International Association for the Evaluation of Educational Achievement (IEA). In the 2011 cycle of testing, the science and mathematics curriculum knowledge of year 4 and year 8 students were examined in 69 countries. The intention of the TIMSS differs from PISA in that it is focused on student understanding of curriculum knowledge in mathematics and science.

The data collected through both of these tests are rich and complex. Consideration of the full detail is beyond the scope of this report. We focus on a small number of points of interest that illuminate Australia's comparative international performance.

Country ranking by average score

When PISA and TIMSS results are released most of the focus of media and governments falls on the overall ranking of countries on the basis of average scores. In that regard the overall performance of Australia is comparatively good. In the latest cycle of PISA Australia is ranked equal 7th in scientific and reading literacy, and equal 13th in mathematical literacy (OECD, 2010c; and Thomson et al. 2010). Performance in TIMSS is not as good. In the average performance of year 4 students Australia was equal 18th in mathematics and equal 19th in science (Mullis et al, 2012a; Mullis et al, 2012b; and Thomson et al, 2012a). By year 8, Australian students had raised the nation's position to equal 7th in mathematics and equal 10th in science (ibid.).

Figure 7: Mathematical literacy performance of students from countries above the OECD average in the 2009 PISA testing cycle

In cases in which the proportion of students in a proficiency level is one per cent or less, the level still appears in the figure but the numeral label '1', does not.

Source: Thomson, S, De Bortoli, L, Nicholas, M, Hillman, K & Buckley, S 2010, Challenges for Australian education: results from PISA 2009, Australian Council for Educational Research, Melbourne, viewed 11 January 2013, http://research.acer.edu.au/ozpisa/9.

In the last cycles of testing in TIMSS and PISA, countries/systems that consistently performed equal to or above the level of Australia included Korea, Finland, Taiwan, the Hong Kong and Shanghai regions of China, Japan, Canada, Singapore, New Zealand, the Netherlands and Germany.

The tail of underperformers

More important than the ranking of average scores is the distribution of student performance. When examining this distribution, there are two key groups to watch: the 'tail' of low achieving students, and the top performing students. The tail is pertinent to the broad distribution of basic scientific and mathematical literacy. The smaller the low achiever group – or alternately, the

average scores achieved by the bottom quintile or quartile – tell us how close we are to achieving universal competence in STEM. The size of the top performer group – or alternately, the average scores achieved by the top quintile or quartile – help us to understand how strong Australia will be in future in terms of advanced STEM capability.

Participants in both PISA and TIMSS are divided into groups according to their demonstrated proficiency. A benchmark performance level is set, below which students are thought to be at risk of having difficulty in participating work and life as productive citizens in the twenty-first century.

In PISA, 16 per cent of Australian students fall below this point in terms of mathematical literacy, and 12 per cent in scientific literacy. A further 20 per cent fall into the level immediately

Figure 8: Scientific literacy performance of students from countries above the OECD average in the 2009 PISA testing cycle

In cases in which the proportion of students in a proficiency level is one per cent or less, the level still appears in the figure but the numeral label '1', does not.

Source: Thomson, S, De Bortoli, L, Nicholas, M, Hillman, K & Buckley, S 2010, Challenges for Australian education: results from PISA 2009, Australian Council for Educational Research, Melbourne, viewed 11 January 2013, http://research.acer.edu.au/ozpisa/9.

above (level 3 of 6) where the skill level is considered to be insufficient for people to thrive (Thomson et al. 2010). In TIMSS testing of mathematics at year 4, 30 per cent of students fall below the specified benchmark. This proportion rises to 37 per cent by year 8. In science, 29 per cent of year 4 participants in TIMSS fail to reach the international benchmark. At year 8 the size of the group is much the same, at 30 per cent (Thomson et al, 2012a).

In international testing the distribution of achievement tends to correlate with demographic factors. Low socio-economic status is associated with poorer performance in both scientific and mathematical literacy in PISA. Thus while only 3 per cent of Australian students in the highest SES quartile fall below the international benchmark in mathematical literacy, 22 per cent of students in the lowest SES quartile fail to reach this level. Difference is more marked in mathematical literacy, at 4 per cent and 28 per cent respectively. Less variation is observed according to immigrant status, however. Young people born in Australia to immigrant parents are the highest achieving group in Australia.

The international comparison reveals that Taiwan, the Shanghai region of China, Korea, Singapore, Finland, Hong Kong and Canada are among the countries with significantly smaller groups of under-performers. There are no countries where all students reach the minimum benchmark. But should *any* level of underperformance be an acceptable part of Australian education?

High achievers

The top performers in science and mathematics at secondary school constitute the primary pool of talent with the potential to contribute to the future STEM workforce at the high-end, including research and development functions and technology management. In mathematics in PISA, the nations/systems with the largest number of top performers are the Shanghai region of

China, Singapore, Hong Kong SAR and Taiwan. Those nations/systems with the largest group of students at the top three proficiency levels are Shanghai, Singapore, Hong Kong SAR, Taiwan, Korea, Finland and Switzerland. Interestingly, these are also the systems with the smallest proportion of underperformers. It would seem that there is no need to choose between boosting high achievement and eliminating disadvantage.

In PISA science fewer nations/systems are above Australia in terms of the size of the group of students reaching the top three proficiency levels. Those that are ahead include the Shanghai region, Singapore, Finland, Hong Kong SAR and New Zealand.

Performance through time

The PISA and TIMSS data also allow Australia's performance to be tracked over time. Are we improving, declining or standing still?

In PISA performance in science can be tracked only between the 2006 and 2009 testing cycles. There was no significant change. We have longer comparisons for reading and mathematics, however. In both domains there has been a statistically significant decline in performance. In reading literacy, Australia achieved an average score of 528 in the year 2000 but only 515 in 2009. In mathematical literacy, the average score fell from 524 in 2003 to 514 in 2009 (OECD, 2010d; and Thomson et al, 2010).

In several other countries there were significant improvements in the PISA results. However, in reading and mathematics, only Korea improved so as to reach an overall mathematical literacy score above that of Australia.

Although the average scores of year 4 and year 8 students in TIMSS tests have fluctuated since the first test in 1995, the only statistically significant change since then has been an overall improvement in year 4 mathematical performance.

The impact of performance ranking and the country perspectives

Since it began in 2000, PISA has made a large splash in the international media every time a new set of performance data has been released. The results often kindle public discussions on school reform in countries around the world. Through an examination of European responses to the outcomes of the first two rounds of PISA testing in 2000 and 2003, Grek (2009) identified three types of reaction.

First, some countries experienced 'PISA-surprise'. For example, the Finnish were pleasantly surprised by their success in the assessment and by the international interest they garnered through this result (Grek, 2009, p.34; and Breakspear, 2012).

Second, in some countries the results created national consternation, described by Grek (2009, p.34) as 'PISA-shock'. For example this occurred in Germany in 2000 and Japan in 2003, when students from these countries performed at a level below general expectations (Grek, 2009; and Breakspear, 2012). This triggered national debates about education and contributed to subsequent reforms that were then monitored using ongoing PISA performance and nationally observed benchmarks. Kingdom (1995) argues that an external shock like this generates a policy window during which time it is politically possible to enact large scale reforms.

The third type of reaction was termed 'PISA-promotion' by Grek (2009, p.34). It is typified by countries such as the United Kingdom, where the media was uninterested in the early cycles of PISA. The national results were relatively good

and the national government touted the student achievement scores as evidence of the success of British education. No reforms were generated in this process (Grek, 2009; and Breakspear, 2012). These last two types of reaction, shock and promotion, underline the importance of the media's interpretation of the comparative test results (Grek, 2009). Breakspear (2012) notes that the three reactions vary on the basis of differences between expected and actual test outcomes (higher than expected, lower than expected, consistent with expectations). He notes that in New Zealand, students' high performance level in the test reinforced existing positive feelings about recent reforms, while in the United States, the below average results achieved by students were also consistent with expectations. In both cases, no new reforms were proposed.

The consultants' reports demonstrate that individual countries have their own perspectives on PISA. The report on Canada describes stable performance levels but notes the lack of national improvement when compared with the improving performances in some other countries, which has reduced Canada's ranking over time. Japan experienced shock about its performance in science and mathematics in the year 2000, with some further decline in 2003. Educational reforms since then have been associated with some improvement in student results, though more so in relation to reading than STEM. There are continuing equity gaps. The consultants' report on Korea notes the improvements in students' international test scores in recent years. This increase is attributed to a concerted and directed effort using several strategies in concert. However, policy makers know they face an ongoing challenge to generate interest in STEM among bright students.

5 STEM in society

Generic role of STEM

The STEM disciplines create direct economic benefits in that they help to form skilled labour. Nevertheless the case for expanding and improving STEM provision and participation on the basis of labour market demand or rates of return is less than clear-cut (see Section 11 for more discussion). At the same time, the total economic and social argument in favour of STEM provision is larger than this. The STEM disciplines generate a broad range of benefits, individual and collective.

The argument for the STEM disciplines is in large part about their generic role in the workplace and beyond. The widespread emphasis on universal STEM acquisition, throughout the world's schooling systems, reflects the ubiquitous role of science and technology in work and living. Preparing students in STEM helps to prepare them to be good citizens and persons able to shape the course of their own lives. There are many human activities and problems where understanding requires at least a basic scientific and technological knowledge and confidence, such as global warming, ecological transformation and changing energy

patterns; issues related to health and medical care; and the use of communications and other digital technologies, especially their use as modes of production and creativity. It is often stated that design skills, which are now underpinned by digital and quantitative capacities, are increasingly required in many domains.

More specifically, in terms of the economy, we need an ever-growing proportion of the workforce to have quantitative and symbolic skills and basic scientific knowledge. In manufacturing and advanced services and agriculture not just technical specialists but most workers require some scientific and technological literacy and this is increasingly true also in education and health. This means that both academic and vocational programs need to be STEM strong.

As the consultants who prepared the report on the United States argue:

> The steadily rising technological baseline of day-to-day activities, including school work and typical work-related tasks, requires a higher level of STEM skills from everyone over time. The transition to a more technology-intensive economy in the 21st century has raised the bar of entry in most professions, and now jobs which used to be available for high school graduates require skills at the level of a professional certificate or an associate's degree in STEM. This applies to the entire workforce, in a sense the entire workforce is increasingly made of technicians.

In this respect the line between the increasingly ubiquitous role of STEM in employment, and the larger formative role of STEM learning for individual and social capabilities, is blurred. As the same consultants put it:

> Beyond the job demands, STEM-related skills are increasingly adaptive in the modern world. As Professor Richard Larson from M.I.T. says: 'A person has STEM literacy if she can understand the world around her in a logical way guided by the principals of scientific thought. A STEM-literate person can think for herself. She asks critical questions. She can form hypotheses and seek data to confirm or deny them. She sees the beauty and complexity in nature and seeks to understand. She sees the modern

world that mankind has created and hopes to use her STEM-related skills and knowledge to improve it'. These skills, often developed from STEM courses, are sought by employers in most sectors, making STEM students highly marketable, while at the same time giving those with advanced technical training a number of career options outside of STEM fields.

Here we want to emphasise the importance of disciplinary contents in STEM, in terms of knowledge, techniques and ways of understanding. There are no short-cuts here. Students need to acquire these contents in solid programs of study taught by teachers qualified in the specific discipline. This is a key issue and problem in Australian schooling, particularly in relation to mathematics (see also Sections 2 and 9). Further, contents acquired at secondary school are an essential foundation for later learning, especially in mathematics and the physical sciences. We note that here the loosening of prerequisite requirements at Australian universities has partly decoupled foundational learning from later learning.

Broadening and deepening STEM engagement

In sum, it is desirable to persuade (1) more students to aspire to STEM learning and STEM-based careers; and (2) more high achieving students to shift from higher education programs in business and law, to science, mathematics and engineering. We need to persuade more young Australians to aspire to science and mathematics because learning in those fields is economically and socially useful, and intrinsically worthwhile, and a powerful intellectual formation that can be foundational to many different kinds of individual achievement. We might also persuade more young people to aspire to engineering, on the grounds that an engineering degree is a valid and valuable preparation, not only for work as a professional engineer but also in other occupations and professions.

The goals of lifting participation and performance in STEM should not be seen in conflict with other educational goals, such as improving reading, literacy, language acquisition, knowledge of

history, society and culture. STEM learning and non-STEM learning are complementary. Reading skills underlie all scientific work. The PISA data show that countries strong in reading tend to be strong in mathematics and science, and vice versa. We see STEM as part of a larger educational program in which, all else being equal, we would hope all students achieve across the board to the highest possible level. Choices do need to be made and it is impossible for senior secondary and tertiary students to maintain a fully inclusive curriculum without sacrificing depth. Here our concern is less to ensure that every student does more STEM, and more to spread STEM participation to those who currently opt out in the senior secondary years, and increase the number engaged in deep STEM work. In this scenario there are modest opportunity costs. To the extent that part of the student body increases the time commitment to STEM learning, those students will have less time for non-STEM disciplines and other pursuits.

The consultants' country reports confirm that there is now an emphasis, in many countries, on the role of STEM-related education in 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. Below the senior secondary school levels STEM-oriented curricula are positioned as a form of general education and cultural acquisition. As noted, a key objective of strategies and programs is 'science for all' and this aspiration is expressed in changes to the junior and middle secondary curriculum in many countries, and an increasing focus on science-specific education in primary schools in some countries.

The discussion rarely takes the form of 'mathematics for all', though arguably mathematics is the key generic element in developing competence and confidence in science and technology. Perhaps it is assumed that the period of compulsory mathematics, to the end of year 10 or year 11 in most countries, is sufficient to ensure a common numeracy across the population. However, it can be argued that the stage of mathematics for all should be shifted further up the educational scale. Higher

order mathematics such as statistical modelling is increasingly useful in a broad range of areas. One of the factors working against mathematics for all in senior secondary education is the role of mathematics education as a selector and elite streamer of school populations, so that many students opt out of, or are ejected from, the mathematics track. Until mathematics becomes universal at a higher level, the goal of 'science for all' is also inhibited.

The notion of science for all is positioned alongside the 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 STEM students, and also fostering research and world-class universities in higher education (see also Section 10). A typical policy formulation of the focus on STEM high achievement is that of the United Kingdom Treasury Ten-Year review:

> … the 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. (DfES 2004, p.12)

Structural responses include specialist science and mathematics schools providing elite education, frequently in high performing Asian countries (e.g. Super Science High Schools in Japan; Science and Arts Schools for the Gifted in Korea; National University of Singapore High School of Mathematics and Science, and School of Science and Technology). In some instances such schools reflect historical specialisations (e.g. Russian residency-based schools associated with universities where students specialise in advanced mathematics and science studies, and may progress from school to the military sector), or well-established systemic responses such as the United Kingdom where some 1,300 schools have a specialisation in science, technology, engineering or mathematics and computing. These schools frequently provide advanced

mathematics and science curriculum, involve participation in high-end enrichment activities such as the International Olympiads, and provide rigorous preparation for students aspiring to university study – either in STEM- or indeed non-STEM disciplines.

In contrast, the South African Focus Schools ('Dinaledi Schools') project provides resources to selected schools in previously disadvantaged African communities with successful science and mathematics teaching. The initiative supports advanced science and mathematics education required for students to gain entry into science-based higher education programs. The project has grown to encompass over 500 schools, representing 18% of all students taking mathematics and science in the South African school-leaving examination. In Argentina, school structural reform has witnessed the restoration of an integrated model of secondary technical education to support increased participation in science and technology.

The focuses on science for all, and high-end STEM cohorts, are not inherently contradictory. For example, science for all maximises the talent pool for high-end achievement. The consultants' reports often describe this dual focus as a tandem. For example, most interventions described at the primary and lower secondary level are focused on engaging all students with science and mathematics to increase numbers, including under-represented groups, participating in STEM in upper secondary and higher education. Evidence can be found in the literature, for instance, that 'science for all' types of programs provide a superior preparation for advanced STEM training (see Smith & Gunstone, 2009).

The need to provide STEM for all *and* enhance high achievement in STEM is repeatedly emphasised in country strategies, especially in the high achieving East Asian polities such as Korea, China and Singapore. It is part of the Russian tradition, where all students study mathematics to the end of school and there are special science schools and numerous mathematics and science 'battles' (competitions). It has been a strong theme in the policy rhetoric of Japan, though undercut by an enhanced

Key Finding 5.1: Broadening STEM engagement and achievement

In all strong STEM comparator countries, broadening STEM engagement and achievement entails improving participation in the STEM disciplines through 'T' policies (i.e. learning in both breadth and depth) and covering the full spectrum of prior student achievement levels. In particular:

- Provision of at least some discipline-based STEM learning for all school students, up to and including students in senior secondary education.

- Improving the engagement and performance of students from groups currently under-represented in STEM, that on average perform relatively poorly in mathematics and science.

- Lifting the size and average achievements of the group of students engaged in intensive STEM learning in depth, in both schooling and higher education.

role for choice and reductions in content-based learning in the two decades before 2008. Japan maintains high achievement streams such as super science high schools but science and mathematics are no longer compulsory to the end of senior secondary school. In Taiwan students continue with an integrated science for all curriculum until the end of year 11 before tracking between STEM and non-STEM programs. Taiwan is one of many school systems where the dual objectives are managed sequentially rather than simultaneously. In principle it is possible to maintain both objectives until the end of senior secondary school or even the end of the first degree, at the price of restrictions on student choice, and the study of other disciplines.

The reports thus demonstrate the need to tackle the problem at 'both ends' – increasing the pool of students coming through the STEM pathway, and paying special attention to STEM-enthusiastic

students through a more concentrated STEM experience. Within this however, there are quite different cultural presumptions operating in Asia compared to the west, concerning the nature of STEM-talented individuals. The China report emphasises the profound belief in Chinese societies that excellence comes through effort rather than innate talent, so that the process of selection of talented STEM students presumes a) that this achievement occurs through effort and that b) all students are capable of high quality work, compared to more individualistic western cultures where the selection mechanism is thought of as identifying innate talent.

This belief in effort as the pathway to academic success, and that most if not all students are capable of high level work, is consistent with research in Australia and elsewhere on strategies to build resilience and optimism concerning student engagement with mathematics. Students often lock in early lack of success in solving mathematics problems as an essentialised lack of capability, whereby failure is reinforced through repeated instances. Strategies are being successfully explored to build optimism and resilience in problem solving in students who may otherwise identify as untalented and unsuccessful in mathematics.

If Australia is to produce a strong STEM educated populace, and lift our PISA and TIMSS rankings, serious attention needs to be paid to currently low scoring populations of students (low SES, indigenous). The drift towards fragmentation of the education system with the concentration of STEM students in high SES public and private schools to the detriment of these under-represented groups, is at odds with the overwhelming thrust of these country reports that emphasis wide community participation with STEM and science and mathematics for all students. The Asian countries offer a model for attending to the involvement of students from all SES levels. There are notable examples of attention to indigenous education in the Canadian, the United States indigenous reports, in the New Zealand report, and in other reports such as the Brazil and South African reports.

Irrespective of the logic of country comparisons in the PISA and TIMSS tests, the fact that 30 per cent of science and mathematics students in a developed country like Australia are scoring below levels of minimal competency (level 3) in science and mathematics is cause for considerable concern. Much of the lower scoring cohort is associated with disadvantaged, low SES school populations, and there is a need to focus attention on these students for reasons of equity, and for the practical reason that they represent a potential source of STEM expertise.

In metaphorical terms, we need to lift the level of the peaks of the STEM mountain range, and broaden and elevate the whole of the range at the same time. Framing Australian STEM policy around the need for (a) a highly educated and innovative STEM workforce, and STEM talent capable of high end creative achievement and innovation and (b) the need for all students to have STEM knowledge and skills, suggests a comprehensive set of initiatives, with several concurrent objectives:

- The need to strengthen high-end STEM cohort size and capability, and as part of that, to pay special attention to STEM-enthusiastic students by providing a more concentrated and more exciting STEM experience;

- Related to that, the need to secure more retention of high achieving year 11 and 12 STEM students at the higher education stage;

- The need to increase the size of the pool of students coming through the STEM pathway; and specifically, the need to increase the proportion of senior secondary students doing mathematics and one science subject. One possibility is mandatory mathematics till the end of year 11 or year 12 of secondary school. Compulsory science is also possible;

- The need to elevate and universalize educational performance in disadvantaged schools and communities and through that to lift the STEM potentials and performance in such schools. If the aim is STEM for all, then this means 'every school a good school', and 'a good STEM school';

- The need for effective remedial programs, especially in relation to mathematics;

- The need for appropriate adult education programs to popularise science and technology and enhance literacy in those domains. Here science lends itself more easily to lifelong learning than does mathematics. This suggests that it is essential to both universalise maths achievement at school stage, as far as possible, while creating viable 'second chance' STEM pathways.

Different societies bring different assumptions to bear on this dual focus: lifting the peaks and elevating the broad mountain range at the same time. East Asian notions of STEM-talented individuals differ in some respects from those in English-speaking nations. The China report emphasises the profound belief of Sinic societies that excellence comes through effort rather than innate talent, so that the process of selection of talented STEM students presumes that this achievement occurs through effort, and that all students are capable of high quality work. This contrasts with the more individualistic notion that the selection mechanism identifies innate talent. Yet the Sinic belief that effort is the pathway to academic success, and that most if not all students are capable of high level work, is consistent with research in Australia and elsewhere on strategies to build resilience and optimism concerning student engagement with mathematics. Students often lock-in early lack of success in solving mathematics problems as essentialised lack of capability. Failure is reinforced through repeated instances.

The front line solution is to build optimism and resilience in problem solving, in students who may otherwise identify as untalented and unsuccessful in mathematics. A secondary strategy is to enhance remedial programs in STEM disciplines, especially mathematics; possibly making these available in community education for adults as well as in schools and tertiary education. France and Singapore appear to have developed effective remedial approaches to STEM.

Arguably, the positioning of STEM disciplines as the premier device for identifying innate talent, and assigning privileged pathways to the bearers of talent, corrupts the potential for STEM for all. STEM imagined and practiced solely as the high ability/high performance/high ambition track is the death of universal science literacy. This approach forces a tradeoff between the two parts of the dual strategy. If Australia is to produce a strong STEM educated populace, and lift our PISA and TIMSS rankings, serious attention needs to be paid to currently low scoring populations of students (especially low SES students, and indigenous). But the present fragmentation of the Australian education system, with the concentration of STEM students in high SES public and private schools, to the detriment of under-represented social groups, is at odds with the overwhelming thrust of the reports commissioned for this project. They are clear in coupling broad-based STEM achievement with a stronger high performance track.

The structuring of the curriculum

The relationship between high achievement-focused programs, and STEM for all, has implications for the structuring of the curriculum. The relationship is handled in different ways around the world. In many systems that emphasise wide community participation and science and mathematics for all students, educational professionals work very hard to break down the barriers to universal STEM achievement. The East Asian countries offer models for involving students from all SES levels. There are notable examples of attention to indigenous education in the Canadian and the United States indigenous reports, in the New Zealand report, and in the Brazil and South African reports. Finland assigns its best teachers to the low achieving students and schools, enabling it to pursue excellence and inclusion at the same time. This approach depends on good resourcing. In countries that invest in education as a proportion of GDP at the level of the OECD average or below, or where GDP per head is modest, policy makers are more likely to face trade-offs between STEM inclusion and STEM excellence.

Most European and Asian countries have a defined 'sciences' strand as one of a few options, rather than a smorgasbord of subject options, attracting between 30 per cent and 50 per cent of students. The advantage of this is the creation of a sizeable population of STEM focused students. The disadvantage is the lack of flexibility in choice, and the creation of a sizeable proportion of the school population with no senior science or mathematics. It is difficult to discern a clear pattern that links these broader subject grouping choices with participation levels in the sciences, but in the United Kingdom policy on creating opportunities for greater science specialisation at Graduate Certificate of Secondary Education (GCSE) level has led to greater participation at the tertiary stage.

The patterns of choice in a country reflect a history of subscription to particular views of disciplinary education and the appropriate degree of specialisation at the senior school level. The Australian system has grown up around maximising choice of subject offerings, and a relaxing of pre-requisites to delay choice. The disadvantage of this is that students can choose away from challenging subjects. There are no ready models in the consultants' reports that could be adopted unchanged, but the strong commitment in most other countries to disciplinary depth and coherence signals a need to look carefully at trends in subject choice and the quality of content-based learning in Australia.

Five possible kinds of structural change have been identified flowing from these findings, which could develop further the reach and educational effects of the STEM disciplines and extend and intensify their social and economic contributions to Australia. These structural changes can be considered independently of each other, and they could not all be implemented at the same time: indeed, the first and third are contradictory. These structural changes have varied implications for on one hand lifting high achievement STEM, on the other hand STEM for all. These options are suggested by consideration of the experience of comparator countries, as described in the consultants' reports.

i.   *STEM tracking:* A firm and possibly early bifurcation between STEM and non-STEM tracks, as distinct from a comprehensive curriculum in secondary education. This may strengthen high achievement STEM and broaden the size of the STEM cohort, at the cost of the universal 'science for all' approach;

ii. *Academic and technical-vocational institutions:* The development of a strong group of STEM-heavy technical and vocational schools and tertiary institutes, alongside academic secondary schools and universities (the latter also including some STEM);

iii. *An integrated secondary curriculum:* A less specialised and more integrated upper secondary curriculum, more comprehensive of the disciplines, 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;

iv. *Mandatory STEM in years 11 and 12:* Related to strategy 3, or separately from it, the possibility of mandatory mathematics and/or science to the end of senior secondary school or to year 11 inclusive;

v.   *A broader role for degree programs in engineering:* A broadening of the role of engineering degrees in the professional labour markets, together with an expansion of the number of higher education students studying engineering and technologies.

These five possible structural changes will now be considered in turn.

i. STEM tracking

In some countries the upper secondary curriculum, or middle and upper secondary curriculum, is divided into firm STEM and non-STEM tracks. In those circumstances the STEM track normally enjoys higher prestige and is populated by a disproportionate share of the high achieving students.

In China, students track between a predominantly science and predominantly non-science curriculum in the last three years of secondary school. In total 55 per cent of applicants to the

higher education entrance examination, the National College Entrance Examination (NECC), choose the science and engineering division of the test. As a result more than half of students enrolled in bachelor degrees are likewise in STEM related fields. In 2010 first-degree enrolment shares were engineering (31.6 per cent), science (9.8 per cent), medicine (6.3 per cent) and agriculture (1.8 per cent). Likewise in Japan students choose between a science track that emphasises science and mathematics, and a humanities track that emphasises Japanese and social studies. Unlike the situation in China, more students choose the humanities path. In Korea students attending general high schools choose between a humanities/ social sciences track, and a natural sciences/ engineering track. However, other students are enrolled in specialist high schools that focus on either science, foreign languages, art, or vocational training. In Taiwan students track between STEM and non-STEM curricula at year 12, a year later than their counterparts in China.

Most Western European countries have bifurcated senior secondary education with large numbers of students – typically about half of the age cohort – enrolled in secondary vocational institutions or streams. Vocational tracks tend to be STEM-heavy and practical in orientation, though not all fall into the former category, and feed into vocational tertiary institutions. Switzerland has a plethora of vocational options. In France the main academically-oriented upper secondary level pathways are divided by discipline grouping. Students may choose one of three tracks: science, economic and social sciences, or literature. Beyond this, the options are very limited, though recent reforms expanded student choice somewhat. Another European country with this model is Russia, where senior secondary students undertaking general academically oriented programs are channelled through discipline based tracks/streams/profiles: a physics and mathematics profile, and socio-economics profile. This 'profile' based curriculum is not implemented in all senior secondary institutions. There are other kinds of schools that have specific streams. In addition to general high schools, there are gymnasiums that focus on

humanities, and lyceums that focus on technical and scientific subjects.

General education in the United Kingdom also in effect provides a discipline-streamed curriculum. General high schools offer a range of year 12 subjects from which students have significant choice. However, they end up specialising in either science or the arts/humanities. While it is not compulsory, specialisation is both recommended and encouraged through timetabling.

In Australia a strong STEM track could strengthen the number of students enrolled in rigorous learning in mathematics and sciences, and broaden the pool of students with knowledge foundational to STEM-based programs in higher education, potentially boosting STEM numbers in both senior secondary and higher education.

At present separated institutional and curriculum tracks play a modest role in Australia. There are school-based apprenticeships and VET in schools programs within academic schooling, many of which have some STEM components. Some students spend the years 15-18 in VET rather than schools and higher education, not all in STEM programs. Arguably, however, the principal specialist STEM strand is created by the pre-requisites for entry into science-based programs in higher education (though as noted, the role of science and mathematics pre-requisites has diminished in recent years), and by the scaling systems used to collate results in the final secondary school examinations. These scaling systems boost the scores of students undertaking STEM disciplines, such as the harder mathematics subjects, physics and chemistry, to compensate for the increased competition for marks in these subjects because of the selective cohorts. Students with medium to high performance in the STEM disciplines are protected in the competition for university entrance. As noted, this produces a concentration effect, with clusters of high performance STEM students in the leading private schools and selective public schools. The best STEM teachers also tend to concentrate in those schools, whose students mostly come from affluent families.

Thus Australia constitutes a high performance STEM cohort. However, as noted, the STEM

disciplines function also as a privileged route to the most sought after university courses (and a means of reproducing the educational and social advantages of upper middle class families). STEM's role in social selection tends to overshadow disciplinary learning. Many students use STEM to secure entry into sought after places in medicine, law and business education, not engineering or science. Most of those enrolling in law or business then move away from STEM at university. The tension between STEM as high performance disciplinary formation and STEM as elite track for university entry and social advantage shows itself also in other systems, like China, where STEM is the best route to the top universities.

The other downside of STEM tracking is that it tends to narrow intellectual formation. It could be argued that a balanced and inclusive curriculum which includes all of science, mathematics, language and humanities is a better preparation in many ways. It might be better to ensure that all secondary students do at least some high quality STEM work, while none enroll in a curriculum which is almost entirely STEM-based. Then all would be at least moderately well prepared for the full range of possible higher education and vocational programs (and probably would be more rounded and more creative and socially skilled people). However, if STEM-destined secondary students took one mathematics subject instead of two, and one science subject instead of two, university programs in the STEM-based areas would have more work to do on foundations. These issues need thought and wide discussion.

ii. Academic and technical-vocational institutions

As well as tracking between STEM and non-STEM, most countries track between academic and technical-vocational sectors in secondary and/or tertiary education. This is especially true in countries with strong manufacturing sectors and/or technologically-based services. While this sectoral divide is not identical to the STEM/non-STEM distinction within a single school sector, the secondary-technical sector is usually a STEM-heavy sector with a focus on applied engineering and related knowledge and skill. The key is to

resource the secondary-technical sector properly, with advanced teaching and equipment. Given that there is a STEM track within the academic stream, the overall outcome is a stronger overall level of participation in STEM, with a diversity of skills and approaches matching different STEM and STEM to work pathways.

Secondary vocational education

Countries with strong secondary-technical sectors include Germany and Singapore. Korea has vocational high schools, which have played an important role in training people for growing Korean industry, and strengthening these schools is an important priority in government; though as the consultants' report indicates, these schools suffer somewhat from lower status in Korean society. Japan has struggled to give technological education enough status, though its technical institutions have a reputation for being flexible and inventive. In Taiwan the senior secondary vocational schools are important, enrolling almost as many students as the academic high schools. The consultants' report notes that: 'Since these vocational schools mainly offer subjects related to technology, the vocational students are also a potential source of STEM manpower'. In 2010 just under 80 per cent of all graduates from vocational schools went on to higher education. The corresponding proportion from academic high schools was about 95 per cent. A feature of Korea, Singapore and Taiwan is the status given to STEM work in technical-vocational institutions and the possibility of articulation between these and academic study pathways. The technical-vocational institutions are an important source of STEM professionals, often at a high level of expertise.

The OECD provides comparative data on participation in STEM in upper secondary vocationally oriented study. Just over 64 per cent of all male upper secondary level vocational graduates in Australia in 2010 were in STEM fields, including sciences, engineering, mathematics, statistics and computing. This is essentially the same as the OECD average at just under 64 per cent. A further 5 per cent of Australian males at this level choose studies in health and welfare fields. A greater proportion of young males chose STEM fields at this level of education in countries

like Korea, Norway, Argentina and Finland. International comparison of the proportion of Australian young women in upper secondary level vocational education choosing studies in STEM fields shows poor levels of participation. As few as 6.5 per cent of female upper secondary vocational students graduate from STEM fields, while the OECD average is twice this number at 12.2 per cent. In contrast, 51 per cent is the comparable figure for Korea. A further 35 per cent of young Australian women graduate from health and welfare studies at this level of education, compared to figures for the OECD average and Korea of 21 per cent and 6 per cent respectively. It is important to note that the international differences in participation here may be as much a product of the kind of courses that can be studied at this level within the system as the choices of the participants.

Figure 9: The distribution of male upper secondary and vocational graduates by field of education
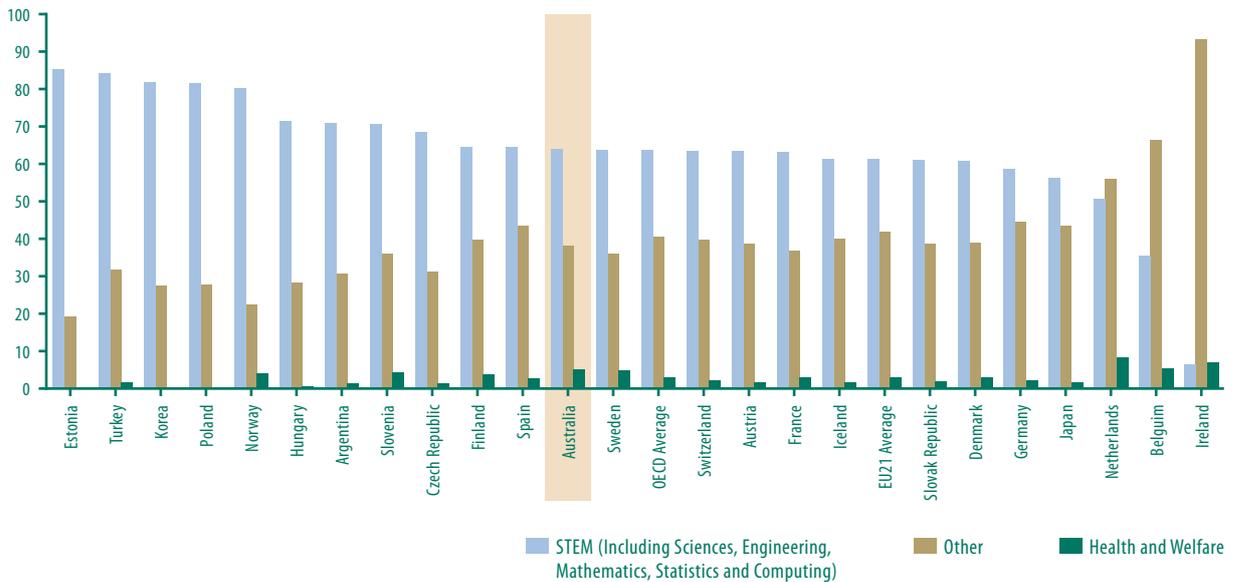
Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators*, OECD Publishing, Paris.

Figure 10: The distribution of female upper secondary and vocational graduates by field of education
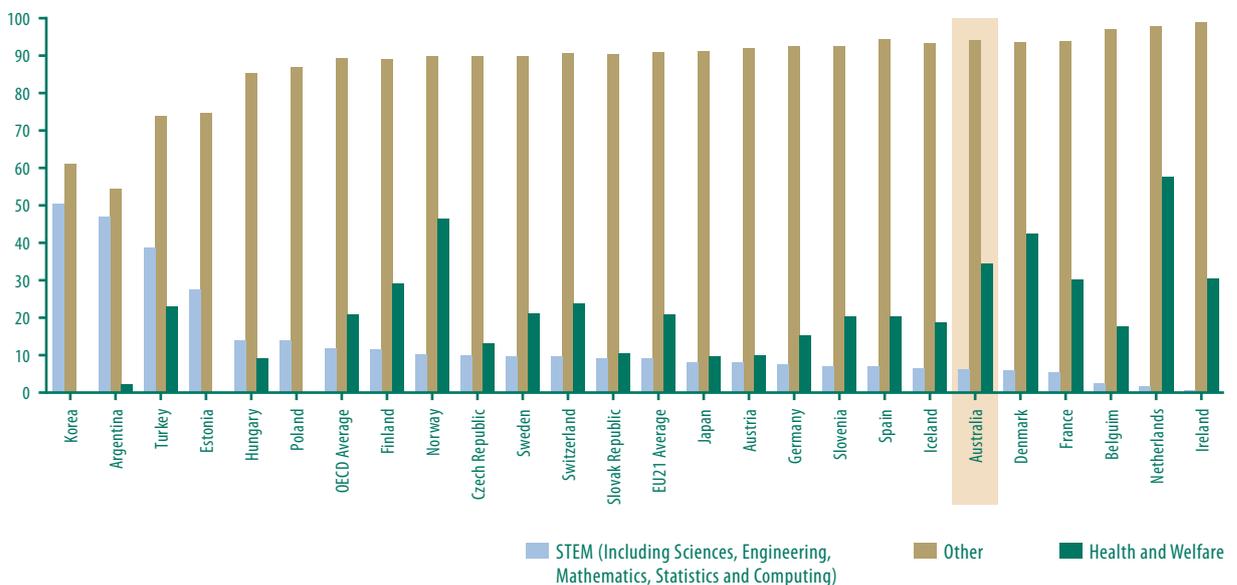
Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators*, OECD Publishing, Paris.

Arguably vocational education and training in Australia is poorly resourced and overshadowed in status terms by the academic stream, aside from the trades course which continue to attract some strong students. This does not stop VET from playing a significant role in many industries and communities. Progression from VET to higher education is not as strong as many would like, though the principal function of VET is less to feed into higher education than to offer distinctive pathways through education and into the labour markets. The growth of degree programs within VET may help to close the status gap between VET and higher education though it might also enhance status differentiation within VET.

Tertiary vocational education

Most European countries provide vocational tertiary sectors. Germany has universities of applied sciences, the world-famous *fachhocschulen*. The Netherlands provides HBOs, Finland polytechnics and Sweden higher vocational colleges. One limitation, however, is that the vocational track has a limited association with research work in STEM. In Taiwan there are two kinds of university, comprehensive and technical, and in that system technical universities are involved in applied research. The consultants' report states:

> Technical universities were upgraded from technical colleges in 1990s. Universities of technology recruit students mainly from vocational high schools, and they are also allowed to enrol graduates from traditional academic high schools. As a result of the upgrade, technical universities have a similar structure to general universities and offer degree programs from Bachelor to PhD. They are responsible for basic and advanced science-technology education. For basic science-technology education, the aim is to train qualified technologist for various industries. The curricula are designed to teach the student science-related knowledge and mathematics theories, and students are required to manipulate sophisticated machines, equipment and apparatus or to manage complex production processes. They can obtain a Bachelor degree after completing the course. For advanced science-technology education, the aim is to cultivate engineers. In the curricula, in addition to the advanced science and mathematics theories, students are also required to acquire advanced knowledge of a special technical field and management. This kind of program will last two years and grant a Masters degree when the student graduates.

> Technical universities in Taiwan have developed explicit goals to complement the general university. … In order to cultivate application-oriented talents, teaching and learning in technical universities focus on practice rather then theory. In general, students studying at technical universities in Taiwan receive vocational training … which emphasises practical knowledge and skills. The curricula are designed to be student-oriented and enterprise-oriented. The teaching plans are jointly developed by teachers, enterprise staffs and graduates. The majors and curricula are adjusted according to the analysis of market demands. Adaption to the society, and sustainable development of the capacity of students are highly valued [outcomes] … Many technical universities have adopted sandwich programs containing practical training to help their students acquire professional know-how… The implementation of sandwich programs at a university may consist of a half-year or a full year in a company. Basically, learning alternates between school and factory… Like the general university, technical universities in Taiwan also place considerable attention in the cooperation with industry. As a result of the close relationship with enterprises, students are trained in necessary skills for employment and when they graduate, they are easily employed. Experienced technical staff in different enterprises comprise a large proportion of teaching staff in technical universities. They … not only possess high qualifications but also have extensive practice experiences, and they clearly know the exact demands of enterprises. Moreover, cooperation with industries enhances the research ability of technical universities.

Key finding 5.2:
STEM-specific tracking in secondary education

Many of Australia's comparator countries achieve strong participation in STEM through bifurcation at secondary school level between STEM and non-STEM tracks, and vocational tracks leading to significant STEM training. There may be benefits in significant discussion in Australia concerning the potential for, and the pros and cons of:

- Firm bifurcation between a comprehensive STEM track, and a non-STEM track, in the final two years of secondary education.

- Development of STEM-heavy technical and vocational schools and tertiary institutes, alongside academic secondary schools and universities (the latter also including some STEM).

The major funding of technical universities comes from enterprises and universities encourage their teachers to obtain funds from enterprises by actively involving themselves in market-oriented research.

iii. An integrated secondary curriculum

While tracking and institutional specialisation offers one set of routes to possible strengthening of STEM, a more comprehensive curriculum, including mandatory STEM subjects provides another. However, this would work against the long-term trend to increased individualised choice in secondary education.

In the last fifty years the upper secondary school curriculum in Australia has moved towards an increased scope for student selection of subjects. English is the one compulsory subject in the final two years of school. University prerequisites have been reduced in number, further freeing student choice. Students freely opt for subjects they like doing, or subjects in which they excel, or subjects which maximise their Australian

Tertiary Admission Rank (ATAR) at the point of university entrance. It is likely that overall, this has led to some evacuation of the most difficult mathematics and science subjects, despite the fact that the scaling systems used in some states enables students who do well in those subjects to achieve high ATARs. There are other concerns. The number of students doing foreign languages is low and has reduced as a proportion of the senior secondary cohort. More generally, it can be argued that it would be intrinsically desirable for all senior secondary students to have knowledge of both STEM and the non-STEM strands of learning, and for these students to share a common educational culture, as they do at year 10 and below.

A common comprehensive approach to years 11 and 12 might involve all students doing English, mathematics to at least intermediate level, at least one science subject, and a foreign language. There might be two additional subjects at year 11 and one at year 12, that would be determined by student choice. This approach would strengthen the goal of 'STEM for all', though it may marginally weaken high value STEM learning. STEM-focused students would be limited to three possible science and mathematics subjects rather than four as at present. There would also be opportunity costs for some other students who might prefer a mix of subjects more strongly loaded in favour of the humanities and social sciences.

Another possible approach – and one that reconciles several of the options presented in this section – would be:

- Year 11: An integrated program, whereby all students complete compulsory mathematics, science, English and a foreign language, plus two more subjects of their choice;

- Year 12: A two track program, similar to that prevailing in China, whereby all students would complete compulsory English and mathematics but would otherwise divide into STEM-specific and non-STEM tracks.

However, issues of a common curriculum and compulsory languages are beyond the ultimate scope of this report. Our focus is on the STEM disciplines. We will discuss only the possible

introduction of mandatory mathematics and/ or science in year 11, or years 11 and 12. Sub-section iv. looks at this possibility in detail.

iv. Mandatory STEM in years 11 and 12?

The international picture

Up to the 1970s in Japan, high school students who aspired to higher education were required to take four science subjects: physics, chemistry, biology and earth sciences. In 1982 the Curriculum Guidelines were revised so that only two science subjects were required, leading to declines in the proportion of students doing each science subject. The national universities require just one science subject for students entering humanities faculties. Many private universities do not require any science for students entering humanities, though they require Japanese and English. Physics dropped from almost 90 per cent in the 1970s to 20 per cent in the last decade. In addition, revisions to the Curriculum Guidelines reduced the mandated hours of learning in science and mathematics subjects.

The Curriculum Guidelines of 1998 significantly decreased the number of school hours of STEM subjects in Japanese compulsory education. Promoting the idea of '*yutori* education' ('relaxed education'), designed to reduce the pressure of intensive study and examination anxiety, while enhancing students' motivation to learn, the 1998

Curriculum Guidelines reduced the school hours of mathematics and science curricula to approximately 150 hours for mathematics in primary education and 50-70 hours for junior secondary mathematics as well as primary and junior secondary science. The contents of the curriculum were reduced by 30 per cent and simplified.

These changes did not trigger any observable increase in student motivation. The Japan consultants' report stated that: 'Many families and schools failed to take advantage of the flexibility afforded through relaxed education policy to promote creative and independent learning of children. Instead, children and young students filled spare hours playing computer games and exchanging text messages'. Examination anxiety did not disappear because schooling was still used for social selection. But the level of learning deteriorated. There was a decline in Japan's comparative performance in international tests of student achievement, triggering the public backlash known as 'PISA-fright', and a decline in the proportion of students enrolled in the STEM disciplines at university. Nevertheless, the study hours dictated by the Curriculum Guidelines for senior secondary education continued to decrease up to the revision of the Curriculum Guideline in 2008.

This revision saw a reversal of the '*yutori* education' approach. Mandatory content and hours were increased, cutting off the choice to

Figure 11: Total study hours of mathematics and sciences in Japanese junior secondary education, 1958 to 2008
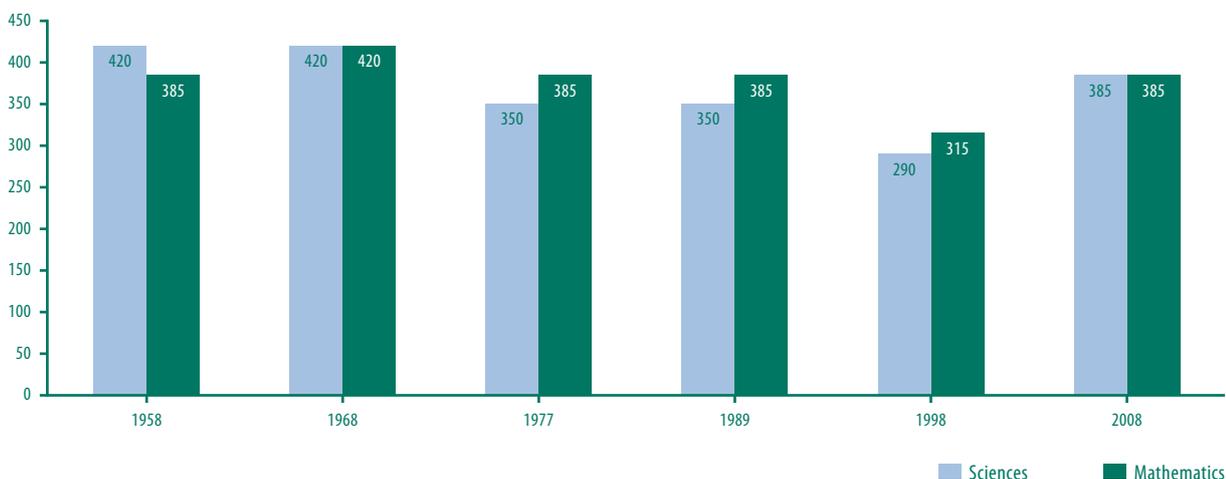
Source: MEXT, http://www.mext.go.jp/a_menu/shotou/new-cs/youryou/index.htm, and NIER (2005), http://www.nier.go.jp/kiso/sisitu/siryou1/2-02.pdf, cited in the Japan consultants' report.

opt out. The 2008 changes increased the study hours of mathematics and science up to the standard of 1988. The study hours of science in junior secondary education were increased by nearly one-third (95 hours). The content of programs was also substantially increased.

In many countries students are required to study mathematics to the end of year 11. This happens in Australia's closest and least foreign country, New Zealand. After year 11 subject specialisation often tends to inhibit compulsory curricula. There are very few instances of compulsory mathematics to year 12 in European countries (though we note this finding cannot be considered definitive without further research). Russia has mandatory studies of both mathematics and Russian till the end of school. In Finland mathematics study is required throughout upper secondary level schooling, though students are given the choice between studying basic or advanced level mathematics curriculum within either a general/academic program or a vocationally driven pathway in the form of upper secondary level VET.

Mandatory mathematics is part of the curriculum in some non-European countries. In Brazil, although recent curriculum reforms created more student choice, the study of mathematics is compulsory through to the end of upper secondary school. The curriculum includes advanced level mathematical sub-disciplines/ knowledge areas. The report notes consensus among policy makers that this practice should continue. In China mathematics is a compulsory subject all through school, as a part of the general primary and lower secondary curriculum, and then as a compulsory component of all discipline grouping options offered to senior secondary students. The position in Taiwan is similar to but not quite the same as in China. Mathematics is compulsory to year 11, then students choose to spend their year 12 year preparing for one of the two university entrance exams on offer. Both of these include some form of mathematics. The track with greater focus on social science and language requires only one general mathematics topic. In Japan and Korea senior secondary students divide between STEM and non-STEM tracks. In neither country

are students beyond year 10 required to study mathematics at an advanced level**.**

In Israel high school matriculation from mainstream high schools in Israel requires minimal mathematics through to the end of year 12, but advanced mathematics courses are optional. However, a large proportion of Israeli students in PISA do not meet minimum proficiency levels in mathematical literacy. Reasons for this in the consultant report include both that the requirement is for only basic level study in mathematics, not advanced. And also, Ultra-Orthodox Jewish schools offer little or no mathematics, diluting national proficiency averages.

Australia might have something to learn from some other countries' more stringent approaches to STEM education, and also from the case of Japan, which reversed its 'dumbing down' of the STEM curriculum. We suspect that the increased range of choices in Australian schooling, the reduced role of science and mathematics prerequisites in university entrance (and the corresponding greater emphasis on score level rather than content preparation), and thus the ease of opting out of harder STEM subjects, are associated with both the deterioration in the proportion of the student cohort taking STEM subjects and the deterioration in the proportion of students doing the most challenging subjects. If so too much choice has undermined both STEM for all and high performance STEM. One way to increase the proportion of students doing STEM, while not compromising the rigour of the STEM subjects taken by those who use STEM to differentiate themselves from the pack, is to introduce mandatory mathematics and or science either to year 11 or 12. If this were to be done there should be a companion commitment to targeting mathematics curriculum and pedagogy in the middle years to provide enjoyable and rewarding learning experiences, such that the groundwork was laid for extension of mathematics into the senior years.

Current Australian requirements

As part of the senior secondary level national curriculum recently developed by ACARA, mathematics study to year 10 is a focal/ foundational area of study. The year 11 and 12

position is less clear at this stage. The mathematics curriculum at this stage will be divided into four alternative subjects that meet the differing abilities and vocational needs of students. These are (from least to most complex): Essential mathematics; General mathematics; Mathematical methods; and, Specialist mathematics. The Australian Curriculum in mathematics, science and English has been published for levels from Foundation (reception) level to year 12. The Commonwealth has negotiated implementation plans for F-10 Australian Curriculum with all States and Territories, and the F-10 Australian Curriculum is progressively being implemented around the country. The process is not complete for years 11 and 12.

It should be noted that under the Australian Constitution, the States and Territories have authority for education, and so for senior secondary certification. Negotiation with the States and Territories regarding exactly what parts of the new Australian Curriculum will be incorporated in to their senior secondary curriculum offerings is ongoing. And, even if the states adopt the Senior Secondary Australian Curriculum, they are responsible for determining senior secondary certification requirements which mandate which curriculum elements are required for certification purposes.

In terms of current mandatory requirements for senior secondary certificate requirements (in addition to other requirements):

- New South Wales students must complete a Board Developed Course in English to qualify for the Higher School Certificate (HSC)

- Victorian students taking the Victorian Certificate of Education (VCE) must include English units; Victorian students taking the Victorian Certificate of Applied Learning (VCAL) undertake core studies in literacy, numeracy and personal development (along with a VET program and work placement)

- Queensland students undertaking the Queensland Certificate of Education (QCE) must fulfil literacy and numeracy requirements

- Western Australian students undertaking the Western Australian Certificate of Education (WACE) must meet English language requirements

- South Australian students undertaking the South Australian Certificate of Education (SACE) must complete compulsory requirements in literacy, numeracy and a Research Project (SACE Board of SA n.d.)

- Tasmanian students undertaking the Tasmanian Certificate of Education (TCE) must meet five standards regarding literacy, numeracy, ICT, participation and achievement

- Australian Capital Territory students undertaking the ACT Year 12 Certificate have no specific mathematics or science requirements

- Northern Territory students undertake an award based on the South Australian Certificate of Education (SACE), and must complete literacy, numeracy and planning requirements (Keating et al, 2011).

As such, at least minimum numeracy requirements for senior secondary certificate purposes are in place for Victorian students doing the VCAL (about 12 per cent of the cohort), Queensland students doing the QCE, South Australian students doing the SACE, Tasmanian students doing the TCE, and Northern Territory students doing the SACE. However, these numeracy requirements do not imply mandatory mathematics course participation, nor suggest that participation in at least one Australian Curriculum – Mathematics course will necessarily be a compulsory requirement of the respective senior secondary certificates (assuming at least some States and Territories adopt some elements of the senior secondary Australian Curriculum – Mathematics). For example the Tasmanian 'everyday adult mathematics' standard currently involves 'using common maths knowledge and skills to measure, solve basic problems, develop budgets, collect survey information and interpret it, and carry out calculations involving fractions and metric quantities' (Tasmanian Qualifications Authority, n.d.).

Table 10: State and Territory populations and year 12 enrolments for 2004. Data from Barrington (2006), Tables 2A, 2B, 3A, 3B, 4

	Column A: Number of students in year 12	Column B: Number of students in Advanced Mathematics (In NSW: Mathematics Extension 1 and possibly Extension 2) (note 1)	Column C: Students in Intermediate Mathematics but not in Advanced Mathematics (In NSW: Mathematics) (note 2)	Column D: Students in Elementary Mathematics Subjects (In NSW: General Mathematics and Mathematics Life Skills) (note 3)	Column E: Students not in Mathematics (note 4)
NSW	66279	9959	13306	30382	12632
	100%	15.0%	20.1%	45.8%	19.1%
Vic	49975	6293	12090	22759	8833
	100%	12.6%	24.2%	45.5%	17.7%
Qld	40592	3430	12887	21246	3029
	100%	8.4%	31.7%	52.3%	7.5%
WA	19792	1628	2655	12785	2724
	100%	8.2%	13.4%	64.6%	13.8%
SA	13324	1211	2134	3937	6042
	100%	9.1%	16.0%	29.5%	45.3%
Tas	4161	228	595	1340	1998
	100%	5.5%	14.3%	32.2%	48.0%
ACT	4098	488	1148	2156	306
	100%	11.9%	28.0%	52.6%	7.5%
NT	1390	45	198	543	604
	100%	3.2%	14.2%	39.1%	43.5%
Totals	199611	23282	45013	95148	36168
	100%	11.7%	22.6%	47.7%	18.1%

Source: Coupland, M 2006, *A critical analysis of selected Australian and international mathematics syllabuses for the post-compulsory years of secondary schooling*, Report prepared for the NSW Board of Studies, Sydney, viewed 19 March 2013, http://www.boardofstudies.nsw.edu.au/manuals/pdf_doc/maths_st6_lit_curr_rev_pt1.pdf.

In fact, as illustrated by Coupland (2006), despite the numeracy requirements established in several senior secondary school certificates no states have compulsory mathematics requirements that involve 100 per cent of year 12 students. Year 12 participation ranges from highest in the Australian Capital Territory, where there are no minimum numeracy standards, and Queensland, and lowest in Tasmania (where there are minimum numeracy standards). Arguably, students who complete secondary school without at least intermediate mathematics, including calculus, probability and the foundations of statistics, are effectively excluded from a broad spectrum of occupations, and will be increasingly disadvantaged over time because of the growing use of creative digital applications in many fields.

If STEM-specific prerequisites were to be strengthened, this would shift the emphases away from maximising student choice and flexibility, and away from fostering competition for the highest possible scoring student regardless of discipline. It would enable greater focus on optimising preparation in the disciplines so as to lift the level of study in both senior secondary and higher education.

We note also that if all students are to learn mathematics to at least level 3 in year 11 or year 12 in classes in which they are taught by teachers trained in mathematics at university level, this will require a substantial increase in qualified teachers. This might require several years to achieve, even if coordinated action is implemented immediately.

In addition, any decision to increase the spread and/or depth of mathematics or science learning at years 11 and 12 stage has implications for primary education and for junior and middle secondary education. It is widely perceived that in Australia there are deficiencies in primary

Key finding 5.3: Compulsion vs choice in senior secondary mathematics and science education

There is a concerning trend in the senior secondary and undergraduate tertiary years in Australia away from the sciences and particularly away from advanced mathematics. There is a range of structural elements in the curriculum offerings of many of our comparators strong in STEM that offer possible models for consideration by Australia. Many of these countries have a more stringent approach to curriculum offerings, for instance requiring the study of mathematics to Year 11. An extension of mandatory STEM curricula in senior secondary schools has opportunity costs, by restricting student choice and engagement in non-STEM subjects of educational value. Nonetheless, there may be benefits in discussion among the states, territories, subject teacher associations, universities and relevant science and mathematics organisations about the pros and cons of possible reforms to senior secondary education certificate requirements, to enable one or more of the following:

- Including the study of mathematics (at any level from Essential Mathematics to Specialist Mathematics) up to the end of year 11 – making mathematics compulsory for everyone to the end of year 11.

- Including the study of mathematics (at any level from Essential Mathematics to Specialist Mathematics) up to the end of year 12 – making mathematics compulsory for everyone to the end of year 12.

- Including the study of mathematics for all to the end of year 12, with standards differentiated according to pathways. For all students, including those taking vocational pathways, the minimum curriculum level required would be equivalent to the Essential Mathematics course from the Australian Curriculum. For students to receive an Australian Tertiary Admission Rank (ATAR) and go to university, the minimum curriculum level required would be equivalent to the General Mathematics course from the Australian Curriculum.

- Including the study of at least one science subject up to the end of year 11 – making science compulsory for everyone to the end of year 11.

- Including the study of at least one science subject up to the end of year 12 – making science compulsory for everyone to the end of year 12.

Key Finding 5.4: STEM-specific prerequisites for higher education

In a number of high performing countries STEM subjects at upper secondary school level are strongly linked to university entrance. One way of lifting the level of 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, optimising preparation in the disciplines.

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mathematics learning and in primary teacher training in relation to mathematics knowledge (see chapters 10 and 11). If so, these would need to be addressed in secondary school where many mathematics (and science) classes are taken by teachers with no tertiary mathematics (or where relevant, science) qualifications. Senior secondary and tertiary education can not be expected to play a routine remedial role occasioned by gaps in the provision of primary education.

v. A broader role for degree programs in engineering?

Section 4 noted that when comparing Australian practice with other countries, a relatively low proportion of first-degree higher education students are enrolled in engineering. Students commencing programs in engineering, manufacturing and construction constitute an average 15.0 per cent in tertiary education in the OECD, and 25.4 per cent in Finland, 23.8 per cent in Korea, and 15.7 per cent in Germany. The

proportion in Russia is 23 per cent. In Australia it is 8.7 per cent. The proportion commencing engineering and related disciplines in the United Kingdom (8.2 per cent) and New Zealand is even lower than in Australia. In contrast, Australian participation in health sciences and natural sciences is above the OECD average though the proportion of tertiary students entering mathematics programs is low (OECD 2012, p.358).

There are a number of possible reasons that may explain the relative position of Australia and of the other English speaking nations. In Australia aspirations of students at age 15 to enter careers in engineering or computing are below the OECD average, being 10.5 per cent for boys and just 1.2 per cent for girls compared to OECD averages of 12.4 per cent and 1.6 per cent respectively. However it is a feature of all nations, including the engineering-strong nations, that at age 15 years aspirations to enter work in science – typically shared by about a third of the cohort – are much stronger than for entering work in engineering (ibid, p.82). The deeper question is why in Australia more students do not transfer their aspirations from science to engineering, as the youthful glamour of science wears off a little, and students become more aware of the nature and potential of more prosaic engineering degrees.

Australia's manufacturing sector is modest in size when compared with Germany or Korea. This constitutes one limit on the potential for professional work in engineering. However, the larger question is the role of engineering and related qualifications – whether these are seen as solely focused on professional engineering, or can function also as generic preparation for other occupations in the public and private sectors. It is likely that most prospective students would see the study of engineering as linked to professional practice, and this impression is reinforced by the close relationship between university engineering programs and professional engineers' associations. In that context, while the profession remains male-dominated and there is a close nexus between university training and professional work, the male domination of the profession reproduces the male domination of enrolments in higher education, limiting the capacity of actions by the educational institutions to correct the historic gender imbalance.

Arguably, engineering provides a valuable training in problem solving, design, practical construction and project organisation, as well as strong foundations in quantitative and spatial techniques. Many graduates in engineering in the engineering-strong countries, such as Korea, Finland, Russia and Germany, enter jobs in business and government. In the last three decades in the English speaking countries there has been a major expansion in the proportion of tertiary students doing business studies. The study of law has also expanded sharply in Australia and now functions as generic preparation for careers in government and business, as well as the legal professions. It may be that the nation would be well served if engineering came to play a larger generic role in professional labour markets. Such a change may hasten growth in female participation. But this would require a shift in the assumptions dominant in tertiary engineering programs.

Key finding 5.5: Generic role of engineering degrees

Relative to our strong comparator countries Australia has low participation in tertiary engineering degrees. The participation of women in these degrees is also low.

5.5.1 Tertiary institutions and the professions in engineering and the technologies might consider ways and means of strengthening the generic role of engineering degrees in professional labour markets, broadening the pathways between the study of engineering and employment in fields beyond professional engineering, including business and government. Such an approach would have implications for program design, marketing and student counselling.

5.5.2 There is potential for strategies designed to make engineering more attractive as a generic degree, especially for young women.

6 Attitudes to stem

The public and parents

The consultants' report on STEM in the United States notes that according to studies conducted by the National Science Foundation, the United States public expresses strong support for the value of science and technology, though it has some ambivalence about the quality of STEM education in schools. The consultants' report states that 'Overall, an overwhelming 91 per cent of adults agree or strongly agree with the claim that science and technology will result in more opportunities for the next generation. There are gender differences, however. Only 29 per cent of women "strongly agree" with this premise' compared to 41 per cent of men. Support for science and technology is stronger among young people than other age groups and not surprisingly, rises with the level of educational achievement. At the same time 'consistently 60-70 per cent of respondents indicating some agreement with the idea that science and math education is inadequate'. The consultants also report on the American public's handling of the respective claims of science and religious faith. Essentially, both views of the world are strongly valorised. In both respects the United States public contrasts with some other nations, as Table 11 shows.

The United States consultants report sums up the comparative position as follows:

> On the one hand, the US seems most similar to South Korea and China in that a large percentage of their citizens believe in the promise of science for improving our lives and expanding opportunities for the next generation. This sets it apart from Japan, India and the European Union in the level of agreement with those ideas. Conversely, there is evidence that a majority of Americans believe that we depend too much on science and not enough on faith, which puts us ahead of all others, spare South Korea, in this regard. Yet, we also lead the group in our lack of agreement with the notions that it is not important to understand science for everyday life and in the belief that science makes our lives change too fast. In sum, Americans are at or near the top of a number of countries in terms of their belief in the importance of STEM and what it can do today and will do in the future. The belief that we do not depend enough on faith is deep-rooted in the fabric of this country and is likely not to change any time soon. However, this does not mean that Americans reject science, and they're unique in this respect among the sample of countries investigated.

Table 11: Percentage of respondents who Agree with statements about science, by country

Statement	United States (2004 or 2010)[a]	Japan (2001)	South Korea (2008)	China (2001 or 2007)[b,c]	India (2004)	Malaysia (2008)[d]	European Union (2010)
Promise of science							
Science and technology are making our lives healthier, easier and more comfortable	90	73	93	86	77	84	66
With the application of science and new technology, work will become more interesting	76	54	85	70	61	71	61
Because of sceince and technology, there will be more opportunities for the next generation	91	66	84	82	54	NA	75
Reservations about science							
We depend too much on science and not enough on faith	55	NA	54	16	NA	39	38
It is not important for me to know about science in my daily life	14	25	30	17	NA	NA	33
Science makes our way of life change too fast	51	62	73	73	75	66	58

NA = not available, question not asked or different response categories offered; S&T = science and technology.

[a] US responses to 2004 survey include "Science and technology are making our lives healthier...", "With the application of science and new technology...", "We depend too much on science...", and "It is not important for me to know about science..." Responses to other items are from 2010 survey.

[b] China's responses to 2001 survey include "Promise of science" questions and "We depend too much on science..." China's responses to 2001 survey include "It is not important for me to know about science..." and "Science makes our way of life change..."

[c] Chinese respondents to 2001 survey were given different categories (Agree, Basically agree, Don't agree, Don't know), with neutral category.

[d] Malaysian question corresponding to "Science and technology are making our lives healthier, easier, and more comfortable" stated as "Science and technology improves the quality of our lives." Question corresponding to "With the application of science and new technology, work will become more interesting" stated as "Our daily work will be more effecient with the use of science and technology." Question corresponding to "It is important for me to know about science in my daily life" stated in a positive form as "We need to have knowledge about science in order to manage our daily lives", Malaysian responses of agree and disagree reversed to make them correspond to negative form of statement asked by other countries.

Sources: United States: University of Michigan, Survey of Consumer Attitudes (2004) and University of Chicago, National Opinion Research Centre, General Social Survey (2010); Japan: Ministry of Education, Culture, Sports, Science and Technology in Japan (2002); Korea: Korea Foundation for the Advancement of Science and Creativity (formerly Korea Science Foundation), *Report: Survey of Public Attitudes Toward, and Understanding of Science and Technology* (2006), Korea Gallup; *National Understanding of Science and Technology: Survey Report Results* (2009); Russia: Gokhberg L and Shuvalova O, *Russian Public Opinion of the Knowledge Economy: Science, Innovation, Information Technology and Education as Drivers of Economic Growth and Quality of Life*, British Council, Russia (2004); China: Chinese Ministry of Science and Technology, *China Science and Technology Indicators 2002* (2002); India: Shukla R, *India Science Report: Science Education, Human Resources and Public Attitudes towards Science and Technology*, National Council of Applied Economic Research (2005); Malaysia: Malaysian Science and Technology Information Centre, *Public Awareness of Science and Technology: Malaysia 2008* (2010); and EU: European Commission, Special Eurobarometer 340/Wave 73.1: *Science and Technology Report* (2010).

Science and Engineering Indicators 2012.

Source: United States consultants' report.

The Korea consultants' report notes Korea poll data which suggest that 'over the past decade, Korean people have increased their interest in science and technology. Their interest in new scientific discoveries and the use of new inventions and technology has gradually grown. The reasons for their interest include the relevance of science and technology to their daily lives, the acquisition of new knowledge, and media influence … [Comparative data suggest that] the level of Koreans' interest in science and technology is higher than that of the Chinese, but still lower than those of Americans and the Japanese'.

However, the Korean consultants' report notes that while 'overall, Koreans have become more interested in STEM and consider it important for Korean society … they do not necessarily prefer to pursue STEM-related professions for themselves'. Doctors, government officials and teachers enjoy higher prestige than STEM workers. There are widespread perceptions that STEM careers are relatively insecure and do not pay well. The consultants link these perceptions to a partial retreat of high quality students from STEM studies. This underlines the point that positive public attitudes to science do not necessarily translate into high national participation and performance in the STEM disciplines in education.

Most consultants explicitly report that science and technology are valued by the public, in both the sense of public as media and public as community 'grass-roots', and by parents of school students. Overall social respect for STEM is high in China, Singapore, the United States and Israel; and in all these cases parents exhibit a high valuation of STEM. New Zealand reports ambiguous attitudes by parents, with support for science diminishing over the 2005-2010 period. The Israel consultants' report raises the issue of an ultra-orthodox population in particular who do not participate in STEM education. On the other hand, in mainstream Israel there is strong support for science and innovation from families and a strong desire for students to move into science, engineering and medicine, linked to a history of research and development innovation.

The extent and distribution of these positive valuations of science and technology, the extent to which they become expressed as explicit understanding of and valuation of the STEM disciplines, and the extent to which parents want STEM studies and STEM careers for their children, are more variable. These opinions matter. There are many points in the reports that indicate a strong influence of families, and public attitudes, on STEM participation.

Positive family attitudes to STEM affect student participation in a number of ways. The Chinese and Singapore reports emphasise parental involvement in children's education through out of school tutorial provision. Out of school learning is a major factor also in Korea (especially), Japan and Taiwan. The Singapore consultants' report focuses on parent committees supporting schools including involvement in arrangements for low SES, low mathematics achievers, and high levels of involvement in enrichment activities such as clubs or science and mathematics competitions.

The United Kingdom focus on informal education links with more broadly based initiatives on public engagement with science, acknowledging the role of families in influencing children through participation in informal science (mainly) and mathematics activities. A number of STEM initiatives in Europe (e.g. Pencil, reported in the Western Europe consultants' report) involve schools linking with local communities, again acknowledging the importance of families. Family perspectives on STEM, and on education generally, influences students through role modelling of respect for such studies, and advice on potential careers. We note in passing that the research literature on STEM achievement also provides data on the impact of parental attitudes and involvement. Families' 'cultural capital' correlates with students' self-efficacy in relation to learning science and mathematics through the twin effects of high expectations, and modelling of STEM interest and career paths.

Parents, and educational institutions themselves, are also affected by what is happening in media, public opinion and the operations of social institutions outside formal education. The United Kingdom has developed a suite of initiatives around the education of the public, including media policy, and informal education.

In Australia interventions focused on families have proven productive in two ways. First, the family as a site for developing positive attitudes to STEM. Students can be encouraged to orient to STEM careers by providing families with information about productive futures in STEM professions. This may involve the provision of resources to careers teachers, who then disseminate those materials to families via students, or it may involve direct contact with parents through school events. Second, the family as a pedagogical medium. There have been a number of primary school programs focused on families, including 'family maths' and 'family science' initiatives, whereby schools organise activity nights in which parents and children explore mathematics or science activities together. Part of this is the design of science and mathematics activities to do at home. Such activities are especially important for families without a history of professional participation in STEM. There is scope to further develop the role of families in mathematics and science education.

Parental attitudes help to shape student participation in, and expectations in regard to, STEM. But not all students have family support. Not all have families. In those cases the role of institutional education, including that of teachers, becomes not just important but all-important.

Student attitudes

Patterns of student response

There is a negative correlation between student attitudes to STEM learning and a countries' index of development. This relationship shows up in a number of comparative studies in the research literature, and is discussed in a number of these reports. The graph at Figure 12, from the Relevance of Science Education (ROSE) study (Sjøberg & Schreiner 2010) illustrates the negative correlation. This underlines the challenge in advanced post-industrial societies such as Australia, of engaging students with science–related subjects and STEM futures. One reason is the wider set of options generally available to contemporary youth in these societies. Another is

Figure 12: Data from the ROSE study showing students' responses to the question 'I like school science better than most other school subjects'. Percentage answering Agree or Strongly Agree, by gender
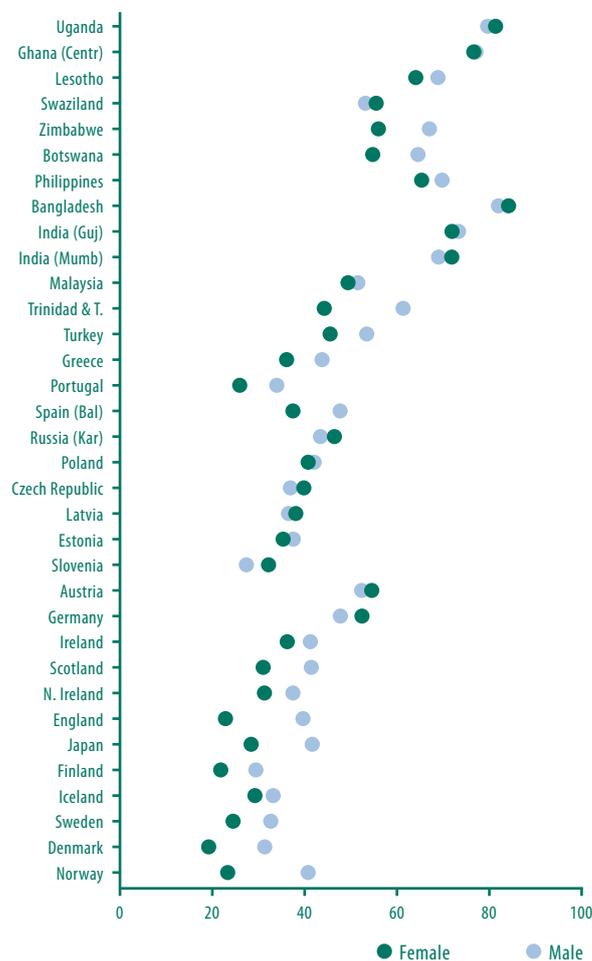
Source: Sjøberg, S & Schreiner, C 2010, The ROSE Project: An overview and key findings, Naturfagsenteret, Oslo.

student perceptions of mismatch between what they see as STEM professional futures, and their own developing identities. It seems that we need to do more to engender interest in STEM-related careers than once was the case, particularly in relation to girls.

The trend of declining attitudes to mathematics and science with age, from primary through the secondary school years, is described in many of the consultants' reports and is well documented in the literature. This means that policy attention should be focused across the entire education spectrum. There are many examples in the reports of initiatives at primary school stage, as well as initiatives directed at enhancing STEM participation in higher education, and STEM

research and development interventions. In Western Europe and the United Kingdom, the United States and Japan, considerable attention is paid to primary school mathematics and science.

In Australia there has been growing realisation of the importance of the primary and lower secondary years in determining students' intentions to continue or not with STEM-related subjects and careers. There is considerable evidence that student experience and developing intentions through these years are strongly indicative of their eventual choices (Tytler et al, 2008). The implication of this is clear – that if we are to help students to keep open the possibility of STEM subjects and eventual career choice, or even to encourage them to engage productively

with science and mathematics as citizens, then a) the mathematics and science experiences prior to the early middle years of schooling need to be positive and engaging, and b) students need to be made aware of the range of people and activities comprising STEM work in society.

Comparative Australian data on attitudes

Data from the TIMSS international testing on student attitudes to mathematics and science show two things. Firstly, student attitudes are linked to performance. In any single country, and in all countries taken together, more positive attitudes are predictive of higher achievement scores (see Table 12a). The data show that in both

Tables 12A and 12B: Data indicative of Australian students' attitudes and consequent achievement scores in TIMSS international assessment of student achievement

Table 12A	Like science		Somewhat like science		Do not like science	
	Percentage of students	Average achievement	Percentage of students	Average achievement	Percentage of students	Average achievement
Year 4 TIMSS 2011						
International Average	53	504	35	469	12	461
Australia	55	529	31	506	14	496
Year 8 TIMSS 2011: Science						
International Average	35	515	44	472	21	450
Australia	25	559	42	521	33	490

| Table 12B	Like science		Like Mathematics	
	Percentage of students	Average achievement	Percentage of students	Average achievement
Year 4 TIMSS 2011				
International Average	53	504	48	509
Australia	55	529	45	535
US	56	555	45	552
Ontario	48	537	35	533
England	44	535	44	548
Hong Kong	52	551	47	619
Chinese Taipei	58	564	34	613
Korea	39	604	23	627
Year 8 TIMSS 2011				
International Average	35	515	26	504
Australia	25	559	16	553
US	29	555	19	536
Ontario	29	543	26	546
England	32	562	14	548
Hong Kong	28	561	19	635
Chinese Taipei	17	618	14	681
Korea	11	623	8	677

Source: Mullis, IVS, Martin, MO, Foy, P & Arora, A 2012a, *TIMSS 2011 International Results in Mathematics*, International Association for the Evaluation of Educational Achievement, Boston; and Mullis, IVS, Martin, MO, Foy, P & Arora, A 2012b, *TIMSS 2011 International Results in Science*, International Association for the Evaluation of Educational Achievement, Boston.

mathematics and science Australian students' attitudes at 4th grade are comparable to the international average, but that by 8th grade the proportions of Australian students who 'like' mathematics and science have fallen well below that international average. However, this must be seen in the context of the generally less positive attitudes to science in developed countries, described above in Figure 12. A comparison with attitudes of our closest comparator countries, and high performing Asian countries, in Table

12b, shows Australian students' attitudes higher than those in Chinese Taipei and Korea, broadly comparable with those of the United States, Ontario and England, but lower than particularly England in science, and Ontario in mathematics.

Data from a PISA survey of 15 year-old student expectations of science and engineering careers provides a proxy for student choices. According to the survey results, 33.5 per cent of 15 year-old Australian students expect to undertake science

Figure 13: The percentage of participating 15 year-old students expecting a career in a science, engineering or computing field

Percentage of 15-year-olds planning a science-related career

Percentage of 15-year-olds planning a career in engineering and computing (not including architects)
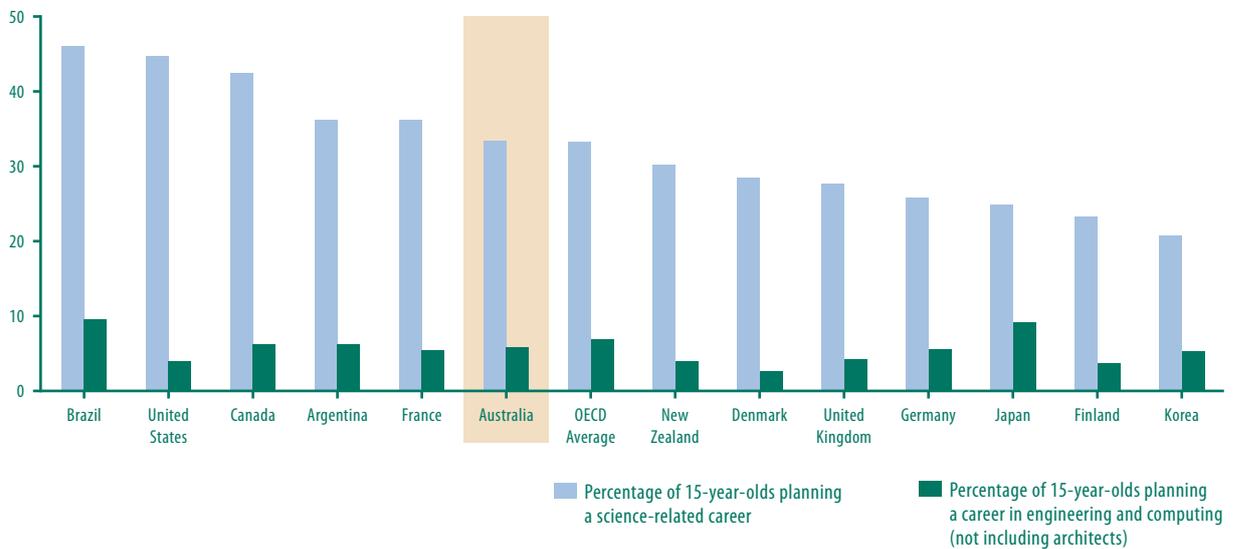
Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators*, OECD Publishing, Paris.

Figure 14: The percentage of participating 15 year-old students expecting a career in a science, engineering or computing field by gender
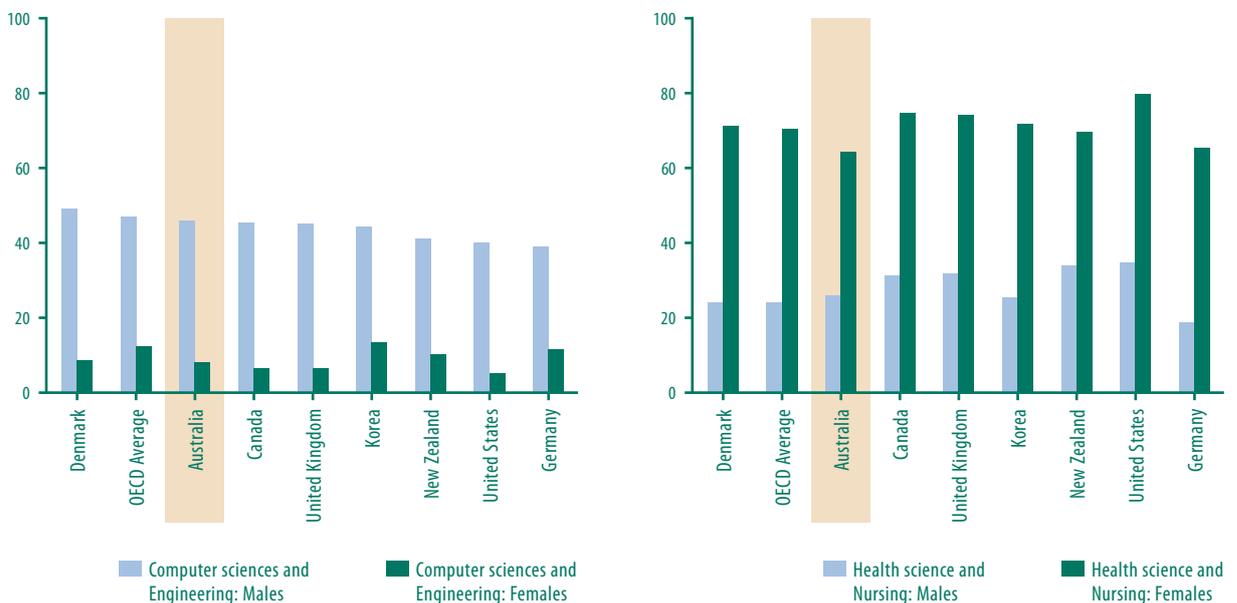
Computer sciences and Engineering: Males

Computer sciences and Engineering: Females

Health science and Nursing: Males

Health science and Nursing: Females

Source: OECD 2010e, Expectations for science-related careers by gender, *OECD Factbook 2010: Economic, Environmental and Social Statistics*, OECD Publishing, Paris.

related careers before the age of 30, near the OECD average of 33.2 per cent, but below the proportion expecting this future in countries including Brazil, the United States, Canada and France. Only 5.8 per cent of 15 year-old students in Australian schools expect to be in engineering or computer sciences related careers, compared to the OECD average of 6.9 per cent, and 9.4 per cent in Brazil and 9.0 per cent in Japan. This lack of awareness of or commitment to engineering as a course option was discussed in section 4.

There are clear gender differences in expectations about STEM careers. Only 26 per cent of 15 year-old Australian males expect careers in health science or nursing, compared to 71 per cent of females. In total 46 per cent of males are planning careers in engineering or computer science fields, compared to only 8 per cent of females.

The detailed patterns of student attitudes to science and mathematics are complex and highly contextual. As noted in the United States consultants' report, the wording of attitude surveys can be crucially important in framing student response. There are differences in attitudes of students towards science, and towards school science. There are differences between 'liking' science or mathematics and intending to continue in these subjects. There are variations in attitudes to the different sciences and to different science-related futures. The Korean consultants' report describes negative social attitudes towards engineering as a profession. Medicine is accorded higher status. The Chinese consultants' report describes the high status of theoretical knowledge and respect for teachers as fundamental values in countries with a Confucian heritage. While the broad patterns of attitude shifts are apparent, and tend to be shared across borders, the contextual details must be noted.

Making sense of student attitudes to science

The literature review: *Student identity related to STEM subject choices and career aspirations* makes the point that the literature on attitudes to science is gradually being supplanted by the identity construct, which is a more powerful way of looking at the factors affecting student commitment or otherwise to STEM. An individual's identity is both fluid and multi-faceted, constructed in interaction with many social and cultural factors such family and friends, feelings of competence, and interest. "Am I the sort of person who is curious about the natural world?" "Who do I want to become?" These are questions central to identity. It has been argued that taking on board the scientific world-view, including values, involves for most students an identity shift that must be negotiated. The identity construct can be powerful in investigating the issues associated with indigenous people learning science, and also the experiences of other minority groups, low SES students, and girls. Identity helps us to make sense of the different and particular strategies needed to support the variety of students in our classes to engage with and value science and mathematics. The identity perspective on STEM participation supports:

- An emphasis on 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 explicit inclusion of values in the curriculum, so that technological objectivity and determinism is not seen as defining of STEM, but 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

- Explicit scaffolding of students to take on and value science ideas, as critical in learning science.

The research literature identifies the cultural capital invested in families with STEM connections that act to set high standards towards achievement in science or mathematics,

provide role models for interest and work in STEM, and increase students' self-efficacy in relation to STEM subjects (Blenkinsop et al, 2006; and Lyons, 2006). As noted, schooling plays a particularly important role for students from low SES areas who may not have family connections with STEM professional work. Under optimum conditions schooling can provide students with academic capital sufficient to largely substitute for cultural capital in the home.

Key finding 6.1: Building awareness of STEM disciplines and STEM-related occupations among young people

For most countries, initiatives targeted at student attitudes and identity were a significant part of the strategic mix. This included initiatives to increase awareness of the nature of STEM professions. Based on the consultants' reports, strategies and programs could be further developed and extended so as to encourage in students positive attitudes to study of mathematics and science, and to STEM-related work and careers. Such strategies would need to take into account the diversity of students' contexts, including their gender, ethnicity/cultural background, SES status and indigeneity. Such strategies could include:

- Awareness campaigns to enrich public understanding of career options in STEM and the nature of STEM work, and to alert young people to the range of possible future STEM lives and identities.

- Strategies at school level designed to involve families in mathematics and science learning and in building positive attitudes to STEM-related careers.

- Role models, in the form of student interaction with practicing STEM professionals, or web-based presentations of narratives of STEM professionals (such as those on the Academy of Technological Sciences and Engineering [ATSE] Science and Technology Education Leveraging Relevance [STELR] website).

- 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.

- The inclusion, in curriculum resources, of materials that speak to the identity needs of the diverse range of students. This includes girls (e.g. science material related to health, or the environment.), indigenous students (e.g. materials that embody respect for indigenous knowledge), and contextual science that relates to youth interests.

- The expansion of opportunities for families and the general public to engage positively with science and mathematics through events, exhibitions and other approaches.

- Enrichment programs whereby students are engaged in science or mathematics projects that entail linking to members of local communities.

7

Framing national STEM policy and strategy

National STEM Legislation and Policy

Several countries articulate a national government commitment to STEM or a broader science and technology agenda in national policy. National policy establishes a framework for STEM-specific objectives and can facilitate the implementation of coherent STEM-specific strategies and programs. Government commitment to STEM, or elements of STEM, may be reflected in legislation, policy or strategy statements focused explicitly on STEM, or more broadly on science and technology, school and tertiary education, and research and development. National STEM policy tends to span more than one government ministry, and in many instances is supported by structures co-ordinating STEM or science and technology activity across jurisdictions and agencies.

Policy objectives

National STEM or science and technology policy is generally conceived in human capital terms. Emphasis on the 'pipeline' of school and tertiary STEM education is frequently motivated by issues concerning the STEM labour force; considered instrumental

to economic growth and wellbeing. Many countries have also adopted an explicit policy focus on increasing scientific literacy. The objectives of national STEM or science and technology legislation or policy vary in focus and breadth, and typically include some of the following:

- promote a positive image of science and mathematics, and STEM

- increase public knowledge and awareness of science (scientific literacy, scientific method)

- support increased student engagement

- support increased student participation in school-based mathematics and science, tertiary-level STEM-disciplines, and the STEM workforce

- support increased achievement in school-based mathematics and science, and tertiary STEM-disciplines

- address disparities based on gender

- address under-representation of minority groups and those located in various geographical locations

- establish mechanisms for co-ordination across STEM-related ministries, agencies, organisations (including scientific agencies, and research and development funding agencies) and STEM stakeholders

- establish annual and long-term objectives

- establish common metrics to monitor progress

- establish an evaluation strategy

- identify key participating STEM-related ministries, agencies and organisations

- identify key strategies or programs.

Different approaches (English speaking and Western European countries; Asian countries; developing countries)

English-speaking (Canada, New Zealand and the United States) and Western European countries with high performing education systems and unmet demand for STEM-qualified positions frequently have national policy specifically focused on, or embracing, STEM. In such countries, variations exist in terms of policy coverage depending on the scope of government responsibility (for example, between federal and unitary systems).

Asian countries with very high performing education systems and growing economies (Korea, Japan, China, Taiwan) have established national policies around science and technology more broadly, and university and industry driven research and development.

Reflecting the imperatives of poverty reduction and equitable education, developing economies (Brazil, Argentina, South Africa) have national policies focused on quality education systems and emerging industry development, rather than STEM-specific policy.

Case study: United States STEM policy and programs

United States governments on both sides of politics have fully embraced the STEM agenda. The consultants' report on STEM in the United States notes that support for STEM is universal in Washington:

> At the federal level, support for STEM is one of the issues that generally remains above partisan politicking. For example, in the most recent election for President, the leading candidates from both major political parties made it clear that they want to strengthen many aspects related to STEM and innovation in the US. Where differences do surface, they generally revolve around how improvements should be made and how such initiatives will be funded.

Government concern with STEM in the United States can be traced back to the report of Vannevar Bush, commissioned by President Roosevelt at the end of 1944, in which proposals as to how science could be turned from warfare to curing disease, development of scientific talent in American youth, fuller and more fruitful employment, and a more fulfilling life, are called for. In his report – *Science, the Endless Frontier* – Bush writes that 'scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress' (Bush 1945, n.p.). This optimism is mirrored in the 2010 Report to the President, *Prepare and inspire: K-12 education in science, technology, engineering and maths (STEM) for America's future* which sets out the rationale for the United States government's STEM agenda:

> The success of the United States in the 21st century – its wealth and welfare – will depend on the ideas and skills of its population. These have always been the Nation's most important assets. As the world becomes increasingly technological, the value of these national assets will be determined in no small measure by the effectiveness of science, technology, engineering, and mathematics (STEM) education in the United States. STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security … It will generate the scientists, technologists, engineers, and mathematicians who will create the new ideas, new products, and entirely new industries of the 21st century. It will provide the technical skills and quantitative literacy needed for individuals to earn livable wages and make better decisions for themselves, their families, and their communities. And it will strengthen our democracy by preparing all citizens to make informed choices in an increasingly technological world (President's Council of Advisors on Science and Technology, 2010, p.vii).

This very broad rationale stands in contrast to the 1993 remarks of the chairman of the United States Congress Committee on Science, Space and Technology, George E. Brown Jr. who reported that: 'Global leadership in science and technology has not translated into leadership in infant health, life expectancy, rates of literacy, equality of opportunity, productivity of workers, or efficiency of resource consumption. Neither has it overcome failing education systems, decaying cities, environmental degradation, unaffordable health care, and the largest national debt in history' (cited in Science, 1993, p.735).

The tone of *Prepare and Inspire* is based on a widespread but usually implicit assumption that the progress of science is now an alternative to the distribution of already existing wealth to deal with hunger and poverty. On this alternative, governments must look to science as a means of creating more wealth: intensive agriculture and genetically modified crops will feed the hungry, and economic growth will reduce and eventually remove poverty. This is of course not an exclusively American view – it is widely assumed by many governments – but it is one that can be questioned. We raise it here to draw attention to the fact that there may be deep-seated political and ideological agendas behind the formulation of particular STEM programs. One can advocate a commitment to STEM programs while remaining neutral to such agendas, as we have tried to do in the body of the report.

The United States government's commitment to STEM is reflected in federal legislation. Initially introduced in 2007 by President Bush, and reauthorised by President Obama in 2010, the *America COMPETES Act* (Congress of the United States of America, 2010) represents a comprehensive, legislative commitment to STEM education, research and development, and innovation. With respect to education, the *America COMPETES Act*: provided the foundation for programs increasing the number of STEM teachers in high-needs areas by 700,000; requested the co-ordination of STEM-related effort across scientific agencies (i.e. NASA, National Science Foundation, National Oceanic and Atmospheric Administration); and suggested that schools observe a National Day

of STEM. The Act also called for an inventory of strategies aimed at increasing performance and participation of minorities in STEM, and identified federally-significant STEM-related programs including *Teachers for Competitive Tomorrow*.

The *America COMPETES Act* required the Director of the Office of Science and Technology Policy (OSTP) to establish a committee responsible for co-ordinating federal efforts related to STEM. The committee is charged with responsibility to develop, implement through the participating agencies, and update once every five years a 5-year STEM education strategic plan, which shall

    a. specify and prioritise annual and long-term objectives;

    b. specify the common metrics that will be used to assess progress toward achieving the objectives;

    c. describe the approaches that will be taken by each participating agency to assess the effectiveness of its STEM education programs and activities; and

    d. … describe the role of each agency in supporting programs and activities designed to achieve the objectives. (ibid, n.p.)

The Director of the OSTP is required to present a progress report annually to Congress. The Reauthorization specifically: directed NASA and NOAA to increase their efforts to improve student interest in STEM; required all agencies to promote increased participation of minority groups; focused on cyber-learning tools to train and retrain the STEM workforce; continued the *Teachers for Competitive Tomorrow* program and promoted greater alignment between school graduation requirements and national needs in STEM. The Reauthorization also established the National Centre for Science and Engineering Statistics, as part of the National Science Foundation, to collect and disseminate data on STEM research, development and education.

There are numerous STEM reports developed to inform government STEM policy. The majority of these have recommended a systemic approach including: the establishment of a structure connecting interested stakeholders; a decision chain coupled with a funding scheme; and a

feedback and evaluation mechanism to record and interpret implementation progress. *Rising Above the Gathering Storm* (National Academies' Committee on Science, Education and Public Policy 2007) included STEM-specific recommendations concerning the multiplicative effect of well-prepared science and mathematics teachers on their students, and the importance of attracting the brightest people into STEM occupations from the national pool (via undergraduate scholarships, graduate fellowships and business tax credits), and international pool (via access to education, employment, visa processing and skill-based immigration). The report also recommended increased funding for research and innovation generally, with emphasis on basic research and strategies to incentivise innovation.

The National Science Board STEM education recommendations to the President-Elect Obama administration in 2009 (National Science Board, 2009) included advancing STEM education for all American students, supporting quality education and ensuring long-term prosperity. Elements of an effective STEM education system were conceived as including: a motivated public, students and parents (via public awareness campaigns); clear educational goals and assessments, regardless of a students' state or school district; high-quality teachers; world-class resources and assistance for teachers; an early start in science (via the inclusion of STEM core concepts in early education programs and elementary school STEM education); communication, co-ordination and collaboration involving coalitions between K-12 school systems, colleges and universities, science education organisations, business and industry; and streamlined federal government co-ordination of STEM education research.

Building a Science, Technology, Engineering and Maths Education Agenda (National Governors' Association, 2011) recommended strategies to increase the number of students undertaking post-secondary STEM education and pursuing STEM careers, and improve scientific literacy. The report recommended: adopting rigorous mathematics and science standards and improved assessments; recruiting and retaining effective teachers; incorporating hands-on mathematics

and science activities and educational opportunities beyond the classroom; enhancing the quality and supply of STEM teachers; and establishing goals for post-secondary institutions to meet STEM labour market needs. Similarly, *Prepare and Inspire* (2010) by the President's Council of Advisors on Science and Technology (PCAST) recommended that: attention be paid to STEM common standards; STEM teachers be recruited via the creation of a STEM Master Teachers Corps; educational technology use be expanded; specialised STEM-focused schools be established; and strong national leadership be demonstrated in terms of the STEM agenda.

Engage to Excel (2013) prepared by the President's Council of Advisors on Science and Technology (PCAST), established a target of one million additional college graduates with STEM degrees over the next decade to address projected STEM labour market shortages. The report envisaged the adoption of teaching strategies that emphasise student engagement, providing all students with tools to excel, and diversifying pathways to STEM degrees. Key recommendations included: the adoption of empirically-validated teaching practices; the replacement of standard laboratory courses with discovery-based research courses; a national experiment in post-secondary mathematics education to address mathematics-preparation gaps; the establishment of partnerships among stakeholders to diversify pathways to STEM careers; and the creation of a Presidential Council on STEM education.

Finally, the Co-ordinating Federal Science, Technology, Engineering and Mathematics (CoSTEM) *Education Investments: Progress Report* (2012) established a five-year federal STEM education strategic plan, including a vision, goals and objectives. The plan's primary goal is to develop a shared pathway between the 13 federal agencies with responsibility for STEM education, scientific literacy and STEM workforce development. The plan aims to 'provide STEM education and training opportunities to prepare a diverse, well-qualified workforce, able to address the mission needs of the Federal agencies and lead in innovation across the broad spectrum of industries and occupations related to the

missions of Federal agencies' (ibid, p.11). The plan established objectives regarding: increasing STEM interest and engagement among the public of all ages; increasing opportunities to develop deeper STEM knowledge, skills, and abilities; improving STEM educator and leader preparation; improving the institutional capacity to support effective STEM education and learning programs; and increasing the STEM learning base and use of evidence based STEM education practices.

There are common themes throughout these policy reports, key to which is coordination of STEM effort, and collaboration between STEM stakeholders. The reports also highlight the need for a concerted effort around recruiting and retaining STEM teachers, promoting consistency in curriculum standards despite the challenges posed by the federal structure, and increasing participation of girls, women and minorities in STEM education and the STEM labour market. The United States approach to STEM conceives a dual focus on STEM for high achievers and scientific literacy for all, and involves a diverse range of strategies spanning schools, colleges, universities, research and development organisations, industry and the broader community.

There are a plethora of initiatives, implemented by a variety of national, state and local organisations that translate these policy recommendations into practice. The consultants' report identified some notable ones. Skills for America's Future established a national network of partnerships between employers, community colleges, industry associations, and other stakeholders to bridge the skills gap between the 3 million unfilled technical jobs and unemployment. The Master Teachers Corps rewards STEM teachers; the STEM Talent Expansion Program (STEP) aims to increase the number of engineering and computer science bachelor-level graduates by 10,000 annually. Educate to Innovate involves public-private partnerships to foster interest and engagement in STEM through out-of-school activities (e.g. greater focus on STEM in Sesame Street). The Common Core State Standards (CCSS) initiative involved the development of common standards for K-12 English language, arts, mathematics and science, with 45 of 50 states having adopted the

standards and in various stages of classroom implementation. A number of immigration-based initiatives have also been implemented to strengthen the STEM labour market. For example, student visa arrangements have been extended for holders of PhD's in STEM fields (from 12 months to 29 months); employment-based visas under the *American Competitiveness in the Twenty-First Century Act 2000* provide foreign nationals working in universities and non-profit or government research facilities with dual-intent visas (where the employer supports applications for employment and permanent residency). (See Section 10 for further discussion).

The establishment of a national framework for STEM policy and programs has not been without challenges. The CoSTEM Report (2012, p.12) identified several factors that constrain the achievement of strategic goals:

- The Federal government's lack of authority to create a national STEM education curriculum or set of standards;

- Budget fluctuations and changes in views of agencies' roles are affecting the long-term planning;

- Certain agencies cannot by law target underrepresented groups;

- Coordination between agencies is difficult with limited funding;

- Data confidentiality rules limit evaluation strategies.

Evaluations suggest that while many of the functional elements of a national STEM policy and strategy are in place, others are in the process of being implemented, or are yet to be implemented.

Case study: United Kingdom STEM policy and programs

The United Kingdom's commitment to STEM is conceptualised in terms of human capital: 'The best way for the UK to compete, in an era of globalisation, is to move into high-value goods, services and industries. An effective science and innovation system is vital to achieve this objective' (Sainsbury 2007, p.3). The United

Kingdom's long-term policy agenda for STEM is represented by their *Science & Innovation Investment Framework 2004-2014*, which states:

> The nations that can thrive in a highly competitive global economy will be those that can compete on high technology and intellectual strength – attracting the highest-skilled people and the companies which have the potential to innovate and to turn innovation into commercial opportunity. These are the sources of the new prosperity. This is the opportunity. This framework sets out how Britain will grasp it. It sets out how we will continue to make good past under-investment in our science base – the bedrock of our economic future. More than that, it sets out not only how we intend to invest in this great British asset – the world-class quality of our scientists, engineers and technologists – but how we will turn this to greater economic advantage by building on the culture change under way in our universities, by promoting far deeper and more widespread engagement and collaboration between businesses and the science base, and by promoting innovation in companies directly. (DfES 2004, p.1)

Despite being commissioned by the former Labour Government and published in 2004, the framework captures the essence of the current official policy position on STEM, and there has been no subsequent government STEM-specific policy announced.

The *Science & Innovation Investment Framework 2004-2014* established objectives in terms of 'world class research at the UK's strongest centres of excellence; … greater responsiveness of the publicly-funded research base to the needs of the economy and public services; … increased business investment in R&D, and increased business engagement in drawing on the UK science base for ideas and talent; … a strong supply of scientists, engineers and technologists …; sustainable financially robust universities and public laboratories across the UK; (and) … confidence and increased awareness across UK society in scientific research and its innovative applications' (Tomei 2013, pp.4-5). In terms of increasing the supply of scientists, engineers

and technologies, the framework articulated ambitions regarding:

- the quality of science teachers and lecturers in every school, college and university
- ensuring national targets for teacher training are met
- the results for students studying science at GCSE level
- the numbers choosing SET subjects in post-16 education and in higher education
- the proportion of better qualified students pursuing R&D careers
- the proportion of minority ethic and women participants in higher education. (ibid., p.5)

The *Science & Innovation Investment Framework 2004-2014* has provided the basis for ongoing government investment through the science research budget despite the economic downturn, and the backdrop for a series of STEM-related strategies and programs.

In the school sector, national curriculum, including standardised mathematics, science and ICT curriculum, is mandated in public schools in England, Wales and Northern Ireland. Independent schools, new academies and free schools are not required to follow the curriculum, however the majority do. The national curriculum has been the subject of ongoing reform, as has the General Certificate of Secondary Education (GCSE) (e.g. 21st Century Science). Mathematics, science and ICT are compulsory in years 10-11, and most students take the national GCSE examinations. One offering is the new 'Triple Science' option in which pupils take three separate GCSEs, in physics, chemistry and biology. Normally only offered to higher attaining pupils, Triple Science has had increasing take-up in recent years, with strong government backing. Various initiatives involve teacher 'continuing professional development' (CPD) and 'in-service education and training' (INSET) to support curriculum reforms and the focus on inquiry based science education.

Mathematics has provided a particular policy focus with the implementation of a *National Numeracy Strategy* in the late 1990s and the

placement of mathematics specialists in each primary school. Specialist schools in science, technology and engineering, and mathematics and computing have been established (there are now 1300 schools in England), and there is a National Network of Science Learning Centres that provides discipline-specific continuous professional development for teachers.

There are a large number of enrichment activities which promote science to the general community, including science centres, museums, science festivals, science talks and activities outside school or university classes, zoos, planetaria, aquaria and botanical gardens, and science centres following the model of the Exploratorium in San Francisco (see Section 14).

STEM-specific initiatives include the Science, Technology, Engineering and Mathematics Network (STEMNET), an educational charity established in 1996 with national and regional hubs implementing the STEM Ambassadors program, co-ordinating the STEM Clubs Network and supporting the Schools STEM Advisory Network.

Whilst the United Kingdom framework provides a backdrop for STEM strategy spanning education, research and industry sectors, it is now somewhat dated in terms of providing a cohesive STEM policy to guide ongoing and future activity in this area.

Case study: Korea STEM policy and programs

The Korean consultants' report articulates the Korean government's rationale for national science and technology policy:

> the Korean government has attributed the recent advancement of the Korean economy and its role in the global community to the development of science and technology. In a public message from the Lee government (2008-2013) on its accomplishments of science and technology policies, it acknowledged the enhanced competitiveness of science and technology over its regime (MEST, 2012a). For example, in this message, the Korean government emphasised that in the IMD

Scientific Infrastructure Subindex, Korea moved up from 7th in 2007 to 5th in 2012, and Korean higher education institutions in the top 200 QS World University Rankings increased from two in 2007 to six in 2012.

The Korean government has established detailed plans for technology development every five years from the 1960s through the 1980s (Hong et al, 2010). In the 1st economic development 5-year plan (in the 1960s), the government focused on educating technicians to promote light industry. In the 2nd economic development 5-year plan the focus shifted to college and university education in science and technology fields (including fisheries). After the 1970s the focus shifted to education for different industries, principally including engineering, as part of a strategy to promote the heavy chemical industry (ibid.). In the 1980s, demand for highly qualified and specialised staff in science and technology intensified, and the government established the Korea Advanced Institute of Science and Technology (KAIST), a graduate school specialising in science and engineering. The government also established the Korea Institute of Technology and specialised science high schools and strengthened undergraduate science and technology education, reflecting a shift in government policy focus from undergraduate to postgraduate higher education.

In the 1990s government investment in research and development and research-intensive universities intensified. The Korean consultants' report notes that at this point:

> the issues of imbalance between demand and supply, as well as quantity and quality of human resources in science and technology, difficulty of finding employment in science and engineering fields, and the phenomenon of avoiding science and engineering emerged. In the 2000s, a need for highly advanced human resources increased with the advent of the knowledge-based economy, but issues from the 1990s still persisted in addition to a decrease in the number of high school graduates in Korea and a mismatch between university education and the demand from industry.

The *First Master Plan for Educating and Supporting Human Resources in Science and Technology* was introduced in this climate to encourage people to participate in science and engineering, and enhance the competitiveness of science and technology. Subsequently, the *Second Master Plan for Educating and Supporting Human Resources in Science and Technology (2011-2015)* under the *Special Support Act for Science and Engineering for Improving National Competitiveness* focused on science and technology education and workforce preparation.

There are a range of strategies and programs that support the *Second Master Plan*. For example, Korea launched Science, Technology, Engineering, Arts and Mathematics (STEAM) as a mechanism to engender inter-disciplinary education, creativity, artistic literacy, student engagement and motivation in STEM education (see section 8). The Korea Institute for the Advancement of Science and Creativity (KOFAC) was established to promote science and technology-related cultural activities, and co-ordinate enrichment activities and STEAM talks. Some strategies focus on elite education, such as the *Comprehensive Plan for Discovering and Educating Talented and Gifted Youth in Science* that provides specialist science, technology, engineering, arts and mathematics schools for talented and gifted students. Korea has also adopted a 'life cycle approach' with respect to human resources for science and technology covering education, employment, research and retirement (e.g. Global PhD Scholarship are available for high caliber undergraduate and doctoral students and postdoctoral researchers).

Korea has launched several initiatives aimed at increasing the number of world-class universities, including Brain Korea 21, the World Class University (WCU) Project, and the Global EXCEL program which aims to increase the number of Korean institutions in the top 100 world universities (see section 12). Given the significant gender disparities, particularly in engineering, the Korea Advanced Institute of Supporting Women in Science, Engineering and Technology (WISET) has been established and various women in engineering programs, and women in science and technology programs introduced. In addition, the Women's Academy for Technology Change in the 21st Century (WATCH21) promotes natural sciences and engineering to high school students.

From a policy perspective, the Korean case study provides a unique example of national government long term planning for science and technology and economic development, which has clearly translated to a high performing education system, and extremely high levels of participation in STEM-disciplines in higher education undergraduate and doctoral programs (principally including engineering).

Case study: Japan STEM policy and programs

The Japanese consultants' report indicates that the Japanese government and scientific community have identified the emergence of the 'research and development mega competition' in the 21st century as a key driver of science and technology reform. As the consultants' report notes:

> there is a measure of national consensus: competitiveness of the national economy depends on the strength and capacity of research and development, and subsequently on human capital development. Education and educational institutions, from primary to tertiary and beyond, which nurture and train human resources to sustain the progress of technological innovation, therefore constitute a renewed political priority for contemporary Japan. Hence, STEM is placed within a framework of long-term national economic development and forms an integral part of such policy deliberations.

The Japanese *Science and Technology Basic Law* (*Kagaku Gijutsu Kihon Hō*, or S&T Law of 1995) provided a legislative commitment to progressing science and technology and established mid- to long-term commitments across several government ministries. The S&T Law (Chapter 1, Article 1, Law No. 130 of 1995) aimed to foster a superior standard of science and technology to contribute not only to Japanese economic and societal development but also the progress of global science and technology as the world

builds toward a sustainable human society. The legislation introduced a range of reforms with significant, wide-reaching effects, including provisions for re-examination and revision of mid- to long-term science and technology policy.

The legislation established the Council for Science and Technology Policy, headed by the Japanese Prime Minister. The Council is the principal mechanism to determine mid-term science and technology strategies. While each ministry oversees the implementation of individual STEM programs, the Council has authority over the general direction of the promotion of science and technology on the basis of five-year basic plans, thereby ensuring mid- to long-term planning and commitments (Kitazawa 2010, pp.31-32).

The Ministry of Education, Culture, Sports and Science and Technology (MEXT), representing a merger of the previous Ministry of Education, Science and Culture, and Science and Technology Agency, has responsibility for science and technology through education, and co-ordination of multiple STEM-related agendas. The restructure was part of a larger effort to downsize government and decrease government expenditure on education. The consultants' report notes that 'the government's STEM strategies and programs thus inhabit a climate of austerity against a backdrop of mounting criticism and concern over deteriorating STEM performance of Japanese students as well as lack of enthusiasm for STEM subjects'.

The Japanese government has introduced a range of national strategies to enhance STEM. Firstly, as discussed in Section 5, national *Curriculum Guidelines* for compulsory primary and secondary school-level science and mathematics have been developed that increase hours and content. These guidelines are complemented by other initiatives that seek to improve science teaching, including disciplinary training of primary school science teachers. These strategies aim to improve the quality of basic STEM education nationwide ('science for all'), generating and stimulating interest in science and creating support for

STEM in Japanese society. A second strategy involves 'elite' education (e.g. Super Science High School program, and the 'science elite track' from secondary to tertiary education). Thirdly, strategies have been implemented which focus on transitions between university and career paths (e.g. job placement of graduate students and post-doctoral researchers in STEM fields). Fourthly, strategies have been developed which specifically address the gender disparities in STEM education and STEM occupations, including initiatives involving public and corporate sector funding. Finally, the *300,000 International Students Plan* aims to send 300,000 Japanese students abroad, and accept 300,000 international students to Japanese universities by 2020, with STEM-disciplines representing a strategic target discipline.

The Japanese Science and Technology Agency (JST) is responsible for implementing many of the Japanese government strategies, including those broadly concerned with enhancing general scientific literacy ('science for all').

Whilst the S&T Law represents a legislative commitment to science and technology, there is no national STEM policy, and no co-ordinated approach to monitoring and evaluation of the various science and technology, and STEM strategies and programs. The Japanese consultants' report suggests that 'the practice of incorporating STEM into policies and programs without giving it primary focus results in fragmentation of information, making it difficult to synthesize a cohesive picture of national STEM strategies and programs, their impact and shortfalls. Doing so requires not only an understanding of current status and statistics, but also of shifting policy priorities and adjustments, as well as changing needs and demands towards STEM spanning wide sectors of society'. As such, while the legislative framework for science and technology, and STEM initiatives reflects government commitment to STEM, more could be done with respect to national STEM policy coherence and financial support.

Other STEM or science policies

Western Europe, Germany, France, Ireland, the Netherlands, Norway, Spain, and the United Kingdom all have national STEM (or science) policies or strategies (Eurydice, 2011) that provide a coherent STEM framework, frequently linked to broader educational goals. Typically, these policies or strategies involve: promotion of a positive image of science; increasing public knowledge of science; improving school-based mathematics and science (teaching and learning); and increasing interest and participation in school-based mathematics and science, tertiary STEM disciplines and the STEM workforce. In addition, Western European national STEM policies seek to address disparities (gender and minority groups) in education and employment-based STEM, and match graduates with employer skills needs. For example, the German government's *High-Tech Strategy* is supported by MINT (STEM) Future, a registered non-profit association supported by the German President as patron. The association promotes the interests of students in STEM, and supports increased participation in school-based science and mathematics and STEM-disciplines. The national strategy is supported by the *National Pact for Women in MINT Careers* that seeks to address gender disparities in STEM education and employment.

The Norwegian *Science for the Future Strategy for Strengthening Mathematics, Science and Technology (MST) 2010-2014* conceives of STEM holistically from kindergarten to employment, and promotes co-operation between education and industry to facilitate transition of graduates into STEM professions. France, Switzerland and Italy have national strategies focused on school education, from encouraging interest in school-based science and mathematics (France), promoting 'synergies' between diverse STEM strategies and programs (Switzerland) and establishing an inter-departmental structure to foster STEM culture (Italy). In Austria, Finland, Slovenia and the Slovak Republic, national STEM-specific strategies are no longer prioritised as STEM has effectively been mainstreamed (Kearney 2011).

Other countries have non-STEM-specific policies and plans that establish national agendas for science and technology, and related issues. The Russian government's science and technology policy establishes a global goal for Russian high technology products and intellectual services (5-10 per cent of global markets) but does not focus specifically on STEM nor provide a coherent, consistent STEM policy. Similarly, China's *Science and Technology Development Goal (2006-2020)* and *National Mid and Long-term Education Reform and Development Framework (2010-2020)* articulate broader objectives regarding industry development and education reform. Taiwan demonstrates national commitment and long term planning, with science and technology plans dating back to 1959 (*Long-Term National Science and Technology Plan*).

The Israeli government has not articulated a comprehensive national STEM policy or strategy. Rather the government's agenda is dispersed between policy commitments to science, technology, education, research and development and innovation (spanning many ministries), supported by legislation (e.g. *Encouragement of Industrial Research and Development Law*; *Law for the Encouragement of Capital Investment*) and regulation through the National Council for Research and Development.

Neither Brazil, Argentina or Portugal have national STEM-specific policies; rather they focus on enhancing the quality of education, industry, and science and technology generally. For example, the Brazil *Education Development Plan 2011-2020* focuses on improving school education through enhanced teaching quality and teacher career pathways. Argentina's national policies focus on research and development, and industry-specific development (such as Biotechnology and Engineering), such that the *Bicentennial Strategic Plan (2006-2010)* seeks to foster research and innovation, and general scientific capacity, and *Biotechnology Multi-Year Plan for Science and Technology* and *Strategic Plan for Science, Technology and Innovation 'Bicentennial'* promote biotechnology and engineering industry-sector development. Portuguese national policy is clearly focused

on quality education, with the *Technological Plan* supporting school ICT infrastructure and equipment; and the *Mathematics Plan* nurturing mathematics participation and achievement, as does the *National Action Plan for Science*.

National STEM centres or agencies

There are numerous examples of national STEM centres or agencies established with a specific STEM, or science focus. This includes national centres or agencies established to: provide policy advice to government; communicate science to the public; stimulate public interest in science; support STEM school and technical education and STEM teaching; conduct enrichment activities; undertake STEM-discipline research, frequently involving industry and education research-focused partnerships; undertake research regarding STEM education; or progress a single STEM-related agenda, such as Indigenous STEM science and education. In many instances, such structures perform a number of these functions and involve partnerships between participant and/or networked organisations. Additional information regarding such co-ordination structures is provided elsewhere in this report. (National STEM centres and agencies, and the potential for such approaches in Australia, are discussed in Section 14).

8

School curriculum and pedagogy

Strategies and programs

The consultants' reports provide a wealth of information regarding school curriculum-based initiatives aimed at enhancing both the spread and quality of science and mathematics school education, and building scientific literacy. Most interventions described at the primary and lower secondary level are focused on engaging all students with science and mathematics, partly in order to increase numbers, including under-represented groups, participating in STEM in upper secondary and higher education. We note here that many countries have nationally consistent curriculum (or curriculum frameworks), or standards which inform curriculum development (e.g. *Common Core State Standards* for mathematics, science and English language curriculum in the United States; compulsory National Curriculum for government schools in England, Wales and Northern Ireland; *National Education 9-year Curriculum Outline* and *Senior Secondary School Curriculum Outline* in Taiwan and the *Common Framework for Science Learning Outcomes: Pan-Canadian Protocol for Collaborations on School Curriculum* in Canada).

In many instances science and mathematics or whole-school curriculum reform has concentrated both on content revision and pedagogy reform. In some instances, such as France, curriculum reform has involved 'thinning' curriculum content to afford greater concentration on student development of problem-based and procedural skills. Curriculum guidelines and resources have been introduced in a number of countries to complement curriculum and pedagogy reform. For example, in Japan guidelines have been introduced for compulsory primary and secondary school science and mathematics that focus on content and enhancement of mathematical and scientific literacy and problem solving. In Israel, the Matar science and technology online portal has been developed by the Israeli Ministry of Education and implemented by Tel Aviv University to support school-based science and technology with podcasts, classroom aids and information for school-based research. In other examples, examination or secondary/senior secondary certification-requirements inform curriculum content; for example the United Kingdom Graduate Certificate of Secondary Education (GCSE, year 10 equivalent) requires completion of three science courses, and the National Senior Certificate in South Africa requires completion of mathematical literacy requirements as one of the four compulsory subjects.

The consultants' reports also provide numerous examples of initiatives generally aimed at increasing participation in school-based mathematics and science, or higher education-based STEM disciplines. For example, the United States *Engage to Excel* program aims to increase the number of higher education STEM graduates to 1 million by increasing student engagement and addressing inequitable participation in pre-requisites to STEM study (due to SES, gender, race-ethnicity, income) via diversified pathways to STEM degrees. In South Africa, strategies include addressing the performance of historically disadvantaged learners by providing high-quality science, mathematics and technology education. General and racial transformation-based strategies also focus on increasing the pass rate for year 12

physical science and mathematics to support increased transition of disadvantaged learners from school to university. In Western Europe, strategies that increase student engagement and promote positive attitudes to science and mathematics are employed to support increased student participation. Strategies identified in various international agency reports include: allowing students to re-enter the STEM pathway; understanding student choices; predicting STEM labour market requirements; information for students; student contact with STEM professionals; and collaboration between stakeholders (including international collaboration between organisations, policy makers, professional bodies, educational institutions and interested parties).

Curriculum – strategic focus, aims, structure

In framing curriculum in mathematics and science, the different countries strike a balance between competing choices:

i. *Curriculum focus:* Between focusing on core science and mathematics disciplinary concepts, or on generic competencies such as problem solving, creativity and flexibility in thinking.

ii. *Focus on all students or a STEM elite?:* Between focusing on science and mathematics for all students, or catering for an elite through streaming or specialist schools (see also Section 5).

iii. *Content breadth and depth:* Between a comprehensive curriculum focused on a wide set of concepts, or a pared back curriculum focused on disciplinary depth and competencies.

iv. *School and teacher autonomy, and accountability regimes:* Between effecting improvement in mathematics and science provision through tight accountability regimes, or through supporting local autonomy and innovation in curriculum, pedagogy, and enrichment processes.

v. *Curriculum structure:* Between the relative effectiveness of invigorated curriculum content, or restructured curriculum.

vi. *Pedagogy:* Between traditional teacher-centred pedagogies focusing on broad conceptual knowledge transmission, or student-centred pedagogies focusing on critical and creative thinking.

These choices will be discussed in turn.

i. Curriculum focus

A choice that becomes apparent in analysing the curriculum initiatives described in the consultants' reports is that between focusing on core science and mathematics disciplinary concepts, or on generic competencies such as problem solving, creativity and flexibility in thinking. In the first case, there is a concern to support high level curriculum content knowledge as part of the agenda to improve a country's standing on the PISA or TIMSS assessments. In this case, teacher disciplinary qualifications are a key focus. In the second case, the argument is grounded in the desire to have STEM education serve the economic imperative to innovate, consistent with a focus on research and development and industry start-up strategies. The second approach might also facilitate the mobility of STEM graduates across a wide range of occupations, enhancing the generic role of STEM programs.

The Asian countries in the present study, all very successful in PISA and where disciplinary knowledge is held in high esteem, report a shift in focus towards nurturing generic skills of creativity, problem solving, collaboration and higher order thinking. Part of this shift relates to a perception that teaching and learning in classrooms is too teacher-focused and does not allow students to develop the creativity and problem solving skills that will drive innovation. Part of it is a feeling that the more individualistic education commitments of the West have been successful in driving innovation.

In North America and Europe, as in Australia, this focus on higher order skills is expressed in a commitment to inquiry in science, and problem solving in mathematics. Inquiry, it is argued, is an approach that should lead to enhanced student engagement with ideas in science. Here again there is a tension between content coverage, and a skills focus. In the United States alongside a commitment to inquiry in science there is a parallel commitment to the development of rigorous science and mathematics standards and assessment. The two foci are not inherently contradictory – the issue concerns emphasis, and whether 'rigour' is conceived of primarily in terms of mastery of a standard set of content prescriptions, or in terms of capacity to use science and mathematical ideas and processes flexibly in novel situations. One cannot imagine the development of strong problem solving skills in mathematics, separate from deep knowledge of conceptual ideas.

The key issues relating to balancing these foci are pedagogy (discussed in sub-section vi. Pedagogy) and assessment. In the 2015 PISA round, collaborative problem solving will be a significant dimension.

Korea has developed a decisive curriculum response to a perception that students were not finding the STEM curriculum engaging, and that the curriculum was not addressing the objective of creativity. Korea is especially concerned about teaching strategies and approaches, and determined to improve the creativity, artistic and innovative flair of students in STEM employment. Towards this end the country has developed a 'STEAM' curriculum with the creative 'Arts' embedded in STEM to enhance student engagement and encourage creativity. This is intended to emulate the philosophy of past Apple CEO Steve Jobs, that infinite imagination and divergent thinking, more than technological advances or industrial structures, define success in technology, including engineering and engineering design, and innovation in science. The STEAM 'movement' also exists in the United States.

A further curriculum innovation mooted in a number of the reports is the introduction into students' school experience of information or activities that open up knowledge about STEM professional work (see the United States consultants' report, and many reports on

strategies of linking students with scientists or scientific practices). This is consistent with a substantial literature pointing out that students make choices regarding STEM subjects largely in ignorance of the varied nature of work and career trajectories undertaken by STEM professionals. It is consistent also with the perspective on identity as a key frame for student choice.

This concern with lack of awareness of STEM professions has been strongly expressed in relation to engineering, and mathematics, which tend to be invisible to students compared to their knowledge of doctors, or even research scientists. Responses to this have included putting students in touch with STEM workers, better representing authentic STEM experiences in classroom activities, or including stories about STEM work as part of the curriculum. These strategies are already being pursued in Australia through the 'science as a human endeavour' dimension of the curriculum, or the many schemes linking scientists with schools.

The Korean example of including creative arts in STEM proffers a potential advantage in introducing more explicit creative design work into the science curriculum to develop students' problem solving capabilities. The creation for instance of models and representations to interpret phenomena and solve problems is central to scientific knowledge building practices, and has precedents in innovative science education practices (Ainsworth, 2011). Such design work could be used to raise the profile of engineering design in the science and mathematics curriculum. Ways should be investigated of including creative work in science and mathematics teaching and learning, similar to explorations common in art and design curricula. This approach would be particularly productive during the primary and lower secondary years when students' identity commitments are being formed.

While in the consultants' reports there are no descriptions of an explicit design/engineering focus in the science curriculum, engineering is included in some vocational courses, for instance in Germany and in Singapore. Given the importance of design in STEM work, and

the relative invisibility of the work of engineers at school level, there exists an argument for incorporating technology design work as part of students' science experience. This would imply, in time, a modification to the science curriculum, but with imagination it could be productively incorporated into the current curriculum as part of scientific and mathematics problem solving and investigative practice. The recent framework for science education in the United States developed by the National Academies of Sciences, and Engineering, the Institute of Medicine, and the National Research Council, listed as major dimensions 'Scientific and Engineering Practices' and in the disciplinary core ideas listed 'Engineering design' and 'Links among engineering, technology, science, and society'. The inclusion of design tasks in science and mathematics curricula is consistent with the Korean focus on creativity and innovation, described above.

ii. Focus on all students or a STEM elite?

A second choice evident in the consultants' reports is between focusing on 'science (and mathematics) for all', and catering for a STEM elite engaged in high performance learning, through streaming or specialist schools. This balance was discussed extensively in Section 5. We will not reiterate the arguments, except to again make the point that these foci are not inherently contradictory, and the consultants' report systems where the two elements are held in balance. It seems likely that a well-developed STEM policy will place greater emphasis on one or other of these approaches at different levels of education.

iii. Content breadth and depth

A third choice is between a comprehensive curriculum focused on a wide set of concepts, and a pared back curriculum focusing on disciplinary depth and competencies. As noted in Section 5, Japan went through a period of cutting back content prescription to emphasize what they called a more 'relaxed' curriculum with room for students to develop autonomy and wider skills. However, falling PISA results

led to a reinstatement of curriculum specificity. The Asian consultants' reports all raise this issue of abstracted content coverage and the associated lecture style classroom practice, and a greater focus on skills supporting innovation, implying more student-centred pedagogies. In Western countries there is a different formulation of essentially the same issue, with a universal commitment to inquiry but a teaching force and assessment regimes focused on traditional content coverage. In both Asia and Europe there is a strong focus on teacher professional learning to support changes in curriculum focus. What is perhaps missing is a sharp conception of what 'rigor' might mean in an environment where disciplinary literacies in support of reasoning and problem solving are balanced against a need for comprehensive conceptual fluency.

If performance on PISA is valued then strong disciplinary commitments are essential. The task is to pursue higher order reasoning and other generic competencies through a strong focus on problem solving competencies of the discipline. Investigative skills and problem solving, creative approaches to investigation and design must be conceptualised as core disciplinary competencies. In analyses of the characteristics of Australian mathematics lessons in the 1999 TIMSS video study, Stacey (2003) coined the term 'shallow teaching syndrome' to describe the combination of low procedural complexity of problems, high proportion of repetition, and absence of mathematical reasoning in classroom discourse that constituted the practices in Australian lessons. Teaching strategies that emphasise problem solving and reasoning must be underpinned by commitment to deep disciplinary knowledge. This implies a program of mutually supportive initiatives that focus on curriculum framing, assessment, and teacher professional learning in both disciplinary and pedagogical knowledge.

Key finding 8.1: Inquiry, reasoning, and creativity and design in STEM curricula

Many comparator countries with strong STEM agendas and results have a well-developed curriculum focus on innovation, creativity and reasoning, accompanied by a strong commitment to disciplinary knowledge. In relation to school curricula, teaching, learning and educational policy and organisation could usefully address elements such as:

- Strong disciplinary frameworks, noting that disciplinary thinking and disciplinary literacies are central to creative problem solving in STEM-related learning and work.

- At the core of learning, methods of problem solving, inquiry, critical thinking and creativity, all of which can enhance both students' attitudes to, and practical competencies, in STEM fields.

- Design tasks into school science and mathematics curricula, in order to support the development in students of problem solving skills, flexibility in thinking, and awareness of engineering design activities.

- Consideration of the inclusion of the visual and performing arts alongside strategies and programs designed to enhance the orthodox STEM-related disciplines, as in the successful STEAM policy in Korea.

- Development of assessment regimes that support the commitment to problem solving, inquiry-based approaches, critical thinking and creativity.

iv. School and teacher autonomy, and accountability regimes

A fourth choice concerns whether to effect improvement in mathematics and science provision through the development of tightly prescribed standards supported by high stakes accountability regimes, or through supporting local autonomy and innovation in curriculum, pedagogy, and enrichment processes. These different approaches are evident in the reports, often within one country. In the United Kingdom, for instance, there has been a high stakes accountability regime for some years, driven through the national curriculum and associated testing, as well as many projects supporting local enrichment activity.

There was discussion in the United Kingdom consultants' report about the longer term effects of such accountability regimes and approved teacher professional development involving prescriptive teaching approaches. Evidence is presented in the consultants' report that over time this has reduced the professionalism of teachers, the richness of teaching approaches, and the quality of student experiences.

This argument is supported by the Finland consultants' report, which emphasises teacher quality and autonomy, the 'trusting' of teachers, and local collaborative curriculum design and teaching approaches. Finland outperforms almost all other countries in PISA paradoxically whilst not paying attention to testing regimes.

This is consistent with experience in the United States. Au's (2007) extensive meta-analysis of all relevant assessment related studies concluded that high stakes testing leads to a more fragmented curriculum and a transmission-dominated pedagogy. Au further argued that this approach tends to lead to performance learning by students, motivated by extrinsic rewards rather than inherent interest in the subject itself.

It is clear from the consultants' reports that the predominant approach to increasing student engagement with STEM involves enriching students' mathematics and science learning experiences through local initiatives, and increasing teaching quality through coherent training and professional development rather than accountability regimes. The many projects spawned by concerns about STEM participation, while often centrally planned, are diverse and supportive in nature rather than constrained and standards driven.

In Australia, partly because of the state-based nature of education, there have been a wide variety of approaches to curriculum and teaching and learning developed within relatively discrete systems. The Australian Curriculum offers an opportunity for greater dialogue between States and Territories, and cooperation concerning innovation in assessment and support of teachers. The lesson from the consultants' reports seems to be that accountability regimes that are put in place to encourage consistency should strike an appropriate balance between the need to support teacher and school professionalism and the opportunities offered by local context. The consultants' reports raise serious questions about the narrowing and de-skilling effects of too prominent an emphasis on the accountability side of this equation.

In framing approaches to increasing student engagement with STEM pathways the emphasis should be on developing initiatives that support and enrich students' and teachers' experience and knowledge, allowing for local character and teacher/school autonomy. The Australian Curriculum provides a framework to clarify purposes and outcomes, and would be inappropriately used as prescribing a tightly constrained set of experiences. Instruments should be developed to explicitly clarify and support approaches to school science and mathematics that are known to engage students in quality learning.

While assessment and accountability measures are important to track progress, they should not invite comparisons between schools or teachers, since this has been shown to have the effect of de-skilling teachers and narrowing the experience and motivation of students.

v. Curriculum structure

A fifth choice apparent in these reports is the relative effectiveness of increasing participation in science and mathematics through invigorated curriculum content, compared with restructured curriculum. While there is a lot of focus on curriculum content as the key to improving STEM engagement, the United Kingdom consultants' report argues that the greater influence over time on participation in science and mathematics is the changing structures of choice in school subjects. In the United Kingdom there has been a marked increase in science participation at General Certificate of Secondary Education (GCSE) with the introduction of double and triple unit science. However, recent analysis (Banner et al, 2010) failed to find evidence of the hoped-for increased social mobility aimed at by the reforms, finding instead that the increased diversity of provision of science offerings may be leading to increasingly stratified student take up, particularly with regard to gender, and SES. Structures vary widely between the different countries. There are very different patterns of subject choice and compulsion, and in the structure of curriculum and the place of vocational studies and academic studies, and articulation between these and into higher education.

vi. Pedagogy

All of the advanced industrial countries comparable to Australia (United States and Canada, United Kingdom, Europe, Asia) favour similar kinds of curriculum reform, shifting from a heavy content focus in science or an instrumental approach to mathematics, towards inquiry, problem solving, creativity and critical skills. Correspondingly, all these countries are focused on establishing pedagogies that are student-centred and inquiry based, with support for a variety of student competencies.

Most of the consultants' reports discuss widespread reform of pedagogies in school-based science and mathematics curricula. In high-performing Asian countries such as China, *New Curriculum Reform* involves the incorporation of inquiry based, creativity-focused, student centred learning with reforms supported by textbook revision, teaching resource material preparation and teacher professional development. Similarly in Singapore, the *Teach Less, Learn More* and *Thinking Schools Learning Nations* initiatives involve moving away from the traditional dependence on rote learning and repetitive tests to discovery-based, student-centred learning that engages students and promotes lifelong learning. Many countries in Western Europe have embraced inquiry based education, particularly with respect to science education, and learning which involves real-world contexts. Others actively encourage evidence based or empirically-validated teaching strategies including France and the United States.

Several consultants' reports explicitly referred to the role of information technology in school education, either generally, or with respect to science and mathematics specifically. For example, in New Zealand ICT-based initiatives include the Laptops for Teachers scheme, School Network Upgrade Project, rollout of ultra-fast broadband, e-learning teacher fellowships and the Virtual Learning Network. In Portugal, the Technological Plan supported the introduction of high-speed internet access in schools, purchase of IT equipment including laptops, development of portals for sharing digital resources, and projects such as the Virtual School and Mobile

School. ICT use is encouraged throughout the curriculum. While ICT use is referred to frequently in descriptions of initiatives, there was not sufficient depth to these descriptions to allow a close analysis of the impact and success of these, that would significantly inform Australian practice. These reports could be usefully mined to provide the basis for a more in depth study of comparative ICT innovation to potentially inform Australian ICT strategies for STEM.

The 'problem' is mostly cast as a traditional curriculum and teaching approach that fail to excite students. The solution is a focus on developing teachers' capacities to enact new pedagogies in the face of considerable inertia in practice. In China the issue of traditional lecture style teaching is explicitly described, and policy is framed in terms of the need to support teachers through developing resources and supporting teachers to be more responsive to students' ideas. In Japan there is an established system of discussion of lesson designs based on eliciting and working with students' ideas. The issue, therefore, of establishing engaging student-centred teaching and learning approaches looks different depending on the prevailing culture in the country. In traditional Chinese culture the status of the teacher, the tradition of transmission of highly valued abstracted knowledge, and the preference for theory over practice, places particular challenges for pedagogical transformation.

These sought after pedagogies emphasise competencies in problem solving and scientific investigative process, and higher order thinking. The argument is centred on the curriculum objective of developing a workforce that will support innovation in research and development, and be flexible in the application of skills. This flexibility is particularly important in late modern societies where the notion of a committed career within a single workplace has given way to requirements for youth to develop a portfolio of skills and experience to confer advantage in a variety of positions.

A key argument in favour of this policy approach is the fact that STEM graduates often find themselves in work only tangentially related to their qualifications. These arguments are consistent with findings in the research literature that scientific workers utilise their knowledge of scientific processes and their analytical skills built around scientific methods, more so than explicit conceptual knowledge that they often learn on the job (Duggan & Gott 2002).

Australia has a long standing commitment to inquiry based and problem solving pedagogies and scientific and mathematical literacy aims. Australian educators have been at the forefront in promoting these ideas internationally. The problem, however, lies in the inertia of schools and teachers in adhering to traditional teaching approaches. This situation is reinforced by strong traditions of assessment that fail to support curriculum and pedagogy intentions, maintaining a focus instead on testing comprehensive coverage of concepts at a relatively low level of reasoning and problem solving. The situation is often exacerbated, particularly in mathematics, by the number of out of field teachers in mathematics classrooms. Such teachers often do not choose to attend professional development events in their out of field subject.

Based on the experience of other countries with comparable reform agendas, the solution must lie in dedicated teacher professional development in conditions that support significant changes in orientation and belief in relation to teaching in mathematics and science. The professional development of teachers in science and mathematics is discussed further in Section 9.

9 | Teachers and teaching

The consultants' reports identify a large number of strategies and programs focused on STEM teaching excellence. These include teacher education focused initiatives, teaching career and school structure considerations such as leadership, teacher input into school decision making, classroom autonomy, teaching standards, and rewarding the best STEM teachers. Reports also focused on teaching resources, including science and mathematics projects, teaching and instructional materials and best practices, teaching tools, innovative teaching methods/pedagogy, curriculum materials, and assessment resource banks. In addition the consultants' reports identified professional development opportunities, including general learning and discipline-specific continuous professional development, workshops, higher education such as Masters programs, peer group projects, in-school lesson evaluation and co-teaching, culturally responsive instruction, funded professional development days, teacher visits to industry; and highlighted the importance of teacher networks, and the value of teachers undertaking and showcasing education research.

Teacher status, training, continuous professional development and career trajectory

Most consultants' reports provide information describing processes and issues around the teaching profession itself, including recruitment and training, continuous professional development, career structures, and the nature and quality of teaching. Teacher credentialing emerges as a significant issue in countries with a low education participation base, such as South Africa or Brazil. In advanced countries the United States stands out as the country significantly concerned with teaching quality, with the issue tending to be characterised in terms of teaching workforce quality. In Australia there has also been a robust discussion at government level and in the media concerning the quality of Australia's teaching workforce, with some emphasis given to 'failing teachers'. This seems ironic given the scores of Australian students on the PISA and TIMSS science and mathematics tests ahead of a number of countries in which teachers are held in high regard.

In Asia a primary concern in relation to STEM is retraining teachers to support the introduction of new pedagogies, with no implications for an essentialised notion of teacher 'quality'. Teachers are highly respected in East Asia and Singapore, a phenomenon that is customarily associated with Confucian traditions. The Finland consultants' report also emphasises high respect for teachers and trust in their professionalism. There are many references to the high entry conditions and status of teachers in European countries and also the United Kingdom. Thus, in most of the reports, the focus on teachers relates not to any lack of professionalism or competence, but to a need for re-training implied by the significant changes in pedagogical approach being promoted – towards inquiry, reasoning and problem solving, and a wider skill set generally – away from traditional conceptions of school science and mathematics. There is general acknowledgement of the significant nature of this shift, and of the time and resources needed.

A number of the consultants' reports emphasised, through descriptions of teacher focused programs, the need to involve teachers in these changes. One difference that is apparent in comparing the consultants' reports is the level of commitment to a specific disciplinary program supported by teachers trained in that discipline. In much of Europe and in China the sciences are taught as distinct disciplines at secondary level, compared to Australia's integrated curriculum. Australian teachers are thus required to be more flexible in dealing with knowledge outside their major discipline area. Further, science teachers in China almost always teach in their science major discipline area. The difference also shows up in the teaching of science and mathematics in primary schools by specialist teachers. The structural elements of the curriculum, and the manner in which teaching labour is trained and deployed, impact disciplinary commitment and depth.

In the consultants' reports a number of inter-related differences relating to teachers stand out:

- The entry level for teachers is high in many countries, and entry into teacher education is very competitive compared to Australia. In Finland a discipline-specific Masters degree is required. In China and other countries teachers increasingly have higher degrees.

- In most European and in Asian countries teachers enjoy high status. This was explicitly emphasised in the Finland, French, Chinese, Korean, Japanese, and Singapore consultants' reports. Status is in each cased framed within a number of facets of the culture, including public respect for theoretical knowledge, perceptions of the importance of education for social betterment, and professional conditions. Another facet is balance of commitment to community values as distinct from individualistic approaches. In China there is a strong belief in knowledge as a communal good, and teaching is seen as having the important function of transmitting communal knowledge. This is in contrast to the lower status of transmission of knowledge as compared to its production in the United States and other English-speaking countries.

- There are major differences in the organisation of continuous teacher professional development and the degree of autonomy in planning teaching and learning. Continuous professional development is built into teacher career trajectories in many countries, and school based autonomy and teacher collaboration is a strong aspect of Asian systems and many European countries, including Finland.

- Related to continuous professional development is teacher career structure. The link is more obvious in some countries than others. In China, teaching standards and career structures are linked explicitly to professional development. To be promoted to a higher salary level teachers must participate in mandated subject-based professional development – not generic professional development as often predominates in Australia – and achieve a higher standard of performance in teaching their discipline. In Singapore there are emphases on mentoring and continuous professional development and a career structure based on professional growth, including a strong focus on potential leaders. The Singapore consultants' report was the only report that specifically mentioned performance bonuses as part of the suite of measures. The consultants' reports indicated that other countries framed teacher rewards as part of an orderly career structure.

- There were few instances mentioned in the consultants' reports of teaching in discipline areas for which teachers were not trained. The United States consultants' report and the Brazil consultants' report were exceptions. The phenomenon of teaching out of field is much discussed in the United States consultants' report and research literature (Hobbs, 2012). In Australia teaching out of field is a major problem. An ACER study found that in years 7-10 mathematics, only 61.5 per cent of teachers had two or more years' tertiary mathematics (the minimum required to teach mathematics subjects in most countries). Thus more than one third, 38.5 per cent, were teaching out of field, and 23.3 per cent had no tertiary mathematics at all (McKenzie et al,

2011). The *Mathematics, Engineering & Science in the National Interest* report of the Office of the Chief Scientist (2012b) found that of teachers teaching years 7-10 mathematics, 24 per cent of those working in metropolitan schools and 31 per cent in provincial towns have no mathematics training at university level. Of those teaching mathematics at years 11-12, 12 per cent in metropolitan schools and 16 per cent in provincial towns had no mathematics training at university level. These problems are less likely to occur in schools serving high SES families. Faced with staffing shortages 46.7 per cent of government school principals require teachers to teach out of field and 57.3 per cent of Catholic school principals, compared with only 14.3 per cent of independent school principals. There are similar, if not quite so pressing, concerns with science teachers, especially in the physical sciences. While senior school physics and chemistry teachers are predominantly qualified and experienced, the majority of teachers of science across the 7-10 years are biology trained (Goodrum et al, 2012). Mathematics teaching out of field is a very serious deficiency in Australian education (ibid, Tables 2.3.6 and 2.3.1).

- The United States consultants' report described at least one initiative involving differential pay for mathematics and science teachers consistent with their earning power outside of schools. There were no other references to differential pay scales in the consultants' reports.

- The United Kingdom consultants' report described how devolution of professional development provision to schools had decreased access to professional development in science and mathematics in favor of professional development on a whole school basis. This corresponds with findings in the Australian research literature (Tytler et al, 2011). In an era focused on literacy, numeracy and general education, science professional development provision in particular has suffered.

Key finding 9.1: Career pathways for STEM teachers

STEM-strong comparator countries have in common the high status of teachers, and high entry level into the profession.

9.1.1 Strong STEM performing countries particularly in Asia have meritocratic career structures that recognise teaching excellence. Australia could develop a specific and integrated career pathway for mathematics and science teachers, one that would be common to all schools and based on teaching effectiveness, innovation and leadership closely tied to recognised continuous, discipline-based professional learning. The Australian Professional Standards for Teachers, developed by the Australian Institute for Teaching and School Leadership (AITSL), provide one possible basis for such an approach.

9.1.2 Higher degrees for teachers are a feature of some high performing countries such as Finland. Australia could consider the scheme put forward by the Academy of Science to attract PhD graduates in mathematics and science into a teaching career. The Academy has recommended that:

> … enhanced career pathways be established to promote the recruitment of science PhD graduates into teaching. This would provide an alternative path for PhD scientists who wish to move out of research careers. It would also ensure that schools have science teachers who are not only passionate about science but are able to draw on their research skills and expertise to engage students in 'learning by doing' – an approach which has already been shown to increase student performance.

These comparisons represent key findings, and have important implications for how best to support teachers to develop and implement new practices. The structure of the reports did not allow for in depth analysis in each country's conditions regarding, for instance, teacher career pathways and support structures for professional learning. The literature contains, however, comparative analysis on some of these issues (see for instance the Jensen et al., 2012 Grattan Institute report "Catching up" comparing Australian practices with high achieving Asian countries).

Career pathways and salary scales

It is often argued that the status of teachers in Australia needs to be lifted, and that entry into the teaching profession should be more competitive. The consultants' reports strongly confirm Australia's disadvantage in this regard. However, there is nothing in the consultants' reports, or particularly the international comparisons, to indicate that Australian teachers are less professional than teachers in these countries. Nevertheless, teachers in some high performing countries have a number of advantages over Australian teachers in their levels

Key finding 9.2: STEM-specific salaries

There are a few examples of differential salaries or incentives for teachers in the STEM area to attract and retain science and mathematics teachers particularly in hard-to-staff schools.

9.2.1 One possible incentive strategy is to provide higher rates of pay for teachers of mathematics and science with honours or higher degrees.

9.2.2 Another possible incentive strategy is to provide bonus starting pay for mathematics and science teachers at schools in low SES schools and regional and remote schools, similar to the United Kingdom's 'golden welcome' scheme.

Key finding 9.3: Discipline-specific professional development in secondary education

A strong feature of some international jurisdictions is the development of an evidence based national approach to professional development of mathematics and science teachers. In high performing Asian countries in particular there is a strong tradition of school-based professional learning through collaborative planning.

9.3.1   One way to strengthen depth of content in STEM at school level is to engage secondary school-level science and mathematics teachers in sustained discipline-specific professional development programs, focused on pedagogical content knowledge and content knowledge that are not part of generic professional development programs common to all teachers.

9.3.2.   Professional development for teachers of mathematics and science could support teachers in the implementation of the Australian Curriculum in Science, Mathematics and Technologies, and include, as key characteristics:

- an evidence-based approach

- use of international experience, and experience at state level

- a framework linking professional development with the acquisition of higher degrees in mathematics and science education, supported by financial incentives.

9.3.3   Consistent with the findings summarised in Sections 5 and 8, discipline-specific professional development could address methods of problem solving, inquiry-based approaches, critical thinking and creativity, and other methods designed to increase student learning and engagement with science and mathematics; and also take into account the diversity of the student population and the need to enhance inclusion and performance among students from social groups presently under-represented in STEM (see Section 5).

of training (e.g. the Masters as a threshold degree in Finland, and less instances of teachers teaching out of field compared to Australia), in achieving high professional levels, and in accessing support for improving practice on a continuous basis.

Professional development of teachers of mathematics and science

A strong feature of some international jurisdictions is the development of an evidence based national approach to professional development of mathematics and science teachers. The starting point here is recognition that it is crucial that professional development is centrally concerned with discipline-based programs, rather than being predominantly programs generic to all teachers (Tytler et al, 2011). The approach to professional development

should be tailored to supporting teachers in the implementation of the Australian Curriculum – Science, Mathematics and Technologies. In addition, professional development could be linked to the development of higher degrees in mathematics and science education supported by financial incentives for teachers.

Australia has a low incidence of primary school teachers with major studies in science or mathematics, compared to our major comparator countries. The United Kingdom has established a national program of training for specialist teachers of primary school mathematics who take leadership responsibility for the teaching of these subjects in their schools. Experience in Australia supports the notion that an enthusiastic and knowledgeable science or mathematics teacher within a primary school can play an important

role in increasing the quality of curriculum and pedagogy. Victoria is currently trialling this approach for both mathematics and science, and the evaluations to date have been very positive.

Teaching 'out of field'

The incidence of teaching out of field for mathematics and science in Australia, especially in regional and rural areas, indicates an urgent need to attract more qualified teachers into the profession. It is unacceptable to have teachers in front of classes who do not have the requisite knowledge and skills to inject enthusiasm and knowledge. The possibility of coherent planning is limited, given that the government does not collect figures on the number of teacher education graduates in the specific science and mathematics areas they are qualified to teach.

10 | The R&D workforce

Government research strategies and funding arrangements are often STEM, or science and technology, specific. For example, the Canadian *Mobilizing Science and Technology to Canada's Advantage,* (2007) report established a strategy for science and technology research involving: the development of national advantages (entrepreneurship, knowledge, and people); increasing private-sector investment in science and technology; sustaining the public standing of science and technology; and providing funding for science and technology students and researchers. The Canadian strategy is implemented via science and technology research funding agencies including the Tri-Council Granting Agencies. The Canadian Industrial R&D Internship Program involves tripartite arrangements between universities, industry and government to support world-class research and graduate research students and post-doctoral fellows, and foster technology-transfer between universities and industry.

In Israel, students excelling in science and mathematics are encouraged and supported for example, through the Atuda (academic reserve) program and Talpiot program, several of which integrate academic studies in science and

defense-related research and development. The consultants' reports identified a series of initiatives to increase participation of indigenous university students, including scholarships, mentoring, internships, supplemental instruction, bridging programs, and preparation for pre-requisite science and mathematics courses. In Japan, internships are offered for doctoral students, and programs are run which target science and technology honours students. More generic in nature, the South African *R&D Strategy* (2002) identifies government initiatives aimed at enhancing science and technology research and development through tax incentives, competitive grant funding, the Research Chairs Initiative, Centres for Excellence, and Competence and support for 'big science' (such as the successful bid with Australia for the Square Kilometer Array radio telescope).

Perhaps the principal aspect of these policy approaches is strategies and programs for forming, attracting and retaining high-skill human capital in the STEM disciplines.

Doctoral training in STEM

The majority of the consultants' reports for specific countries focus on the supply of STEM doctoral graduates. For the most part nations with developed or emerging research capacity are increasing doctoral graduates in STEM more rapidly than STEM graduates at first-degree level. Further, in many countries doctoral graduates in the STEM disciplines are increasing faster than doctoral graduates in other fields. For example, between 2002-2003 and 2009-2010 in the United Kingdom, Higher Education Statistics Agency data show that total non-STEM PhD qualifiers increased by 4 per cent while STEM PhD increased by 8 per cent. Numbers in mathematics increased by 21 per cent, in physical sciences by 9 per cent, computing by 6 per cent, and engineering and technology by 6 per cent. There were falls in biological sciences and medicine. Between 2005 and 2010 the number of PhD graduates in Canada increased by 31 per cent overall but 39 per cent in mathematics and statistics, 48 per cent in the physical sciences, 65 per cent in engineering, manufacturing and construction, and 134 per cent in the life sciences.

Between 2005 and 2009 Australian doctoral graduates increased more rapidly than in the United Kingdom, slightly faster than in Korea but less rapidly than in the United States and Canada.

The supply of doctorally-trained STEM personnel is essential to both national research effort and the reproduction of the research university systems that provide most of the education in the STEM disciplines at degree level. However, national research capacity and the Australian research and development and innovation system are discussed only briefly in this report. These elements are not specifically included in the terms of reference for this project, and arise elsewhere in the SAF program and in government consideration.

Table 13: Doctoral graduation rates, select countries, 2005-2009

Country	2005	2009	Growth 2005-2009
Canada	4,116	5,440	32.2%
United States	52,631	67,716	28.7%
France	9,578	11,941	24.7%
Australia	4,886	5,808	18.9%
South Korea	8,449	9,912	17.3%
United Kingdom	15,778	17,651	11.9%
Japan	15,286	16,476	7.8%
Germany	25,952	25,527	-1.6%

Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators,* OECD Publishing, Paris.

Among the matters discussed by the consultants:

- Universities in the United States implement a range of strategies to attract 'world-class' domestic and international students, early career researchers and researchers.

- In China engineering, which is overwhelmingly dominant in national research funding, is much the largest field of STEM doctoral training. Between 2005 and 2010 the number of entrants to doctoral programs increased by 14.3 per cent in engineering, 19.6 per cent in natural science and 25.7 per cent in agriculture, though it declined by 4 per cent in medicine.

- In Taiwan in 2011, 13,248 of the 33,686 doctoral students (39.3 per cent) were enrolled in engineering. There were just 4,745 in science and 3,563 in medicine.

- In Korea between 2008 and 2012 the number of doctoral graduates in engineering increased from 2,078 to 3,050 (46.8 per cent) while those in natural science increased from 1,592 to 2,242. Engineering graduates were 25.2 per cent of all doctoral graduates in 2011.

- In Japan 43.5 per cent of doctoral graduates in technologies enter private companies, in contrast to 22.0 per cent in science and 7.9 per cent in health. Concerns about the supply of doctoral researchers, especially in science, have led to government action. The consultant for Japan reports that:

    One of the policies to support career development of young science and technology researchers is a five-year grant for universities and research institutions titled 'Improvement of Research Environment for Young Scholars', started by JST in 2006. The program allocates up to 200 million yen per year to 9-12 universities and institutions. In 2012, total budgets for this program increased to 7.5 billion JPY per year. Selected institutions install a 'tenure track system' in which up-and-coming researchers are given fixed-term employment while they gain experience conducting independent research. Upon passing a strict evaluation at the end of the contract period, these

young researchers are given tenure positions. Although the program is not restricted to STEM fields, it is designated at host institutions as 'research organisations currently striving to become world-class research bases', effectively singling out most universities and institutions with strength in science and technology fields.

    … the 'Young Researchers Training Program for Promoting Innovation' promotes internships for doctoral course students and postdoctoral fellows in private sectors in order to establish a variety of career-path opportunities. The program nurtures highly skilled professionals who are capable of undertaking innovative projects and who can work competitively for Japanese industry in a globalised context. A chief goal of the program is to achieve full uptake of STEM doctoral graduates into the labor market.

- Gender imbalance (see Section 12) is a serious weakness in STEM doctoral training in most countries. For example, in Canada women comprised 44 per cent of all doctoral graduates in 2008, but 42 per cent of those in the physical and life sciences, 26 per cent in mathematics, computing and information sciences, and 23 per cent in engineering, architecture and related technologies. In Taiwan more than two thirds of all doctoral students are men.

In a number of countries there are specific immigration policies designed to augment the supply of doctorally trained labour. Doctoral graduates in STEM often enjoy advantages at the point of immigration. This intention is often in some tension with the restrictive aspect of immigration policies. The United States has several schemes. The consultants' report on STEM in the United States notes that:

    PhD graduates can remain legally and work in the US for up to 12 months beyond graduation on the non-immigrant F1 status. As recently as 2007, for certain STEM fields this period has been extended to 29 months. As of 2011, the list of disciplines eligible for this extension has been expanded.

Under the provisions of American Competitiveness in the Twenty-First Century Act of 2000 annually up to 65,000 H-1B visas are issued to foreign nationals sponsored by US companies. Additionally, each year up to 20,000 foreign nationals with graduate degrees from US universities can be issued H-1B visas. Foreign nationals working in universities and non-profit or governmental research facilities are issued H-1B visas in addition to the first two categories. The H-1B is a dual-intent visa; the employer can file on employees' behalf for permanent residence, the first step toward naturalisation.

In the past two years, several legislative initiatives were discussed. While the two of them introduced in 2011 in the House of Representatives did not get the committees' approval, the SMART Jobs Act initiative, later renamed STEM Jobs Act, co-sponsored by senators Lamar Smith and Chris Coons was approved in December 2012 by the House of Representatives by a margin of 245 to 139 only to be blocked a few days later by the Senate Democrats. The final form of STEM Jobs Act proposed the reallocation of immigrant visas from the Diversity program (popularly known as the Visa Lottery) to highly qualified foreign graduates of American graduates with advanced degrees in STEM fields. Earlier in 2012, another legislative initiative, called the STAR Act, sponsored by Senator John Cornyn, stipulated that STEM graduates working in institutions receiving at least $5 million a year in federal research grants could be granted permanent residence. The legislative project was referred to the House committees, but was not enacted.

The United States consultants recommend Australia should 'Take advantage of the qualified immigrant STEM workforce by providing them with legal pathways to gaining legal residence, while keeping a judicious balance between the STEM workforce trained in Australia (Australian-born and assimilates of them) and immigrants'.

The Canadian Mitacs-Globalink Internship Program supports international undergraduate students studying with Canadian universities and industry research partners. In Japan, the 300,000 International Students Plan aims to attract international students to Japanese research programs, including those in STEM-disciplines, and in Western Europe, mobility is one mechanism to address STEM labour market shortages.

Building World-Class Universities

Several consultants' reports outline government programs and policies designed to enhance the scientific outputs of research universities by building 'World-Class Universities' more highly placed in world rankings of research outputs (see also Salmi 2009). This is an explicit objective of all higher education and research systems in East and Southeast Asia, where World-Class University programs are linked to programs designed to enhance the supply of doctorally-trained research labour and to benchmark local research activity against international leaders. Typically, World-Class University programs involve the designation of a group of institutions for special development, the application of performance targets, and the allocation of specific monies to achieve those targets on an accelerated basis.

In Russia, a presidential target has been established to increase the number of universities ranking in the top 100 universities globally to five by 2020. This target is supported by increased government expenditure on higher education research, stratification of the higher education landscape to concentrate resources and promote excellence, and strategies to attract leading researchers and develop world class laboratories.

China's Project 211 and Program 985 have been much discussed in the world literatures on higher education, and science policy. Project 211 now involves 112 universities. It consists of two major components: the improvement of overall institutional capacity and the development of key disciplinary areas, including the capacity to train high quality research and development labour in fields of research seen as strategically significant. Program 985 initially designated nine universities for development as globally competitive institutions. The number of universities has now

been expanded to 39. Government funding targeted at bringing diasporic researchers back to China makes a significant contribution to university improvement. It enhances the internationalisation of research and pushes research standards closer to those of North America, the United Kingdom and Western Europe.

In Taiwan, the Ministry of Education encourages research universities 'to establish interscholastic (international) research teams or cooperate with research institutions in specialised areas in order to focus human resources and equipment investments, develop key national research areas, [and] assist with the creation of new opportunities for integration of research and development and innovation'. Five of the seven designated research priority areas are in STEM. The consultant for Taiwan notes further that:

> The Ministry of Education is using competitive funding to assist with the creation of research universities with development potential, boost the efficiency of overall university instruction and research, integrate human resources, improve university management strategies, and establish a sound organisational operation system. This project has invested NT$50 billion over five years in twelve universities (the 'T12' universities) to boost their international competitiveness. The T12 universities include both large comprehensive universities (e.g. National Taiwan University) and small, specialised universities – both public and private (e.g. National Yang Ming University, a small university specialising in biomedical research).

The consultant for Taiwan notes that 'the forging of world-class universities and enlistment of outstanding talents' requires a long-term investment approach'. In order to develop internationally competitive higher education institutions and to provide strong incentives for universities to participate, 'the government has promised ten years of funding support. NT$500 million has already been earmarked for the first five-year period'.

South Korea has had a long-standing commitment to building the Korea Advanced Institute of Science and Technology (KAIST) as a strong research and graduate training university. The Brain Korea 21 program was launched in 1999 with a focus on supporting graduate students in science and engineering fields. The World Class University project of 2008-2012 set out to recruit outstanding faculty from abroad, create strong departments and enhance collaboration between Korean and foreign scholars. The emphasis on established foreign faculty was in some tension with Brain Korea 21's focus on local graduate students. However in 2011, the Korean government initiated the Global Ph.D. Fellowship (GPS), which funds doctoral students so that they can focus on their academic studies without concerns about tuition and living expenses. The program aims to educate them at a global level to advance the level of Korean science and technology. The program is ambitious, setting out to prepare highest quality researchers including Nobel laureates.

The next program, Global EXCEL (2013-2019), is closer to Brain Korea 21. It consists of three strands, global leader teams (30 per cent), interdisciplinary teams (10 per cent), and innovative teams for graduate education (50 per cent in the natural sciences and engineering and 10 per cent in the humanities and social sciences). According to the consultants' report: 'The Global EXCEL focuses on supporting graduate students by increasing funding for doctoral students, but eliminating the program for international faculty from the previous WCU project'.

East Asia and Singapore already contain a significant number of universities comparable to the leading Australian research universities in their output of scientific papers and their rate of citation. On both quantity and quality measures the National University of Singapore is ahead of all Australian institutions.

The 2012 Henry review of *Australia in the Asian Century* recommended that the nation seek to achieve ten universities ranked in the world's top 100 by 2025 (Henry et al, 2012, p.171). This objective was endorsed by government when the report was released. However, Australia has allocated no special investment monies to achieve such an objective, which appears to be seen as an institutional responsibility rather than

Table 14: Universities in East Asia, Singapore and Western Pacific by volume of scientific papers, 2005-2009, universities with more than 6000 papers only

Institution	Volume of science papers 2005-2009	World rank on paper Volume	Proportion of papers in top 10% most cited in field
U Tokyo JAPAN	18,382	4	10.2%
Kyoto U JAPAN	14,941	11	9.5%
Seoul National U SOUTH KOREA	13,052	19	8.9%
Zhejiang U CHINA	13,037	20	9.1%
Osaka U JAPAN	12,266	25	8.1%
National U Singapore SINGAPORE	11,838	29	13.8%
Tohoku U JAPAN	11,736	30	7.9%
Tsinghua U CHINA	11,478	34	10.8%
National Taiwan U TAIWAN	11,302	35	8.9%
Shanghai Jiao Tong U CHINA	10,683	40	8.2%
U Sydney AUSTRALIA	10,155	45	10.1%
U Melbourne AUSTRALIA	9,724	50	11.9%
Peking U CHINA	9,153	53	10.4%
U Queensland AUSTRALIA	9,088	54	11.8%
Kyushu U JAPAN	8,462	62	6.8%
Hokkaido U JAPAN	8,043	71	6.1%
Yonsei U SOUTH KOREA	7,399	79	7.8%
U New South Wales AUSTRALIA	7,263	82	10.6%
Nagoya U JAPAN	7,203	87	8.1%
Nanyang Technological U SINGAPORE	7,136	90	11.9%
National Cheng Kung U TAIWAN	7,126	92	8.5%
Fudan, U CHINA	7,061	94	11.1%
Tokyo Institute Technology JAPAN	6,932	99	8.3%
U Hong Kong HONG KONG SAR	6,820	103	11.5%
Monash U AUSTRALIA	6,797	106	10.4%
U Science & Technology China CHINA	6,789	107	13.0%
Nanjing U CHINA	6,584	114	10.7%
Shandong U CHINA	6,087	130	7.6%
Chinese U Hong Kong HONG KONG SAR	6,029	131	10.1%

Source: Leiden University 2012, *Leiden Ranking 2011/2012*, viewed 19 March 2013, http://www.leidenranking.com/ranking.aspx.

a national one. The Australian government has not been willing to create a special category of high achievement research universities for the purposes of funding and administration. It generally applies a 'one-size-fits all' approach to policies on, and funding of, all universities on the public schedule. Accordingly the 'World-Class University' policies of Australia's East and Southeast Asian neighbours, while constituting a powerful shaping force in the enhancement of regional research capacity, have no specific implications for Australian policy at this time.
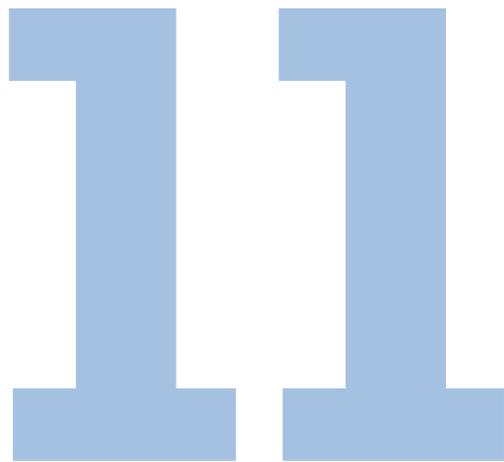
11 Labour markets and STEM

All consultants preparing national and regional reports were asked to furnish data on the take-up of STEM-qualified graduates in the labour markets, and reflect on issues of shortage/oversupply and the matching of graduate skills and knowledge with the needs of employers. Most consultants were unable to respond to this request at the expected level of detail. In many countries there is a lack of relevant data. In most countries government does not directly regulate the education-employment relation, though it regulates education. Therefore data are much stronger in relation to the output of graduates than the use of graduate labour. Further, while some countries such as Australia collect information on the broad sectors where graduates by discipline are employed, the practical relationship between education and work, especially the deployment of skilled labour in the workplace – the manner in which, and the extent to which, graduates' human capital is utilised at work, industry by industry, in the short- and long-term – remain largely a 'black box' for research. There is much scope for work in this area.

Nevertheless, some consultants did provide suggestive data. The reports on the United States, United Kingdom and Korea stood out. Some consultants' reports identified the transition from further education to employment as a potential source of 'leakages' in the STEM 'pipeline'. For example, in the United States, the National Science Board recommended that the National Science Foundation create a 'roadmap' to improve STEM education from pre-kindergarten to college. In Singapore, career service centres provide guidance for students through career counselling, careers fairs, industry visits, online recruitment services and information resources. In Japan transition support is provided for university STEM-discipline graduates and post-doctoral researchers seeking permanent employment in STEM research positions.

We also commissioned a report by the National Institute of Labour Studies (NILS) at Flinders University, on 'The STEM labour markets in Australia'.

International findings

The research literature on STEM and national (and global) labour markets is driven by varying assumptions, and has varying and often contradictory findings. Much of the discussion focuses on shortages of STEM-related skills. One characteristic of the shortages literature is that potential and predicted shortages tend to exceed actual and measured shortages. Other

evidence suggests that the main employment growth is likely to be occupations that do not specifically require STEM-related skills (though we note that some such jobs are likely to be filled by STEM-educated workers). A recent EU Skills Panorama (European Union, 2012) forecasts demand for STEM-related occupations in the period 2010-2020. These estimates are taken from a 2012 report on skills demand and supply by CEDEFOP for the 27 European nations. This suggests modest growth and some declines in STEM-specific engineering and manufacturing occupations. There is larger growth in communications, computing and also professional services. The report concludes that: 'Most job opportunities will be in the "other professionals" (which covers jobs such as business and legal professionals), "other associate professionals" (which includes finance and sales associate professionals, business services agents, police inspectors and detectives), as well as "sales and service elementary occupations" (which include street vendors, domestic help) occupational groups' (European Centre for the Development of Vocational Training [CEDEFOP] 2012, p.29).

This perspective is generally consistent with the consultants' reports commissioned for the current project. The report on the United States highlights data provided by the National Science Foundation, probably the most useful single data set anywhere. There were 15.8 million people

Table 15: Anticipated future employment demand in key STEM-related sectors, EU-27 countries, 2010-2020

Sector	2010 ('000s)	2020 ('000s)	Change 2010-2020
Pharmaceuticals	494	493	0.0%
Chemicals not specified elsewhere	1,168	1,169	0.1%
Non-Metallic Mineral Products	1,618	1,549	- 4.3%
Mechanical Engineering	3,453	3,644	5.5%
Electronics	967	980	1.3%
Electrical Engineering & Instruments	2,750	2,780	1.1%
Motor Vehicles	2,208	2,164	- 2.0%
Manufacturing not specified elsewhere	2,204	2,206	0.1%
Communications	3,011	3,156	4.8%
Computing Services	3,040	3,270	7.6%
Professional Services	7,530	8,578	13.9%
All industries	223,219	230,847	3.4%

Source: European Union 2012, *EU Skills Panorama Analytical Highlight*, viewed 21 March 2013, http://euskillspanorama.ec.europa.eu/docs/AnalyticalHighlights/EngineeringProfessionals_en.pdf.

working as US-born scientists and engineers in 2006, which was 10 per cent of the total workforce. Two thirds worked in business and industry where they represented 12.8 per cent of the total workforce. They were also 40 per cent of those employed in the education sector. The consultants note a widespread belief that there is a national shortage of STEM labour, especially for research and development purposes, and this belief has driven policy attention to the area. However, some experts argue that the United States has a surplus of STEM graduates. The consultants also note tensions within the country around the role of immigrant labour, some see immigrant STEM workers as essential to national capacity, while others argue that they drive down wages. Similar debates play out in Australia and in many other countries.

When considering issues of supply and demand, the consultants find that in contrast with the common rhetoric about a shift to knowledge-intensive production at higher levels, generating demand for graduates, most STEM vacancies require a lower level of skills and knowledge than that generally embodied in a bachelor degree: 'Thus technician openings are experiencing a large shortage of applicants, while positions requiring high level skills, at the Bachelor's and graduate levels, are much more competitive'. Second, in part STEM qualifications are generic rather than pointing to specific occupations end-on to the field of training. Some STEM graduates go to non-STEM employment. When doing so they tend to earn higher than average wages. In that respect – the generic function of STEM in the labour markets – it is possible to identify shortage. These findings about generic employability, and relatively strong wages, may have implications for Australia:

> STEM skills are not only needed in STEM occupations, but in other economic sectors as well. Given both the competitiveness of obtaining employment in some of the highly specialised STEM occupations, and the transferability of STEM competencies to other categories of occupations, it seems that part of the STEM workforce diverts into non-STEM – fulfilling demand in those fields, especially when wages offered are higher than in STEM

occupations. Even in non-STEM fields, STEM degree holders earn more on average than non-STEM degree holders … Given this process of diversion and the economy as a whole demanding workers with STEM skills, a picture emerges of a shortage in the available workforce having STEM-related competencies.

The American Bureau of Labor Statistics predicts that in the next decade there will be robust growth of employment in healthcare (29 per cent), computing and IT (22 per cent) and mathematics (17 per cent). In professions requiring doctoral degrees employment is expected to grow by 20 per cent. However, of the 20 detailed occupations that are forecast to have the fastest growth between 2010 and 2020, only three of these occupations require STEM training (biomedical engineers, veterinary technologists and technicians and diagnostic medical sonographers).

The United States consultants' report also focuses on immigration-related schemes that are intended to enhance high skill STEM labour. These issues are discussed briefly in Section 10.

Like the report on the United States, the consultants' report on the United Kingdom notes a widespread belief that the United Kingdom does not have enough science and engineering graduates, and professional scientists. There are also concerns that the quality of STEM graduates may be inadequate. Here the question of demand and need for STEM qualifications turns in part on the economic role envisioned for STEM. Some analyses position STEM qualifications as end-on with STEM-specific occupations. Others, including the Council for Industry and Higher Education (CIHE), see STEM graduates as economically valuable regardless of whether they go into a STEM-specific career or not. In this context boosting STEM is seen as a means of broadly boosting workforce quality. Almost half United Kingdom employers are willing to pay STEM graduates more than other graduates. As a 2012 House of Lords report put it in broad terms, citing the CIHE, what is needed is STEM *capabilities*:

> … the workforce of the future will increasingly require higher-level skills as structural adjustments in the economy force businesses

to move up the value chain. These jobs of the future will increasingly require people with the capabilities that a STEM qualification provides. (House of Lords, 2012)

Nevertheless, the same report also found that STEM graduates were insufficiently informed about potential career openings, undercutting the generic role of STEM. The United Kingdom consultants' report, in referring to *STEM graduates in non STEM jobs* 2011 (Department of Business, Innovation and Skills, 2011), reports that:

> … the majority of STEM graduates did not use their STEM specific degree knowledge at work, whether they were or were not in a STEM related job. For example, only 16 per cent of STEM graduates interviewed for the BIS study believed they used their STEM skills a lot at work. Furthermore, STEM graduates appeared to be working in a range of occupations across STEM and non-STEM related employment. In contrast, however, 90 per cent of STEM graduates interviewed felt they used general skills learned through their degree in their work. For employees, the broad skills of STEM graduates, such as numeracy and analytic skills were perceived as more appealing than specialist subject knowledge.

The United Kingdom's consultants' report also noted that the leading STEM graduates often earned higher salaries in business and law than in STEM occupations: 'Overall, the BIS report concluded that the linear and simple view of supply and demand for STEM graduates was not reflected in the complexity of the employment decisions made by STEM graduates and employers, with many factors involved in career decisions. Thus the linear trajectory from STEM student to STEM professional is far from self-evident'.

The Canadian consultants' report noted that between 2008 and 2017, specific demand for STEM-related occupations, including science and engineering, is expected to grow faster than labour demand as a whole: 'It is anticipated that this growth will be driven by increases in professional business services, especially those related to engineering, computer science, and research and development, specifically in

the civil, mechanical, electrical and chemical engineering fields, and other technical inspectors and regulatory officers'. However, there is no discussion of the potential for STEM qualifications to function as generic preparation for work.

The Russian consultants' report provides relevant data related to the latter point, by comparing field of training, broadly defined, to actual graduate occupations in the workforce. It finds that computing specialists (66.6 per cent) are most likely to be working in the field of their degree, followed by mathematicians and statisticians (61.0 per cent), scientists and science-based technicians (42.1 per cent), engineers and architects (35.9 per cent) and specialists in biological and agricultural sciences (21.6 per cent). The report also notes that almost 30 per cent of scientists and engineers are working in fields not requiring higher education at all. Graduates in computing and mathematics are less likely to be 'downwardly mobile':

> The analysis also does not confirm the thesis, frequently repeated by some, of an over-production of economists and lack of engineers in the Russian economy. The engineering workforce trained in Soviet or Post-Soviet time is less successful in the labor market and engineering graduates more likely than many other graduates to work in a position not requiring higher education at all. Those with technical vocational education are even less likely to get a job in the area of training, than are those with university degrees.

On the other hand engineers and scientists are more likely to be upwardly mobile. This again points to the heterogeneity of science and engineering graduate destinations in Russia. This suggests that it is possible for engineering to function as a gateway to multiple destinations, as does science, in contrast with the more profession-bound role on engineering degrees in Australia. The position of engineering graduates in Russia contrasts with that of France, where, according to the consultants, engineers enjoy both relatively high starting salaries and relatively stable first jobs: 'The 2010 national study of the 2007 cohort of graduates shows that unlike the

61 per cent of engineering school students who maintained their first job, more than half of the 2007 graduates from other courses changed jobs at least once during this first three years in the labour market'. The position of Russian engineering graduates also contrasts with the position in China. The consultant notes that as in many countries, a STEM qualification constitutes an advantage in the labour markets and this is particularly the case with engineering.

Notwithstanding the overwhelming dominance of engineering students in STEM enrolments in China, the average employment rate of engineering graduates, 95.2 per cent, was 4.4 per cent higher than the overall graduate employment rate. This can be partly attributed to the high rate of investment in buildings and urban infrastructure in China. Infrastructure and construction are engineering-heavy activities. STEM graduates in general, and engineering graduates in particular, also enjoy labour market advantages in Taiwan: 'Among the top ten high monthly earning industries in 2011, STEM-related fields took eight places'.

In East Asia and Singapore, with the partial exception of Japan, engineering graduates are both more numerous as a proportion of all graduates and all STEM graduates, and on the whole more advantaged, than elsewhere. The most extensive data in the consultancy reports is provided in relation to Korea. In Korea 'the academic major and knowledge are key factors for hiring STEM graduates when compared to … non-STEM graduates. Similar results have been found in the assignment of job duties … employers consider it important to utilise STEM graduates' knowledge and skills related to their academic majors'. Data for 2008 show that engineering and science graduates had the highest rate of graduate participation in 'economic activities' (91.5 per cent), comparable to medicine and pharmacy (91.1 per cent), though unemployment (3.5 per cent) was slightly higher than in medicine and pharmacy (1.8 per cent). The rate of employment of natural science (life sciences) graduates was lower at 84.5 per cent. As in France, and in contrast with Russia, engineers and applied scientists were less likely to change jobs than other graduates. Natural

science graduates were more likely to change jobs. This suggests that in Korea a natural science degree is likely to be more generic in function than an engineering degree:

The main reason for changing jobs appeared to be due to pay raises, both in the natural sciences and engineering fields, but those from the natural sciences tended to get new jobs unrelated to their majors, compared to those from engineering. In other words, those who studied the natural sciences experienced more difficulty in findings jobs related to their majors.

Those who had their first jobs in the STEM fields continued to stay in STEM two years later in 2008, but those with jobs outside of the STEM fields had difficulty moving into STEM, and continued to stay in non-STEM jobs. Those from engineering majors tended to work for jobs within the natural sciences and engineering field more often than those with natural science majors.

Natural science graduates were more likely to be in part-time work. In part this was because there was a higher proportion of women graduates in the natural sciences, than in engineering. Some women prefer part-time work for family-related reasons. On the whole science and engineering graduates enjoyed advantages: 'Those who pursue expert careers in the STEM fields in Korea tend to be males, unmarried, graduates of higher education institutions located in Seoul or other regions related to industries, majoring in science and engineering rather than the natural sciences, and high academic achievers'. Interestingly, the consultants found that the proportion of top 100 company CEO positions held by STEM graduates increased from 35.9 per cent in 2003 to 46.4 per cent in 2007. The proportion of CEO positions held by business graduates declined.

Only STEM doctoral graduates overwhelmingly matched training and job. The majority of first-degree graduates were working out of field:

The level of match between academic major and job is generally better with STEM graduates than those from the humanities and social sciences, but not those from medicine and pharmacy. The match is also better

with college graduates from engineering majors than those from the natural sciences. However, according to a recent study, only 42.4 per cent of STEM college graduates were working for jobs in the natural sciences and engineering. This result gets better only with those with advanced education: 64.7 per cent for master's degree holders and 90.0 per cent for doctoral degree holders in the natural sciences and engineering.

There are some concerns in Korea that the STEM curriculum has become 'old-fashioned', in that it is too focused on the manufacturing sector, though industry is 'switching to a service industry based on a manufacturing or tertiary industry. It has been reported that more than the half of employers consider STEM graduates not to have adequate competence to match what companies require for jobs'. On the question of future shortage or oversupply of STEM graduates in Korea, different studies have produced conflicting findings.

Australian report

The NILS study notes that according to the 2011 Australian census, STEM graduates have high employment rates (81 per cent) and low unemployment rates (4 per cent) compared to graduates from most other disciplines. This is consistent with patterns in other countries. Compared to engineering (10 per cent) and computing (12 per cent) graduates, graduates from the natural and physical sciences (18 per cent) were more likely to be employed part-time. In part this is a consequence of the male domination of engineering and computing: whereas most men want full-time work, some women opt for part-time work for family reasons. There is much variation within these three broad categories of graduates. For example, whereas just 53 per cent of graduates in the natural and physical sciences were employed full-time in 2011, in mathematics and statistics the rate of full-time employment was 67 per cent, similar to engineering at 69 per cent. This reflects variations in the gender composition of the three broad groups.

Again using the 2011 census data, NILS notes that the three largest occupational groups for employing STEM graduates are Design, Engineering, Science and Transport Professionals, ICT Professionals, and Specialist Managers. Between 2007 and 2011, employment in the top eight STEM occupations grew by an average of 11.1 per cent compared to overall growth of 8.1 per cent in all occupations. The total number of employed Design, Engineering, Science and Transport Professionals grew by 23.1 per cent. We note that these data understate the number of STEM-trained persons working in education. The census asks respondents to report on their 'highest qualification'. School teachers with bachelor-level science degrees who have also completed an education qualification at graduate diploma or masters level report their discipline of highest qualification as 'education' rather than 'science'.

NILS also provides recent (2011) data on private financial rates of return to the costs of study by STEM qualification. These are compared with the average returns of 15 per cent for men and 12 per cent for women for all graduates. The rate of return was highest for IT graduates – 17 per cent and 15 per cent respectively – followed by engineering (15/14 per cent), mathematics and statistics (13/12 per cent) and science (10/11 per cent). Since these data were prepared the labour market for computing graduates has weakened, however. The rates of return to the study of science and mathematics are lower than the average for all graduates. The returns to engineering are above average for women and about average for men. They note that these estimates for the most part exclude STEM graduates who are teachers, for the reason given above. Since teachers get about average pay, it is unlikely that their inclusion would increase the estimated rates of return to science and mathematics graduates.

Data on job vacancies six weeks after advertising show engineers and geologists are in shorter supply than medical laboratory scientists and secondary teachers (Table 16).

Table 16: Recruitment experiences of employers that use STEM skills intensively: 2007-11 (Proportion of vacancies unfilled six weeks after advertising)

ANZSCO code	Occupation name	2007	2008	2009	2010	2011
2332	Civil Engineer	67%	69%	45%	62%	60%
233512	Mechanical Engineer	66%	70%	32%	49%	68%
233513	Production or Plant Engineer	58%	39%	67%	13%	n/a
234611	Medical Laboratory Scientist	26%	38%	36%	14%	18%
133211	Engineering Manager	62%	54%	31%	47%	50%
233311	Electrical Engineer	55%	86%	44%	49%	62%
234411	Geologist	49%	75%	41%	71%	67%
241411	Secondary School Teacher	14%	16%	5%	15%	13%
233611	Mining Engineer (excluding Petroleum)	69%	85%	46%	66%	58%
233612	Petroleum Engineer	n/a	100%	45%	66%	100%

Source: DEEWR n.d., *Survey of Employers who have Recently Advertised (SERA)*, cited in the NILS report.

Table 17: Changes in selected labour market outcomes for recent university STEM graduates, four months after completion: 2007 to 2011

FIELD OF EDUCATION	2007	2008	2009	2010	2011
Mean Full-time Annual Salary ($ 000s)					
Natural and Physical Sciences	47.1	49.5	51.8	53.4	55.3
Information Technology	50.2	53.3	56.8	55.0	58.7
Engineering and Related Technologies	55.0	58.9	62.1	61.6	64.8
Total STEM	51.5	54.7	57.8	58.0	60.9
Education Well-Matched to Job (%)					
Natural and Physical Sciences	n/a	49%	44%	43%	44%
Information Technology	n/a	60%	59%	59%	60%
Engineering and Related Technologies	n/a	80%	79%	76%	79%
Total STEM	n/a	61%	58%	57%	60%

Source: Graduate Careers Australia, Graduate Destination Survey (GDS) unit record files, cited in the NILS report.

Likewise data from the Graduate Careers Australia (GCA) indicate that employers experience relative difficulty in hiring graduate engineers and more so, computing graduates.

NILS cites further 2007-2011 GCA data to show that less than two thirds of recent STEM graduates work in jobs that are directly matched to their education. Engineering graduates are the most likely to be working in their field of training (79 per cent in 2011) compared to computing graduates (60 per cent) and graduates in the natural and physical sciences (only 44 per cent). This underlines the relatively generic use of science degrees in Australia, compared to the relatively professionally-focused use of engineering degrees in Australia. The professional focus of engineering degrees is also associated with relatively high annual earnings compared to science degrees (Table 17)

When discussing STEM graduate employment both government and popular opinion tend to assume that all STEM training is directed towards specific occupations. However, like graduates in arts and the humanities, and business studies,

graduates in science in Australia find themselves working in many different fields. Many graduate jobs do not require a science-specific degree. The generic role of science degrees in Australia has parallels in most countries included in this project. The position of engineering is more variable. Whereas in Australia there is a strong nexus between engineering study and graduate professional work, engineering plays a broader role in China, Korea and Russia.

As was noted above, this larger generic potential of STEM learning and qualifications is discussed in the consultants' reports on the United States and United Kingdom. As the United States consultants' report puts it: 'STEM skills are not only needed in STEM occupations, but in other economic sectors as well'. If we take the view that STEM disciplines can provide useful foundations for many occupations – whether with or without additional study – the question of shortage/oversupply changes. For example, if engineers are in oversupply relative to professional engineering jobs, the surplus engineering graduates nevertheless are potential employees in business and government. And there may be a need for more such generic engineering graduates. We note that an expansion of the generic functions of engineering would not necessarily increase average salaries. Some generic qualifications (e.g. law) are associated with above average private rates of return. Other generic qualifications (e.g. science, humanities) are not.

We need to know more about the uses of STEM knowledge and qualifications in Australian labour markets. We also need a more precise description of the STEM-trained workforce in teaching than the census data provide.

Key finding 11.1: Specific and generic roles of STEM education and training in relation to the workplace

There is a lack of clear data in Australia concerning destinations of STEM graduates and the role of STEM training in a variety of professions. There is also lack of data on qualifications of teachers of STEM.

11.1.1 A key need is data concerning the destinations of STEM graduates (whether at the level of first degree, postgraduate coursework or postgraduate research) in the first 5-10 years after graduation, identifying the respective roles of STEM education and training in relation to:

- work specific to the STEM qualification

- work that is outside field but within STEM

- work in occupations with no specific STEM requirements that may nonetheless draw on STEM graduates' skills and knowledge in a more generic manner.

Such data gathering could also include:

- review and audit of occupations requiring STEM qualifications

- comparison of the labour market outcomes of STEM graduates by field, with those of non-STEM graduates

- factors that facilitate and limit the labour market mobility and flexibility of graduates with STEM qualifications, and employer take-up of STEM qualifications.

11.1.2 A comprehensive survey of secondary teachers in order to identify the number and full qualifications profiles of teachers of all STEM subjects at all year levels.

12 | Girls and women

The proportion of women employed in STEM fields in Australia is undesirably low. A comparison with other developed countries reveals significant scope for improvement in Australia. The evidence presented here highlights the persistence of the problem. A broad range of initiatives, based on international reports, are suggested to solve this imbalance.

What is the problem?

Women and girls are under-represented in STEM fields throughout their education and career. In education, gender based disparity in STEM has been masked by growing numbers of female students enrolling in, and graduating from, universities, and increasing absolute numbers of enrolments in the fields of science and technology. Comparative international data show that women have been participating equitably in tertiary education for some time (for example, Argentina, Canada, Western Europe, Finland, and Russia). In fact, the percentage of tertiary type A qualifications (mainly undergraduate bachelor degrees)

and advanced research degrees awarded to women in Australia has remained steady at around 56 per cent since 2000 (OECD, 2012a). The OECD average increased slightly over the same period from nearly 54 per cent in 2000 to 58 per cent of awarded qualifications in 2010 (ibid.). From these figures, it would seem that inequality for women in education no longer exists. However, an examination of the disciplinary distribution of tertiary students reveals a gendered pattern of participation.

## Gendered patterns of participation by discipline

The gender-based stratification of participation in STEM has roots in the expectations of students prior to the curricular choices they make in upper secondary school. The 2006 OECD PISA test surveyed the career expectations of 15 year old girls and boys internationally. In Australia 32.8 per cent of female and 34.2 per cent of male participants expected to be in a science-related career by 30 years of age. This was close to the OECD average figures, although slightly higher than the average for males. However, it is considerably lower than the corresponding percentages expressed by boys and girls in Canada (girls: 44.9 per cent, boys: 39.8 per cent)

and the United States (girls: 49.4 per cent, boys: 39.9 per cent).

There are much larger differences in other STEM disciplines. In total 46 per cent of the boys tested in PISA 2006 indicated an expectation of a career in computer sciences or engineering, compared with only 8 per cent of girls. This reveals a slightly greater divergence between genders than shown in the OECD average. Of the countries shown in Figure 15, Australia has the lowest number of 15 year old girls expecting careers in health sciences and nursing at 64 per cent, while close to the average number of boys (22 per cent) report this expectation.

A study of secondary participation in sciences in Australian education found that student attitudes and career ambitions are critical in determining engagement in tertiary level science courses. This research specifically found that almost three quarters (74 per cent) of students who studied two science subjects in their final year of secondary school continued on to study science related areas at university (Ainley et al. 2008). The research on student attitudes shows not only that young women are less positive about STEM study, but also that there appears to be a connection between early attitudes and the propensity to pursue study and careers in these fields.

Figure 15: The percentage of participating 15 year-old students expecting a science related career by 30 years of age, by field and gender, in PISA 2006
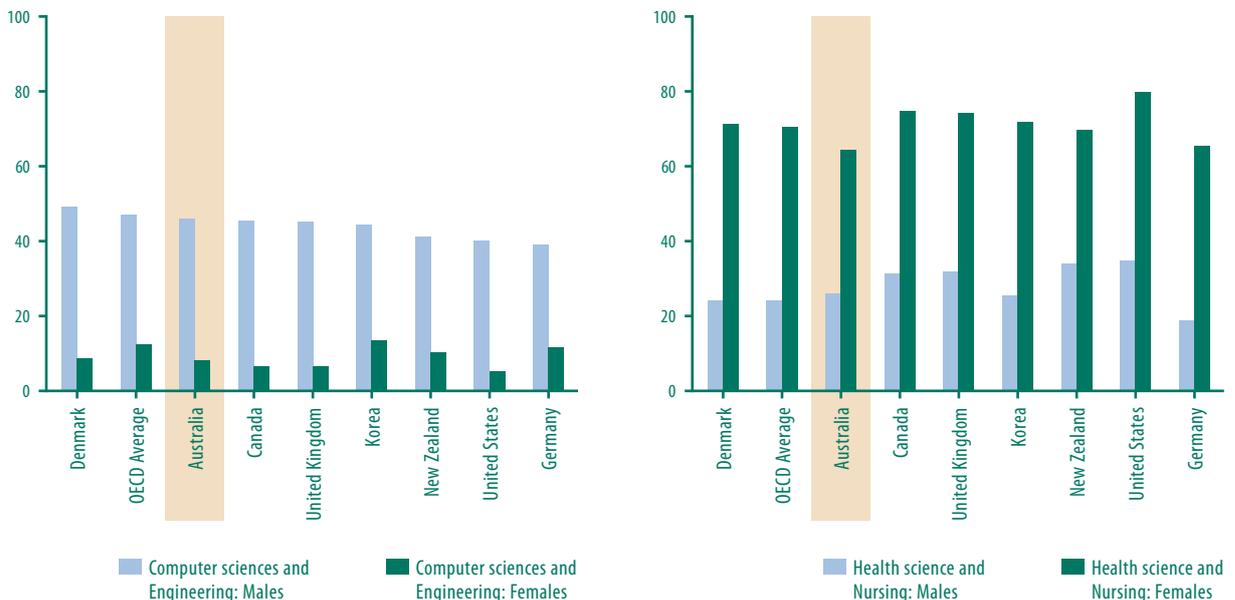
Source: OECD 2010e, Expectations for science-related careers by gender, *OECD Factbook 2010: Economic, Environmental and Social Statistics*, OECD Publishing, Paris.

A recent report on secondary mathematics and science participation in the New South Wales school certificate notes that at secondary level, the participation of girls in at least one mathematics and one science subject after year 10 has been dwindling since 2001 (Mack & Walsh, 2013). The proportion of girls who elect to study no mathematics whatsoever after year 10 has tripled from 7.5 per cent in 2001 to 21.5 per cent in 2011. 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, while women outnumber men in the study of health, welfare, education, humanities, arts, agriculture, life sciences, services, social sciences, business and law. Similar patterns can be observed internationally. Figure 16 illustrates the percentage of tertiary qualifications awarded to women by field of education in Australia compared to OECD averages in 2010, highlighting the gender based disciplinary divergence. While the numbers of women studying in STEM fields has increased in recent years, the figures still stand below half. Female students comprise the majority of the cohort in life sciences, while those in engineering, manufacturing and construction contain the smallest proportion of women.

Table 18 shows disciplinary tertiary qualifications of women by country. Denmark and Finland achieve the highest female representation in fields in which women are under-represented in the OECD averages. Australia is well below the OECD and EU21 averages in engineering, manufacturing and construction, sciences, life sciences and mathematics.

In Canada, women account for more than half of the tertiary students in all fields except for engineering, mathematics and computing, as well as architecture. While 44 per cent of all doctoral graduates in Canada were women in 2008, these women were primarily located in education, social science, law and health. The average was brought down in part by the fields of agriculture, natural resources, physics, life sciences, technology and humanities, and most dramatically by mathematics, computer science, architecture, engineering and related technologies. Only 10 per cent of enrolments in computer engineering in Canada between 1991 and 2007 were women. Female students comprised only 23 per cent of civil engineering students and nearly 40 per cent of those enrolled in undergraduate programs in biosystems, chemical or environmental engineering.

Figure 16: The percentage of qualifications awarded to women in tertiary type A and advanced research programs, by field of education, in 2010
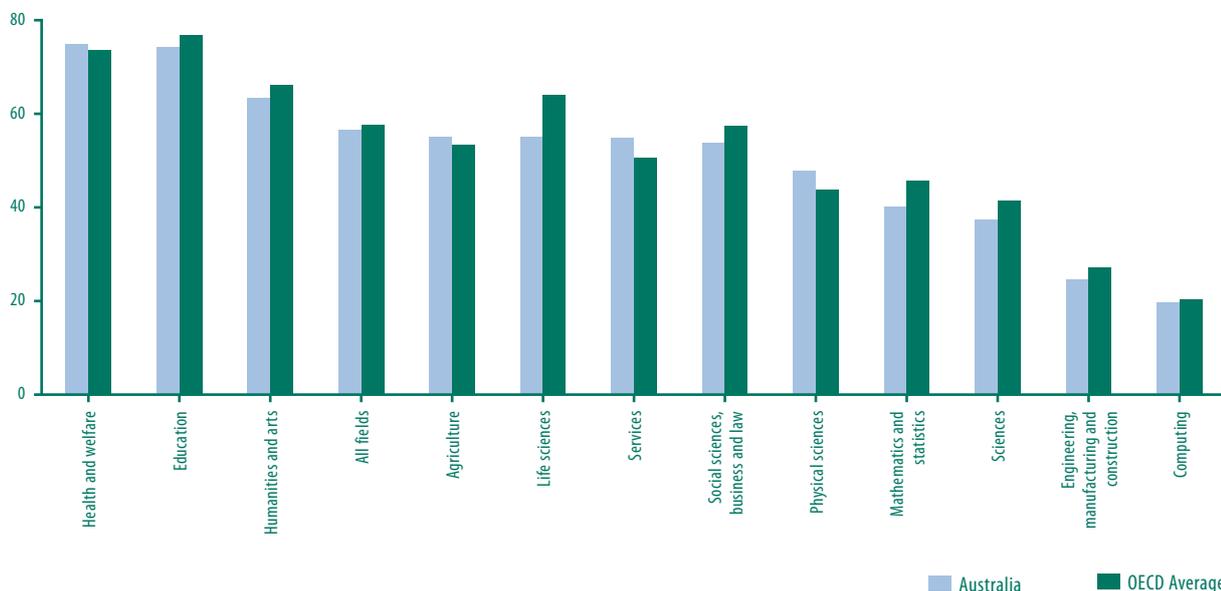

Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators*, OECD Publishing, Paris.

Table 18: The percentage of qualifications awarded to women in tertiary type A and advanced research programs, by STEM field in 2010 for selected countries

	Engineering, Manufacturing and Construction	Sciences	Life Sciences	Physical Sciences	Mathematics and Statistics	Computing
Finland	21.48	46.30	76.18	50.35	47.51	28.40
Germany	21.96	44.30	67.44	42.72	61.36	15.33
New Zealand	30.20	44.31	58.92	45.80	47.80	23.55
EU21 Average	28.39	42.29	66.80	44.85	48.88	18.75
OECD Average	27.19	41.61	64.23	43.81	45.89	19.73
Canada	23.50	49.01	62.64	44.80	42.45	17.91
Korea	23.32	39.22	48.37	46.89	54.80	20.86
Denmark	32.00	37.29	67.36	38.40	36.17	20.89
Norway	26.68	36.17	74.66	38.49	31.05	19.72
United States	21.67	43.50	57.94	39.38	41.61	21.08
Australia	24.31	37.31	55.15	48.05	39.89	19.57
France	30.05	37.62	62.71	38.70	36.15	15.81
United Kingdom	22.56	37.52	50.81	42.58	40.32	18.71
Switzerland	19.53	34.40	52.89	32.29	31.83	8.20
Netherlands	19.51	22.66	62.35	24.22	31.97	10.94

Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators,* OECD Publishing, Paris.

Figure 17: Number of science related tertiary graduates among 25-34 years old in employment per 100 000 of this cohort by gender, in OECD 30 countries
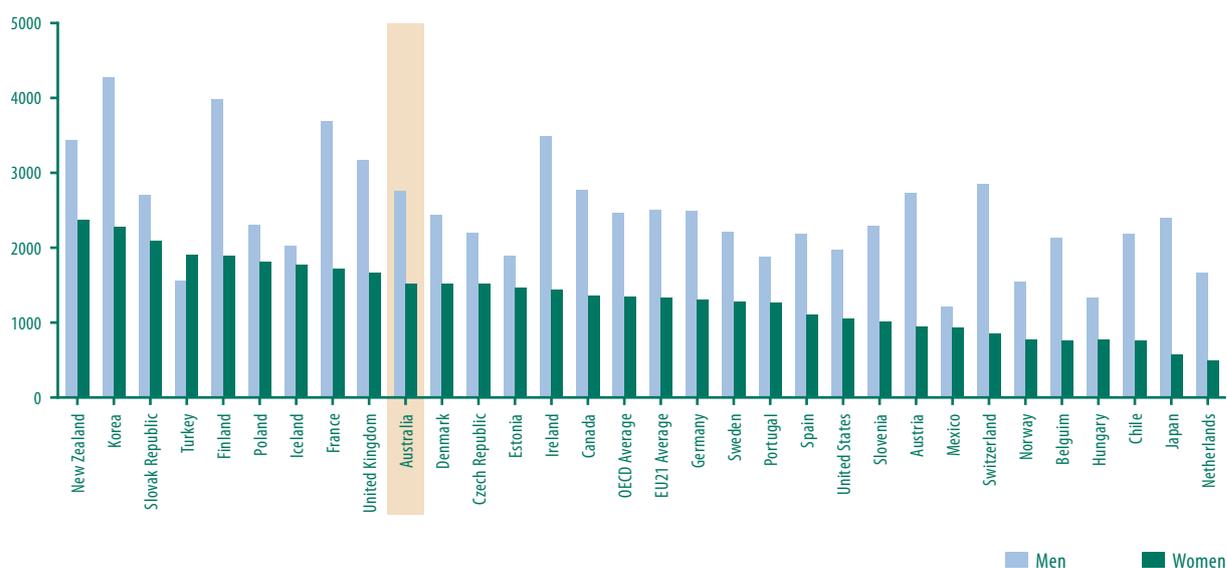
Source: OECD 2012a, *Education at a Glance 2012: OECD Indicators*, OECD Publishing, Paris.

The employment of tertiary graduates from science related fields illustrates a similar pattern of gender differences. Australian figures for employment of female science-related tertiary graduates are a little above the OECD average and display a similar difference between men and women. The best performing countries (with least gender disparity) shown here are Estonia, Iceland, Mexico, Poland and Turkey. It is interesting to note that greater gender disparity occurs in some

of the economies with the more developed or established science research traditions.

In a report on women in science in Australia, Bell (2010) highlights the extent of inequality in STEM employment. In 2008, the participation of women in science, technology and engineering jobs was 45.1 per cent, representing a small 2.8 per cent increase from 42.3 per cent in 1992. For comparison, during the same period, the percentage of women employed in government

administration and defence grew 18.8 per cent, from 37.1 per cent in 1992 to 55.9 per cent in 2008. Even more significant, the percentage of women employed in several other traditionally male dominated fields, while lower overall, also increased more than in STEM fields. For example, a 5.7 per cent rise in women employed in mining was recorded, from 9.5 per cent in 1992 to 15.2 per cent in 2008. The gendered patterns of disciplinary distribution that occur during upper secondary and tertiary education are mirrored in the workforce, with female researchers more concentrated in biology, agriculture and health, rather than engineering, physics or computing (ibid.).

Japan displays the greatest gender divergence in STEM employment, and education. Only 10 per cent of Japanese students in 2012 enrolled in undergraduate and masters programs in the field of technology were female. Furthermore, females account for only 13.8 per cent of researchers in universities, corporations and public research institutions. Women filled only 7.6 per cent of STEM research positions in private corporations, and 24 per cent of these positions in universities. As in other countries, engineering is making the slowest progress. Comprising just 1.4 per cent of all engineers in 1970, women still account for only 8.6 per cent today. In Korea, the situation is better but far less than ideal. Female students represented 28.5 per cent of students in STEM tertiary programs in 2010, and only 24 per cent of STEM students at doctoral level.

Not only is female participation in STEM education and employment low, the attrition rate is particularly high, with women leaving science and other related disciplines in disproportionate numbers at each stage of the career cycle. This happens in highest volume at the post doctoral level, despite the large amount of time invested in education prior to employment. Only a quarter of female science and technology graduates in the United Kingdom actually gain employment in science, engineering or technology sectors. Others work in related jobs, including administrative or other adjunct positions in sales and marketing within the science or research sector, or they pursue totally unrelated careers.

What causes are identified?

There are a myriad of factors that contribute to the under-representation of women in STEM education and employment. These include the perceived nature, organization and career pathways of STEM fields of study and employment, the availability and scope of parental leave, small numbers of women influencing and participating in senior roles on funding and other decision making bodies, the difficulty of breaking through existing disciplinary networks, as well as a lack of effective counter measures and policies within national systems. As the Argentinean consultants' report notes, motherhood creates problems for young female scientists in terms of the balance between work and family demands.

Stereotypes, fuelled by ignorance of what exactly STEM careers entail and who scientists, engineers and other STEM professionals actually are, create significant disincentives for girls and women to become interested in and pursue study and careers in STEM fields. This is particularly the case in engineering, computer sciences and statistics, explaining the strong gender differences in the participation data. The Canada consultants' report in particular notes young people's persistent lack of understanding of what engineering and technology careers entail. This report also notes that when parents or relatives encourage the young person to become interested in engineering and technology, this interest does not necessarily translate into study or career ambition.

Research based on surveys of seventh grade primary students in Europe revealed a striking ignorance of STEM careers and professionals, one that could be easily reversed. The *Draw a scientist test* (DAST) is often used to investigate students' understandings and images of science, identifying a number of key stereotypical characteristics that students have learnt to associate with scientists. Students see the typical scientist as white, male, eccentric, and surrounded by laboratory equipment. Research has established a connection between these views and students' own ambition to engage in future science studies. This phenomenon

Figure 18: Seventh grade student drawings of a "scientist" before (left) and after (right) their visit to a scientific research laboratory

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.

is particularly associated with girls. Figure 18 illustrates the stereotyped image of scientists held by young school students prior to visiting a scientific research laboratory, and then their altered view afterwards. The age and gender of the person depicted in these illustrations changed dramatically.

The report on Argentina notes traditional perceptions that associate STEM fields as masculine, while education and health are seen as feminine. This translates directly into participation levels in Argentina, with women accounting for 25 per cent of tertiary enrolments in physics in 2012, and 64 per cent of those enrolled in biology in the same year. Gender divergence in STEM employment also persists in Argentina. Despite finishing their degrees faster and with higher average grades than their male peers, most female Argentinean STEM graduates are only able to secure lower status positions. The consultants' report on France similarly makes note of strong national perceptions of masculine and feminine disciplines. Women accounted for 30 per cent less of the International Standard Classification of Education (ISCED) levels 5 and

6 graduates from mathematics, science and technology fields in France in 2009.

The Canadian consultants' report notes that the majority of women express negative feelings about engineering and technology occupations, citing undesirable scenarios such as construction or outdoor work, and the probability that such occupations focus more on computers rather than people. There is also a lack of role models for women in STEM careers, particularly engineering and technology, including high school teachers and industry professionals.

Why is it an issue?

The under-representation of women in science and other STEM fields is a problem for a number of reasons. Five arguments are made in the literature and by the consultants to this project. The last is the most emphasised argument.

First, when the gender balance in STEM is aligned with the gender balance in the real world, it is more likely that the STEM research will, accordingly, be better aligned, and so more

productive and relevant. Second, the inclusion of women can boost the quality of STEM research. Diversity of participation enables greater aggregate creativity and reduces potential bias. Both factors tend to improve research quality. Third, gender equality can be supported on the basis of social justice, fairness and human rights. If all people are equal, then all should be able to experience equal opportunity, including the circumstances that enable them to engage successfully in STEM education and careers. Fourth, STEM research attempts primarily to address the common needs and issues facing the population and is financed by common funds, such as tax revenues. It makes sense to adequately involve all subgroups of the population in the research process.

The final argument connects the gender agenda to the economic imperative that drives much of the international debate on STEM enhancement. Improvements in participation and performance in STEM are seen to enhance human capital and innovation, thereby lifting national economic growth and international competitiveness. In this policy context, women are seen as an under-utilised resource with the potential to boost the labour force in this sector and provide a larger talent pool from which to source the best and brightest. The human capital of women who have undertaken training in STEM and left their careers prematurely is considered to be a wasted economic resource.

Searching for options: What can be / has been done about it?

The evidence presented here highlights the persistence of the discipline-based problem and provides a basis for re-invigorating the agenda on women in STEM. This report will now suggest strategic options for Australia on the basis of the international evidence collated in this project.

Numerous initiatives have been proposed and implemented around the world, and are outlined in the consultants' reports. An important message through these is that initiatives or changes that are solely confined to educational goals will not be able to entirely redress the imbalance.

Overall approach to women's participation in STEM

A consistent and broader policy setting is needed. Nationally consistent policy on this issue is known as gender mainstreaming, essentially a systemic commitment is made to gender equality in STEM education and careers. This plays out through a combination of elements including political will, legislation, greater understanding of gender issues, mandated involvement of women on decision making bodies and to senior appointments, more appropriate human resource processes and funding systems.

Legislation can play a significant role. In France, the National Ministry of Education made it a priority to steer the career ambitions of more young women towards the STEM fields. Equality legislation was therefore enacted to encourage the diversification of girls' professional choices. An important strategy extended legislation to top level appointments in academia or positions on decision making bodies, such as research councils. Important elements of this include procedural transparency, standardised selection procedures, widespread publishing of position advertisements, headhunting highly qualified women, and monitoring gender dis-aggregated data on selection and hiring outcomes. Norway is a good example of the success of this approach. At one Norwegian University, equality-oriented searching was conducted through committees established for the identification and recruitment of qualified women. This can be contrasted with the case of Canada, where the under-representation of women in STEM has not been a significant part of federal policy thinking or reports on STEM fields in recent years. Women in Canada are particularly under-represented in STEM fields and the country has experienced little improvement in recent years.

Active and deliberate engagement of women in policy processes, funding and human resource decisions has been shown to improve participation. For example, the EU imposed a target on expert group and committee membership. Since the mid 2000s, all decision-making boards were required to be composed of at least 40 per cent of each sex. The strategy has

apparently successfully 'led to a strong increase in the participation of women on evaluator panels for research proposals submitted' (European Communities, 2008, p.10).

Other policy levers include targets, quotas and financial incentives. These can be applied throughout secondary or tertiary education, as well as in the workplace for STEM professionals. In Sweden, political pressure from policy makers to achieve targets is strong and has effectively increased the participation of women, whilst maintaining institutional autonomy in decision-making and appointments. In Switzerland, a successful program of financial incentives has been in operation since 2000 whereby universities are provided with greater national governments funds for the appointment of female professors. A range of financial opportunities is available to women in France, to enhance their involvement in STEM education and employment, including from industry sources, such as *L'Oreal Paris*.

Labour market conditions often drive student choices throughout school and university education. STEM professions, particularly in the private sector, are noted internationally for conditions that do not attract women, and often create obstacles for those who enter these fields. For example, funding is sourced externally and grants are usually offered preferentially to those working full-time. Also, experiments often need to be conducted outside normal working hours and networking is critically important to success, making it particularly difficult for women to balance work and family life.

Mentoring strategies

The provision of mentoring and other direct support strategies are important for improving the representation of women in STEM fields. Direct methods can address the confidence and attitudinal factors that contribute to females avoiding STEM education and careers. There are numerous examples of this throughout Europe, including the European Network of Mentoring Programs, professorial-PhD linkages in Norway, *Les Femmes En Maths* in France, which depicts successful professional women who graduated from mathematics and science study.

Key finding 12.1: Gender-based participation in STEM

Countries generally are grappling with the issue of under-representation of women and girls in STEM fields, and pursue a variety of gender equity policies and strategies to address this. In Australia, women's participation in STEM has not altered substantially over two decades, and there is a case to be made for re-invigorating the agenda on women in STEM. Comparator countries' initiatives could provide indications of ways forward. Measures designed to lift female participation in STEM, from first degrees to research functions, could include:

- System-wide targets designed to achieve an equitable percentage of women in STEM disciplines.

- Scholarships and fellowships specifically reserved for female students and researchers, in areas such as engineering where women are grossly under-represented. Such scholarships and fellowships would be largely provided by higher education institutions.

- Strategic reservation of funds for women to assist their study and establish themselves as researchers, and/or the allocation of greater points in funding selection processes to projects that include women researchers.

The absence of role models, and lack of familiarity with STEM careers, have been identified as key factors to address if women and girls are to be attracted to STEM fields in greater numbers. In France, there is a program to encourage girls to take up scientific careers called *Pour le science*. In Israel *Mind the Gap!* has successfully brought young women into contact with women working in the world's largest internet company, introducing them to the world of computer science, research and development, and internet commerce. In Korea, there is a

Key finding 12.2: Mentoring programs to encourage female participation in STEM

Mentoring programs in a number of countries have been positively evaluated as improving women's participation in STEM. Examples of mentoring programs include:

- Bringing together young women and successful female STEM professionals (including scientists, engineers, mathematicians and computing specialists) to provide authentic understanding of STEM careers, and access to female role models. Such contact with STEM professionals could start as early as primary level schooling and continue consistently through education and early career training.

- Peer to peer support between high school and primary students, or between tertiary and upper secondary students, through activities and science shows.

- Systematic linkages between professors in STEM fields, and doctoral students or post-doctoral level women in STEM fields.

Key finding 12.3: Gender-related elements in school curricula and pedagogies in STEM disciplines

Gender-related elements in school curricula and pedagogies in STEM disciplines are a feature of some countries' initiatives that are well supported in the literature. Strategies could include:

- Curriculum design and professional development that could generate greater teacher awareness about encouraging girls to consider STEM pathways.

- Content, pedagogy and resources suited to the learning styles and preferences of girls as well as boys.

- An increased focus on inquiry based science teaching, integrated; mathematics throughout the curriculum.

- Engaging science experiences from an early age.

Curricula and professional development

Fostering greater gender awareness among people working within STEM-related fields – including the educational and work culture through attitudes of teachers and colleagues – is another strategy well supported in the literature and with demonstrated success internationally. In schools, this includes teachers understanding the issue and its persistence, as well as learning to create teaching and learning activities to better assist girls.

high school program, known as the Women's Academy for Technology Change in the 21st Century (WATCH 21), which is intended to attract and promote the study of the natural sciences and engineering, through creative problem solving and research activities.

Work and careers

In the workplace awareness and cultural change includes more flexible working hours, child care provision, support for family mobility, greater periods and payments during maternity and paternity leave, and incentives to return to work after periods of time away spent with family. There has been some expansion of career pathways for women in engineering and other STEM fields. In Korea, the Women in Engineering program, along with the Women in Science and Technology program, have supported the career development of young women, as well as contributing to relevant policy research.

Career and course counselling services for STEM pathways need to be revised to provide materials better adapted to attract young women, and include advisors who are familiar with STEM professions and career pathways. In specific fields in Australia this has been successful in the past. Comprehensive and gender-disaggregated data is important to not only better understand discipline based gender divergence, but it is also key to monitoring the progress of implemented strategies. International organisations, among others around the world, call for improvements and expansion of the collated data.

Key findings 12.4 and 12.5

Further strategies for increasing women's participation in STEM, successfully pursued by a number of comparator countries, include career counselling and flexible workplace arrangements. These suggest the following options for Australia:

Key finding 12.4: Course and career counselling designed to encourage female participation in STEM

Counselling services and promotional materials in relation to STEM pathways designed to effectively encourage young women to follow STEM pathways.

Key finding 12.5: Women in the STEM-related workplace

Facilitating female participation in STEM-related fields of work, including issues such as maternity pay and provision for paternity pay and leave, flexible working hours, child care provision, and support for family mobility.

13

Stem and indigenous students

STEM indigenous issues and approaches

There are significant issues concerning indigenous participation in post compulsory STEM subjects, including university studies, and in the STEM workforce, across all countries with significant indigenous populations. The issue is canvassed at length in the Canadian and United States indigenous reports and in the New Zealand report. It is also raised in the Brazil report, and in the South African report for which the issue has quite a different political history. All these reports echo the substantial concerns of the participation and achievement levels of Australian indigenous people in education, and in STEM.

The consultants' reports describe in some detail the disadvantage suffered by indigenous people in pursuing successful STEM pathways. The issue is not only one of social justice and equity – there are significant implications flowing from this loss of a substantive group within the population to STEM pathways and the personal futures these entail. Key points outlining the situation in each of the major indigenous reports are:

- In Canada the indigenous population (First Nations, Métis, and Inuit peoples) numbers 1.26 million, a sizable minority of whom live on reserves. In some provinces and particularly in remote areas that are rich in mineral resources, the indigenous peoples make up a substantial fraction of the population, with indigenous children in Saskatchewan comprising 29 per cent of school age children. Indigenous people have increasingly economic importance, and in northern areas are a significant STEM workforce resource. The participation of Saskatchewan indigenous people in post compulsory school STEM increased at twice the rate of their population increase between 2003 and 2012, but is still half the participation rate of students overall.

- The United States consultants' report focuses particularly on American Indian (AI) and Alaska Native (AN) people's under-participation and disadvantage in the United States STEM system – participation and graduation rates are significantly worse for these groups than other minority groups in the United States. Only 17 per cent of AI/AN have bachelor degrees and only 3 per cent were in STEM careers in 2009. There are particular pockets of disadvantage within this, for instance extremely low persistence rates of AI women in engineering. There is significant growth in Native American populations, and increasing access to higher education, but under-representation in STEM pathways is ascribed to approaches to school science and mathematics that are inappropriate to their needs.

- In New Zealand Māori and Pasifika students under perform in all subjects but the effect is particularly marked in mathematics and science.

In these countries, the momentum for policy and practice action is accelerated as indigenous peoples grow in numbers and in economic importance. There is growing confidence amongst indigenous people in the call for better outcomes and increasing acknowledgement of indigenous views and needs and identity. This is enshrined in New Zealand in statutory rights under the Treaty of Waitangi, and in Canada First Nations reserves have access to increasing potential financial power.

We can identify through the consultants' reports two culture-related disjunctions that act against indigenous participation in STEM:

- A mismatch between cultural beliefs about the world, and science and mathematics curriculum beliefs and teaching approaches (an identity issue);

- Problems for indigenous students in dealing with institutional cultures, particularly at university level.

Cutting across these is the issue of language, which is a particular feature of the New Zealand response to Māori identity and participation in education. Similar issues can be found in Brazil with Amazonian natives, and in a somewhat different form in South Africa with the majority black population.

One could expect that these cultural 'border crossing' issues involve disparities between indigenous parental expectations and presumptions, and the identity/self-efficacy demands of STEM subjects. The Canadian report describes in some detail the ambiguous attitude of First Nations elders and parents towards education – as both the pathway to a fulfilling life (the 'new buffalo'), and an instrument of historical oppression.

The three consultants' reports identify interventions which have proven effective or promising, in three distinct areas 1) developing culturally responsive curriculum and teaching approaches, 2) developing support structures for students entering higher education, and 3) developing a range of community outreach and enrichment strategies to encourage and support indigenous STEM participation.

Culturally responsive teaching

The Canadian report describes the development, over a period of time, of a Saskatchewan science curriculum that incorporates indigenous perspectives, and teacher professional learning to support this. The underpinning insight driving this work is that successful uptake of

scientific ways of thinking involves significant identity work particularly for indigenous people, involving a 'border crossing' into the world of science that teachers need to guide. The curriculum development involved a significant consultative process with indigenous elders, who were also involved in intensive professional development workshops for teachers who were led to an understanding of indigenous perspectives. Teachers described this experience as very powerful. Increased uptake of post-compulsory science indicate these have been very successful interventions. There is evidence that the approach also leads to improved results for non-indigenous students. The consultants make a strong point that a critical aspect of successful intervention is that indigenous people need to be involved as equal partners in framing the approach, and further, that any perceived 'gap' in knowledge between indigenous and western perspectives be seen as needing to be equally spanned from both sides. Indigenous perspectives can add value, for instance, to sustainability perspectives on managing environmental resources.

The report describes six areas that constitute culturally responsive teaching:

- Specific attention to the learning needs of indigenous students

- Integrating indigenous knowledge into science classes

- Culturally appropriate teaching strategies

- Assessment involving culturally valid ways of students communicating what they know

- Culture-based patterns of classroom inter-personal communication

- A learning environment experienced by students that is framed around these five areas.

The United States consultants' report mainly focuses on strategies to support indigenous students entering higher education, but refers to United States experience that is consistent with the perspectives described above.

In New Zealand there has been a significant effort put into incorporating Māori ideas and language into the science and mathematics curricula. New Zealand has a system of immersive Māori schools that are very successful in terms of identity outcomes for Māori students. However, fewer choices because of size, and lack of Māori speaking teachers with science or mathematics expertise mean STEM outcomes are lower than otherwise.

In all of this work on improving indigenous students' engagement with and successful learning of science, the construct of identity is very powerful in enabling a framing of the issue, and the interventions, around the multiple relationships and values that drive students' responses to and possible alignment with scientific ways of thinking. To some entrenched concern about incorporating indigenous ways of knowing into the science or mathematics curricula, the response has been that without these measures students are not inclined to take up scientific perspectives, and that through discussion of alternative perspectives, understanding of the nature of scientific thinking is enriched for all students.

Support structures for students at university

The United States consultants' report describes a range of interventions to support indigenous students entering higher education institutions, some of which have been comprehensively researched. Two significant programs that provide evidence based insight into effective support strategies are the Meyerhoff Scholars program at the University of Maryland, and the public-private partnership 'Building Engineering and Science Talent' (BEST), which identified STEM programs that are effective for under-represented groups in pre-K – 12, higher education, and the workplace.

The design principles for effective programs arising from the BEST review are:

- defined outcomes drive the intervention (goals, desired outcomes, data collection, research and continuous improvement).

- sustained commitment (proactive leadership; sufficient resources; steadfastness in the face of setbacks).

- personalisation (the goal of the intervention is the development of students as

individuals) (student-centred teaching and learning; mentoring; tutoring; peer interaction; recognise individual differences, uniqueness and diversity);

- challenging content (curriculum clearly defined; real-world applications; goes beyond minimum competencies; reflects local/state/national standards; academic remediation available).

- engaged adults (educators play roles as teachers, coaches, mentors, tutors and counsellors; teachers develop quality interactions; active family support sought).

The United States consultants' report indicates that the Meyerhoff Scholars program:

promotes active learning and analytical thinking, provides learner-centered environments mindful of students' cultural orientations, exposes students to mentors in the various STEM fields, provides counselling and peer-group supports, assesses student learning to expose their ways of thinking, and develops classrooms into communities by promoting intellectual and social cohesion.

External evaluations showed that:

Meyerhoff students are nearly twice as likely to persist and graduate in mathematics, engineering, and the sciences than their peers who declined offers of admission to the program and enrolled at other universities.

The Canadian consultants' report attributes the low entry numbers and high drop out rate of indigenous students in STEM university programs to the culture of university STEM departments that are not sensitive to the needs of indigenous students. The report describes transition programs that address the problem of indigenous students transferring from school to university, offering skills and support. There are a variety of forms of undergraduate indigenous student support, always outside the courses as such because of prevailing resistance to discussing indigenous issues by university faculty. These include centres, mentorship programs and others.

Saskatchewan's STEM institutes have a variety of programs for supporting indigenous students;

some are run by indigenous organisations. The support programs include transition support, emergency bursaries, an aboriginal activity centre, access to elders and cultural advisors, special indigenous teacher education programs, and appropriate, locally contextualised course content. Similarly, the New Zealand consultants' report describes a range of STEM outreach programs run by universities a number of which target Māori and Pasifika students. The University of Auckland's 'Vision 20:20' initiative for instance has three components:

- An indigenous admission scheme (MAPAS) involving admission support, academic support (includes additional group tutorials, specific study space and computer labs, study retreats, homework and pre-exam study support, and guidance on forming study groups), and pastoral support (mentoring, peer support, regular lunches …)

- A one year foundation certificate program transitioning indigenous students into university health and medical programs

- A recruitment program offering school presentations, career advice and visits to health science facilities, and financial support.

Outreach, enrichment, and workplace initiatives

The University of Auckland initiative described above has outreach components. A number of school outreach programs are described in the Canadian consultants' report including an 'ambassadors program' with 3rd and 4th year undergraduate students, outreach science programs that teach science in a 'fun' way, camps and 'discover engineering' events.

The Canadian consultants' report includes case studies of successful industry led workplace recruitment models involving large companies, with a number of integrated aspects. These include workplace visits, work placement, and scholarships with guaranteed employment. The cases have led to considerable success in terms of indigenous tertiary education qualifications and achievement of senior positions in companies by indigenous STEM professionals.

There are also specific indigenous programs, in nursing or teacher education, for instance indigenous Bachelor of Education programs to prepare First Nations and Métis teachers. Graduates are encouraged to return to their communities to be role models for Indigenous achievement.

Implications for Australia

Figures 19 and 20 show a significant level of disadvantage for indigenous Australians in mathematical and in scientific literacy, on the PISA test.

What lessons can be learnt from these reports that will help frame policy and practice to improve the involvement of indigenous Australians in STEM, and in education generally? What models might lead to successful transition into higher education, and professional STEM pathways?

The reports describe a number of principles and successful practices to enlist and support indigenous people in STEM higher education and professional pathways. There are many support structures currently existing for indigenous Australians in education pathways. A national policy response needs to be developed that draws on the examples from these consultants' reports and integrates a variety of aspects of engaging indigenous Australians in post-school STEM.

Figure 19: Proficiency levels for Indigenous and non-Indigenous students in mathematical literacy
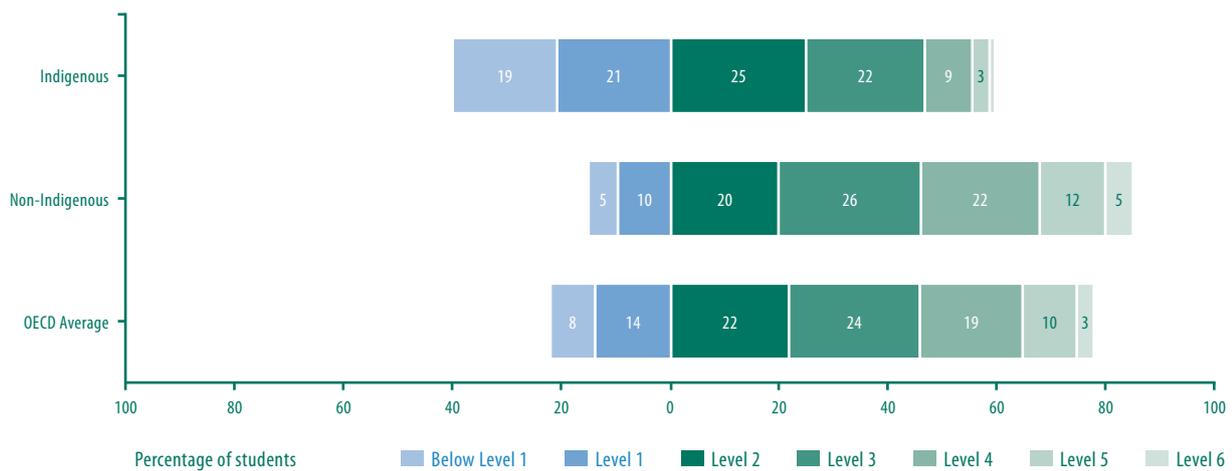
Source: Thomson, S, Hillman, K, Wernert, N, Schmid, M, Buckley, S & Munene, A 2012b, *Monitoring Australian year 4 student achievement internationally: TIMSS and PIRLS 2011*, Australian Council for Educational Research, Melbourne.

Figure 20: Proficiency levels for Indigenous and non-Indigenous students in scientific literacy
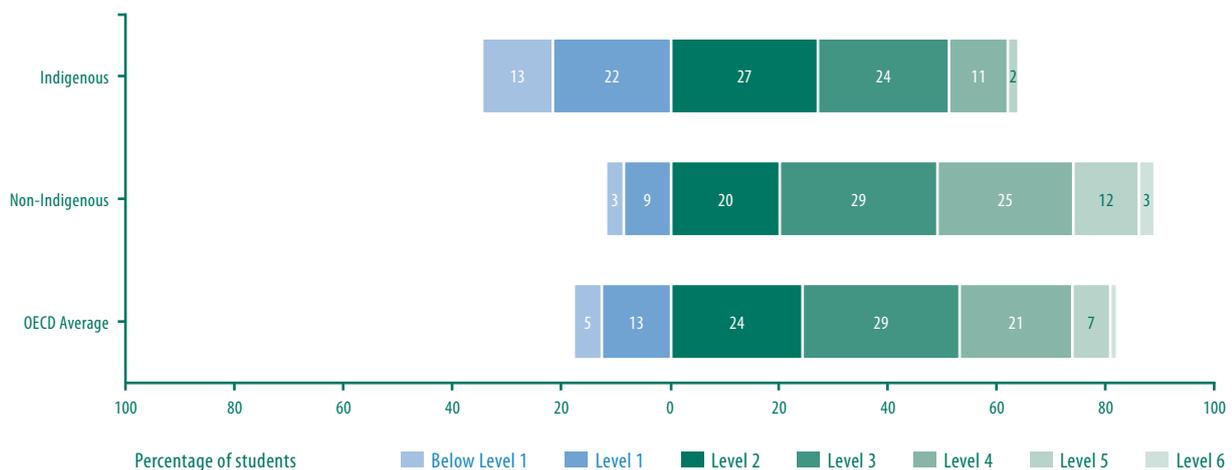
Source: Thomson, S, Hillman, K, Wernert, N, Schmid, M, Buckley, S & Munene, A 2012b, *Monitoring Australian year 4 student achievement internationally: TIMSS and PIRLS 2011*, Australian Council for Educational Research, Melbourne.

Key finding 13.1: National approach to STEM teaching and learning for indigenous students

The Canadian indigenous STEM education experience presents a strong case for pursuing 'culturally responsive teaching' involving the recognition of indigenous knowledge as part of the study of science, and the active involvement of indigenous elders in framing the curriculum and teacher professional development. On the basis of this report, advancing STEM teaching and learning for Australian indigenous students needs wide discussion, including approaches to curriculum and pedagogy in STEM that would more strongly engage indigenous students with STEM subjects at school, in higher education, and into professional STEM pathways. Such approaches could entail, among other elements:

- Recognition of indigenous Australian knowledge in science and mathematics curricula, providing that this draws on systematic research into indigenous Australian perspectives, as well as appropriate international examples such as those from Canada, the United States and New Zealand;

- Involvement of indigenous elders in this research, and in the ensuing development of curriculum and teacher professional learning support;

- Compilation of recent and existing educational programs and practices and support structures, which have proved effective in Australia.

Key finding 13.2: Programs and activities designed to facilitate indigenous students' learning and work in STEM-related disciplines

The experience of Canada, the United States and New Zealand point to common findings concerning the characteristics of programs successful in attracting and retaining indigenous students in tertiary STEM pathways. Programs and activities designed 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;

- 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;

- Higher education institutional structures and activities including specialist societies, mentors, and career counselling;

- Curriculum initiatives and professional learning for higher education teaching staff.

Key finding 13.3: Professional development regarding STEM and indigenous students

The Canadian report in particular makes clear the critical role of professional development in successfully engaging indigenous students in school science and mathematics. Professional development regarding STEM and indigenous students could include:

- Recognition and respect for indigenous ways of knowing; and

- Culturally responsive teaching, whereby students from indigenous backgrounds are supported in engaging effectively with scientific thinking and practices; and also

Programs and activities designed to facilitate indigenous students' learning and work in STEM-related disciplines.

14 Partnerships and enrichment activities

In addition to strategies and programs within formal education, some governments foster science learning and popularisation outside educational institutions (see also Section 15), and encourage partnerships between civil and business organisations, and education institutions. Much such activity also occurs without the involvement of government, though the incidence of independent initiatives varies between countries. In the United Kingdom, according to the consultants' report:

> In addition to STEM education through school and university, a third landscape of science education and engagement takes place out of school. Referred to as 'informal' or 'life-long' science education, amongst other names, for the purposes of this report, we note that in the UK there has been considerable investment in science engagement and education activities in science centres, museums, science festivals, and other environments, that we will refer to here as informal contexts. Alongside activities designed to educate are a host of activities that fall under the broad banner of public engagement with science. These activities are less explicitly education, with a focus instead on science as part

of culture or the political aspects of science in society. With the House of Lords (2000) report which foregrounded the political need for dialogue, debate and discussion on scientific issues in British society, new funding streams for science engagement activities meant that public engagement with science came to refer to educational, as well as cultural and political science engagement activities. As a result, the last 20 years has seen a blurring of informal science education activities with political and cultural science engagement, which has also meant a significant amount of science education and engagement has taken place outside schools and universities.

In many countries there are initiatives that involve partnerships between education institutions (schools, technical education providers and universities), research institutions, industry (companies and professional associations), government and the community. There are also numerous examples of 'enrichment activities' that essentially complement institutionalised education. Such activities frequently involve young people, families, and the broader public. Enrichment activities provide opportunities for authentic learning, elite and remedial education, student engagement by exploration of the identity construct, and sharing good practice. These partnerships provide students with access to STEM professionals, and contemporary practices in STEM, including interdisciplinary teams, and interactions with societal needs.

Partnerships

- In Taiwan, partnerships involving industrial-academic collaboration are a mechanism to support enhanced fundamental research and development activity, the development of incubators in new knowledge-based firms and entrepreneurial technology transfer (commercialisation and patenting activities). Such collaborations span up-, mid- and downstream scientific technological development, and are supported by *Regulations Governing University Industrial-Academic Collaboration*. The collaborations encourage funding from industry to universities, including industry-sponsored research, and include opportunities for investigation of 'real-world' applied research problems. For example, the Ford Company has established a partnership with a number of technical universities which involves Ford technical staff teaching in university and university students visiting the Ford Company.

- In Western Europe, *Xperimania* is a partnership between the Association of Petrochemical Producers in Europe and education institutions to promote chemistry and physics to students.

- In the United States, *Skills for America's Future* was established as a national network of partnerships among industry, community colleges, professional associations to bridge the skills gap. Similarly, *Education to Innovate* has been established in the United States as a public-private partnership to foster interest and engagement in STEM through out of school activities.

- In China, partnerships between universities, research institutes, university-affiliated technology-based enterprises, and industry more broadly have been established to drive the innovation system, support knowledge transfer and increase commercialisation. For example, the Bainbridge Program run by Royal Phillips Electronics with Shanghai Jiaotong University involves joint laboratories and projects; and the Microsoft China Company's collaboration with Chinese universities involves students undertaking internships at Microsoft alongside the Microsoft certification exam.

- In Western Europe, there are a number of community-based partnerships involving schools and local councils (for example the 'Pencil' project). In the United Kingdom, STEMNET, an educational charity, co-ordinates STEM ambassadors, STEM clubs and an advisory schools network. In France, there are national non-government organisations dedicated to enhancing student interest teacher support, resource production or outreach such as 'La main a la Pate' and Universciences in France.

- In New Zealand, there are biotechnology and science learning hubs which produce online engagement material.

Enrichment activities

- Learning experiences outside the classroom (LEOTC) include National Science Week, camps, science centres, museums, zoos, planetaria, aquaria, botanical gardens, science parks, science fairs, historic parks, performing arts and science centres. These activities provide opportunities for authentic, hands-on, interactive learning, and are frequently made available to people of all ages.

- Competitions include Olympiads (physics, mathematics, chemistry, geo-science, engineering), Amazing Science-X Challenge, National Junior Robotics Competition and the Science Award. These activities frequently involve elite education, and are targeted at high achieving school and university students.

- Real-world science activities include 'Meet the Scientist', excursions, hands-on projects, internships, work experience, simulation, activities that students connect with personally, and make science relevant and meaningful. These activities concern the identity construct.

- Support such as mentoring, coaching, science talks, interest groups, 'after-school activities', 'second classrooms', subject-related clubs, student-interest clubs, over-age students, school-university-industry mentoring, confidence-based contracts, I Like Science Project, scientific and technical workshops, laboratories, individual learning plans, financial literacy, and the Israel Technology Transfer Network. These activities provide either remedial support and/or elite education.

- Networking and sharing resources such as the national French framework of activities/programs which is overseen by regional inspectors in each regional education authority, and the 'Ambition and Success Network' for sharing of good practice.

Evaluation outcomes

While the consultant's reports provide a wealth of examples, evaluation results were only provided with respect to a limited number of activities identified. For example, the New Zealand Biotechnology materials, La main de la Pate and STEMNET were all evaluated positively, and the United Kingdom audit office found that enrichment activities could be linked to improved senior secondary school students' science and mathematics grades. The United Kingdom consultants' report makes the point that while enrichment activities have very strong anecdotal support, a clear case has not been forthcoming concerning their impact on students. Very often these projects have not been subject to critical scrutiny.

In Australia there are many examples of the type described in these consultants' reports of partnerships between universities and industry, and with overseas higher education institutions. There are examples for instance of four way collaboration between Australian and Chinese universities and enterprises which do business in both Australia and China. There are many examples of students embedded in companies as part of their undergraduate studies, or spending time at overseas institutions. Links with industry need, however to be improved. Whilst Australia has above the OECD average number of researchers, it is well below average for the number of business researchers (DIISRTE 2012). Australia was ranked low in the OECD for collaboration between business and higher education and government research institutions. The importance of collaboration and partnerships (and Australia's relative low standing) is also highlighted in the Report of the 2011 ATN-G08 Symposium *Excellence in Innovation: Measuring the Dividend* (ATN-G08 Symposium 2011).

Cooperative Research Centres (CRCs) are examples of collaborative arrangements with industry, for instance embedding researchers and PhD students in industry based laboratories. The vocational education system has a very strong network of

industry based part time lecturers at TAFE Institutes and other Registered Training Organisations (RTOs) to ensure the currency and industry relevance of the AQF certificates and diplomas.

There have been some notable engagements with school science by peak scientific bodies that have yielded considerable benefit to the teaching and learning of science in schools. Examples of these are the Academy of Science's 'Primary Connections' project which has developed an innovative approach to teaching science in primary schools that has achieved national scope, and their 'Science by doing' project which is currently developing materials in teacher professional learning, and in student resource materials. ATSE have developed the STELR program which has reached hundreds of schools and is being enhanced with an innovative digital planning platform. The CSIRO's Scientists and Mathematicians in Schools programs have been very positively evaluated.

Separate from these programs with a national focus there are many such partnership and outreach activities in Australia that anecdotally can be very effective. However, they are not coordinated, often not evaluated, nor are their outcomes clearly defined. Schools can often be resistant to such out-of-curriculum activity given the busy lives of teachers, and the sustainability of the initiatives is variable, depending on a number of contextual factors (Tytler et al. 2011b).

Given the successful outcomes of such partnership activities reported in a number of countries, there is a need to better understand how they can be devised and implemented to ensure significant outcomes. There is a need to develop better understandings of how these partnerships and outreach practices can

Key finding 14.1: STEM Partnerships

Successful partnership initiatives in a number of STEM-strong countries demonstrate the important role of partnerships in supporting innovation in school mathematics and science. While partnership activities are common in Australia, clear understandings of their nature and their effects is often lacking. An approach to STEM partnerships could include:

- Developing an understanding of the scale, scope and variety of STEM-related partnership and enrichment initiatives in Australia – many of which are localised in nature – and of their nature, aims, and effectiveness.

- Coordinating the sharing of details about the relevant initiatives, and develop advice for science organisations, business and industry, and school authorities, concerning how best to manage these to good effect.

be effectively embedded into schools' STEM curriculum offerings, and how to encourage schools to be open to such initiatives.

Scientists and mathematicians need to be supported to better understand the needs of teachers and schools in this sort of partnership activity. Schools need to be made aware of the advantages of these activities for student learning and engagement, and ways of arranging the school curriculum to incorporate such activities.

15 National STEM coordination

Many of these reports describe a comprehensive STEM policy framework that integrates activity across the many dimensions including industry, research and development, universities, schools, and the public. Many also describe high level, national agencies or centres through which the whole or parts of the policy are enacted.

This country comparison project has examined initiatives focused on STEM participation. The issue addressed in this section is therefore the need for coordination of approaches to STEM policy in relation to perceptions of STEM, and education. These 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 in STEM by particular groups including girls and women, low SES communities, and indigenous communities. For each of these, the case exists for coordination of response at national level, in order to gather expertise and maximise the possibility of effective intervention.
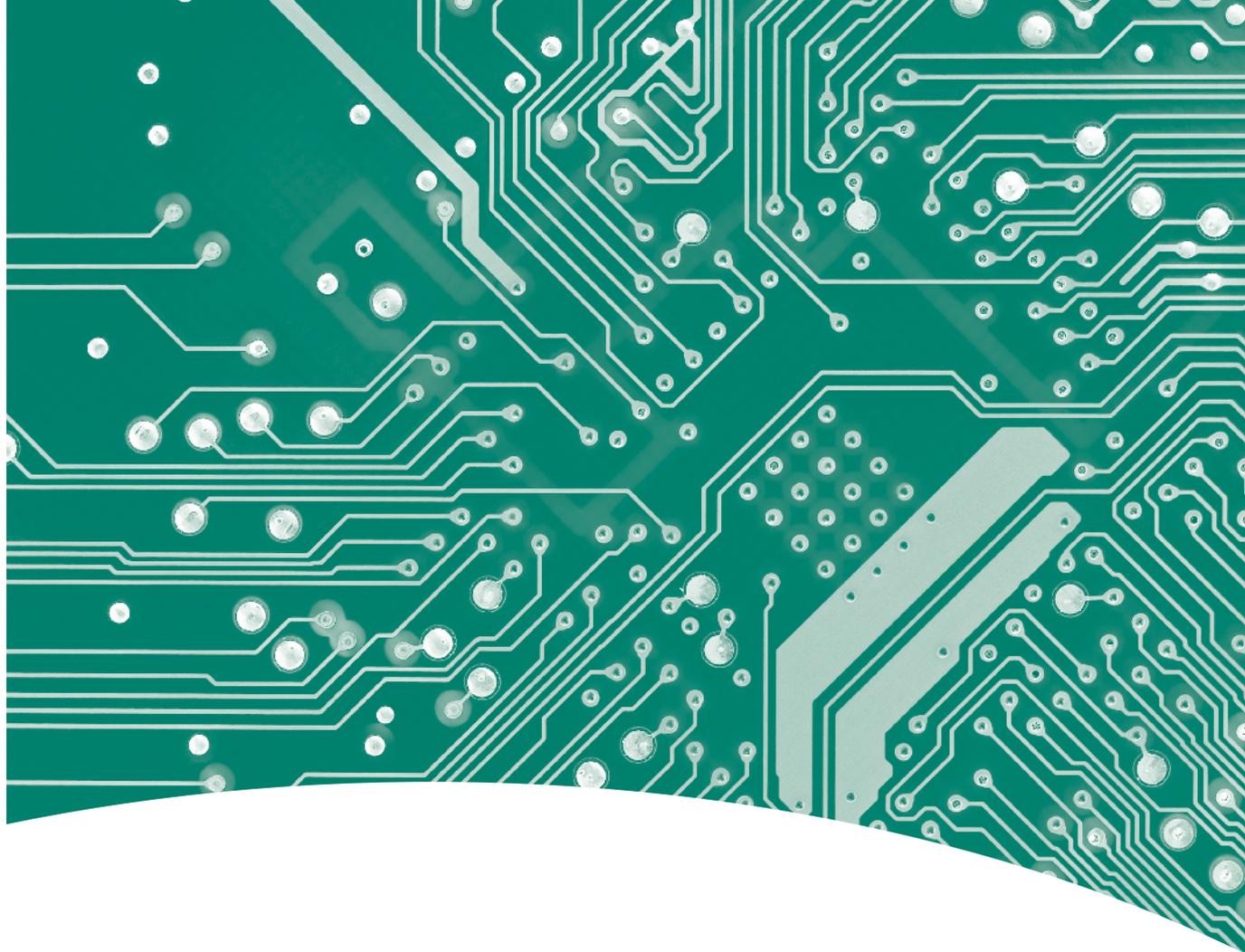
The need for a coordinated national response to STEM participation issues

Currently in Australia, STEM policy in schools is vested in the states. In Australia, a Science & Maths Education & Industry Advisor has recently been appointed within the Office of the Chief Scientist to oversee coordination across the country. Compared to the situation in similar countries, however, where significant structures including centres are common, the level of input of advice, and the capacity to commission studies and generate resources seems limited. There have been notable instances of national guidance and innovation relating to curriculum, and teacher education, which provide an effective proof of concept for a more encompassing national approach in this area.

National direction regarding school mathematics and science education has been provided through the Australian Curriculum, and in this and a previous version (in 1987), the effect has been dramatic in unifying the language through which curriculum is conceived of in Australia. The 1987 curriculum established the language of 'outcomes' as the guiding principle, as well as providing leadership in conceptualising purposes. Even though the curriculum was not directly adopted across all states, it significantly affected what happened in state curricula in the ensuing years and provided a platform for the current curriculum initiative. For the current Australian Curriculum, the move towards a competency focus and the inclusion of the 'Science as a Human Endeavour' dimension has changed the language used in all states, concerning the purposes of science.

There has not been, however, a significant accompanying project to develop the necessary professional learning for teachers to support the changed practices implied in the curriculum document, nor assessment to support the widened set of curriculum purposes. The importance of teachers and teaching highlighted by this report suggests a need for national leadership to address this issue.

The most significant non-governmental developments of curriculum and pedagogy with national reach have been carried out by the Academy of Science, with its Primary Investigations, then Primary Connections, and Science by Doing initiatives. Primary Connections has had varied take up across the states but is a significant resource in each state, and has established the principle of disciplinary literacy competence as a major driver in thinking about primary school science, across Australia. Primary Connections included a significant professional development component but this was of short term duration over the life of project development. Science by Doing has produce professional learning materials for teachers that are based on widely agreed principles. The STELR program which is in some schools in all states is currently offering significant digital planning innovation for teachers.

Thus, there are significant projects in science that demonstrate clearly the strength of a national approach to development of curriculum and resources. However there are significant areas of science and mathematics education and STEM participation more generally, described in this report and listed above, which are not addressed by these projects and approaches.

There is a case to be made for coordination at national level for each of these aspects of STEM participation. Given the interrelationship between these aspects, particularly relating to school curriculum, pedagogy, teachers and teaching, and resources, there is a further argument to be made that these aspects of policy development should be the remit of one coordinating process or agency. This is the case with almost all countries reported.

The benefits of such coordination at national level are: the coherence it could bring, the enhanced status of STEM deriving from a coordinated national approach, the advantages of drawing on significant Australian expertise, and the possibility of developing approaches providing continuity beyond election cycles. The coordination process envisaged would gather together expertise to develop policy options and advice on these various aspects.

The further question to be addressed in this section concerns the process by which this coordination occurs. The consultants' reports offer many examples of the operation of Centres focused on STEM policy and its implementation, from which we might draw.

What other countries do

In the consultants' reports, in almost all instances, structures such as centres, agencies and institutes have been established as part of the STEM infrastructure. This ranges from high level, advisory bodies comprising government ministers and professional association stakeholders, through national STEM or science centres with varying responsibilities, networks to support advances in STEM education and teaching quality, and STEM-discipline research-focused organisations. Many such structures are physical; some appear to be virtual.

There are a variety of objectives, ranging from the provision of advice to government; communication of science to the community and stimulation of young people's interest in STEM education and professions. In addition, such structures provide a mechanism to support STEM education and STEM teaching quality; conduct enrichment activities; support STEM-discipline research and research-focused partnerships; undertake research regarding STEM education; and progress Indigenous STEM science and education. Several seek to do many of these things.

Key differentiating features include the relationship with government (advisory regarding

STEM policy; implementation of government STEM policy or strategy; not-related), level and breadth (regional, national, provincial, local), objectives (broad, focused), and role (advice, promotion, resources, activity-based, and research-focused). What is clear is that most countries have a series of structures or centres to provide a focal point for STEM.

Centres providing advice to government

The Canadian Science, Technology and Innovation Council is a strategic authority established by the Canadian government to centralise science and technology advice. Similarly, the Taiwanese Science and Technology Advisory Group is a science- and technology-focused advisory authority.

Centres communicating science and stimulating interest

InGenius is the European Union co-ordinating body for STEM education, established by European Schoolnet and the European Roundtable of Industrialists (ERT). InGenious comprises European Union ministries of education and industry, and focuses on science communication. InGenius provides a best practice STEM education resource repository and aims to stimulate interest in STEM education and professions. European Schoolnet (EUN) comprises European Union ministries of Education, and provides information to STEM teachers on innovative pedagogy, creative STEM curriculum and strategies to engage industry.

STEM networks established in the United Kingdom include the Science, Technology, Engineering and Mathematics Network (STEMNET), established as an educational charity with national and regional hubs to engage students and support STEM programs (STEM Ambassadors, STEM Clubs Network and Schools STEM Advisory Network). Similarly, the South African Association for Science and Technology Education Centres (SAASTEC) performs a science communication function, and seeks to advance science and technology. The Korea Institute

for the Advancement of Science and Creativity (KOFAC) promotes science and technology-related cultural activities, focuses on science and creativity communication, supports STEAM, and implements enrichment activities.

Centres supporting STEM education and STEM teaching quality

In the United Kingdom, a national network of Science, and Mathematics Learning Centres has been established in response to a lack of structured science teacher training, accreditation, recognition and professional development. The centres support subject-related continuous professional development through financial support for participating teachers. These were well reviewed in a report of the Audit office as one of the initiatives that had been evaluated positively.

In 2004 Professor Celia Hoyles was appointed to the position of the United Kingdom government's Chief Adviser for Mathematics. In 2007 she was appointed as Director of the National Centre for Excellence in the Teaching of Mathematics. These initiatives for mathematics education arose from a well-respected report by Prof Adrian Clark concerning the need to take action concerning participation and learning in mathematics. These initiatives could form models for structures to enhance mathematics and science in Australian schools.

In Western Europe there are numerous national STEM centres supporting STEM education For example, Finland's National Science Education Centre (LUMA) promotes science education, facilitates partnerships between schools, universities, industry, teachers and others, conducts enrichment activities such as the Science Fair and Millennium Youth Camp and is supported by a network of science education centres located at Finnish universities. Other Western European centres include the Norwegian Centre for Mathematics Education and Centre for Science Education; Belgium RVO-Society; Dutch Freudenthal Institute for Science and Mathematics Education; Switzerland MINT; and Danish Centre for Science, Technology and

Health. These centres implement a range of programs and strategies to support STEM. French national non-government organisations also include *Universciences*, which seeks to stimulate students' interest in sciences and make scientific and technical culture accessible. The *La main a la Pate* represents a co-operative scientific organisation with international links that seeks to improve science and technology teaching for primary and secondary school levels.

The New Zealand Mathematics and Science Taskforce, established by the Ministry of Education has developed STEM resources including 'Connected' to stimulate primary school students interest in science, technology and mathematics; Building Science Concepts booklets; and the Numeracy Development Project. The Israeli Science and Technology Administration, located within the Ministry of Education establishes STEM education goals, develops STEM curriculum and related pedagogies, monitors achievement and co-ordinates implementation of the *Adapting the Education System to the 21st Century*.

Centres conducting enrichment activities

In the United Kingdom, Science Centres following the model of the Exploratorium in San Francisco have been established to provide co-ordinated enrichment science education activities. In Portugal, the National Agency for Scientific and Technological Culture (*Ciencia Viva*) co-ordinates a range of enrichment activities including Science and Technology Week, science in the summer, the Robotics Open Festival, MIT professors go to school, the ORION amateur scientific association, debates with scientists, Census Viva, the LONGEVA project, ethnomathematics, the FORUM ciencia viva and Champimovel Project. The national agency is supported by *Ciencia Viva* interactive science centres.

Singapore's education system is supported by numerous 'out-of-school' or extra-curricula science and mathematics activities. Science Centre Singapore supports science activities

for pre-schoolers and organises enrichment activities. The Singapore Academy of Young Engineers and Scientists (SAYES) is a youth science movement that conducts enrichment activities including field trips, co-ordinates lectures by Nobel Laureates and scientists, provides training programs and conducts peer group activities.

Centres involving STEM-discipline research and research-focused partnerships

In Taiwan, Regional Industrial-Academic Collaboration Centres provide opportunities for industrial-academic interchange, exploration of potential R&D partners, and subsidised college technology R&D. These relationships are supported by the *Implementation Guidelines for the Promotion of Industrial-Academic Collaboration between Technical Colleges and Universities and Industry Parks*. The French National Association for Research and Technology (ANRT) and INRIA are dedicated to the study of technology and digital sciences, and are actively engaged in research, innovation and development of European partnerships to improve research. The French Institute for Engineering Sciences and Systems (INSIS) of the National Center for Scientific Research (CNRS) focus on engineering research.

The Singapore Agency for Science, Technology and Research (A*STAR) provides funding for science, technology and engineering research, co-ordinates R&D in science and technology, attracts scientists and industry to Singapore. A*STAR has several councils, including the Biomedical Research Council, Science & Engineering Research Council and Exploit Technologies. Singapore's Biopolis and Fusionopolis shared research facilities and equipment also support science and technology research. In China, National Technology Transfer Centres, based at universities, support the transfer of technology to industry; and various independent agencies support science and technology from a central and devolved perspective.

Centres involving research regarding STEM education

The French Institute for Education (ENS-INRP) and University of Burgundy's institutes and laboratories examine policies and produce research pieces to collaborate with government on STEM education. The centre supports STEM programs such as National Mathematics Conference. The French Evaluation Agency for Research and Higher Education (AERES) evaluates tertiary institution's performance and managerial efficacy.

Most of the federal government support for research and scholarship at Canadian academic institutions is distributed through competitive processes operated by three specialised Councils with jurisdiction over their respective areas

Key finding 15.1: Possible forms and activities in relation to national STEM coordination

There are many examples of potent policy and coordination regimes in our comparator countries, that express the urgency with which national STEM agendas are being pursued, and the benefits of coherence across STEM related areas. National coordination could make a significant contribution to the enhancement of STEM provision and participation in Australia, as it already does in many other countries. Areas of activity in which national coordination might add value to STEM provision and participation include:

- The compilation of data concerning participation and performance in STEM education.

- The generation and dissemination of knowledge concerning effective, evidence based approaches to engagement with quality learning in STEM fields, drawing on international and Australian experience, and on the relevant research literature.

- Coordination and networking of policies, strategies and programs designed to enhance approaches to STEM-related teaching and learning in schools, consistent with the Australian Curriculum, including the coordination of resource development and dissemination across the States and Territories.

- Coordination and networking of policies, strategies and programs designed to enhance approaches to STEM-related teaching and learning in tertiary education, including outreach and placement activities in partnership with schools and with industry.

- Coordination of principles and approaches to professional development in relation to STEM teaching, and support structures for teachers of mathematics and science, designed to build the capacity and status of the profession and to support improvements in student learning.

- Coordination of approaches to the enhancement of knowledge and advice regarding STEM pathways, courses and careers.

- Coordination of approaches to partnership and mentoring designed to support STEM education in schools and tertiary institutions.

- Coordination of policy and program development in relation to the participation in STEM of students from under-represented groups, including girls and women (particularly in relation to engineering), low SES students and disadvantaged school communities, including regional, rural and remote communities, and indigenous communities.

- Coordination of approaches to enhancing public, student and employer perceptions of the potential contributions of STEM, and better understanding of STEM in education, work and careers.

of focus; the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council (NSERC), and the Social Sciences and Humanities Research Council (SSHRC). These Councils jointly share the responsibility for administering, adjudicating, and monitoring the distribution of federal research grants in pursuit of high-quality research and in service to the social and economic well-being of Canada and its citizens.

Centres to progress Indigenous STEM science and education

The United States National Consortium for Graduate Degrees for Minorities in Science and Education (GEM) supports Indigenous student participation in tertiary education science. Various United States based coalitions are established between K-12 school systems, colleges and universities, informal science education organisations, business and industry to address STEM issues, streamline the co-ordination of STEM education research and disseminate successful STEM education activities.

Options for Australia

There is a compelling argument to be made, based on the experience of other countries and on current developments in Australia, for national coordination of approaches to improving participation in STEM.

Australia being a federal system, many of the structures from other countries cannot translate immediately. Nevertheless, the weight of the examples points strongly to the need for some sort of coordinating body or agency to provide advice and leadership on key aspects of STEM participating policy, and in most cases also responsibility for policy administration.

A separate issue concerns the implementation of the policy advice. Most countries have set up one or more centres with responsibility for implementation of some or all aspects of such policy, including commissioning special projects. These sometimes, as in the United States, involving public-private partnerships.

A possible way forward is offered by one well-regarded and positively evaluated model used in the United Kingdom, that of a national mathematics advisor, supported by a high level advisory body.

Key finding 15.2: Possible coordination structures

In the key comparator countries there are a variety of structural approaches to national coordination of STEM initiatives. Australia could productively learn from these. Approaches could take a number of possible forms, not all mutually exclusive, including for example:

- a specially constituted national STEM body (i.e. an agency or centre) reporting to an appropriate government office or department

- an advisory body with State and Territory government representation

- an advisory body with broad representation of peak stakeholder groups including industry, STEM educator and research bodies, and education systems.

The key aspects of such a body or bodies needing considered discussion are the national overview that would be required, the capacity to establish working groups to deal with distinct issues, and the capacity to commission research and to focus resources.

Acronyms

A*STAR	Singapore Agency for Science, Technology and Research
AAMT	Australian Association of Mathematics Teachers
ABS	Australian Bureau of Statistics
ACARA	Australian Curriculum, Assessment and Reporting Authority
ACER	Australian Council for Educational Research
ACOLA	Australian Council of Learned Academies
ACT	Australian Capital Territory
AERES	Evaluation Agency for Research and Higher Education
AI	American Indian
AITSL	Australian Institute for Teaching and School Leadership
AMSI	Australian Mathematical Sciences Institute
AN	Alaska Native
ANAO	Australian National Audit Office
ANRT	National Association for Research and Technology
AQF	Australian Qualification Framework
ARC	Australian Research Council
ASERA	Australasian Science Education Research Association
ASPA	Australian Secondary Principals Association
ASTA	Australian Science Teachers Association
ATAR	Australian Tertiary Admission Rank
ATSE	Academy of Technological Sciences and Engineering
AWPA	Australian Workforce and Productivity Agency
BEST	Building Engineering and Science Talent
BIS	Department of Business, Innovation and Skills
CCSS	Common Core State Standards

CEDEFOP	European Centre for the Development of Vocational Training
CIHE	Council for Industry and Higher Education
CIHR	Canadian Institutes of Health Research
CNSR	National Center for Scientific Research
COAG	Council of Australian Government
CoSTEM	Co-ordinating Federal Science, Technology, Engineering and Mathematics
CPAS	Centre for the Public Awareness of Science
CPD	Continuing Professional Development
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEEWR	Department of Education, Employment and Workplace Relations
DfES	Department for Education and Skills
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education
EC	European Communities
EFT	Effective Full Time
ERT	European Roundtable of Industrialists
EU	European Union
EUN	European Schoolnet
EWG	Expert Working Group
F-10	Foundation to Year 10
GCA	Graduate Careers Australia
GCSE	Graduate Certificate of Secondary Education
GDP	Gross Domestic Product
GDS	Graduate Destination Survey
GEM	National Consortium for Graduate Degrees for Minorities in Science and Education

GPS	Global Ph.D. Fellowship
HSC	Higher School Certificate
ICT	Information Communication Technology
IEA	International Association of the Evaluation of Educational Achievement
INSET	In-Service Education and Training
INSIS	Institute for Engineering Sciences and Systems
ISCED	International Standard Classification of Education
JST	Japanese Science and Technology Agency
K-12	Kindergarten to Year 12
KAIST	Korea Advanced Institute of Science and Technology
KOFAC	Korea Institute for the Advancement of Science and Creativity
LEOTC	Learning Experiences Outside The Classroom
LUMA	National Science Education Centre
MEXT	Ministry of Education, Culture, Sports and Science and Technology
MST	Mathematics, Science and Technology
NAP–ICT	National Assessment Program – Information & Communication Technology
NAP-SL	National Assessment Plan – Scientific Literacy
NAPLAN	National Assessment Program – Literacy and Numeracy
NASA	National Aeronautics and Space Administration
NCVER	National Centre for Vocational Education Research
NECC	National College Entrance Examination
NILS	National Institute of Labour Studies
NOAA	National Oceanic and Atmospheric Administration
NSERC	Natural Sciences and Engineering Research Council
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OSTP	Office of Science and Technology Policy
PCAST	President's Council of Advisors on Science and Technology
PhD	Doctor of Philosophy
PISA	Program for International Student Assessment
PMSEIC	Prime Minister's Science, Engineering and Innovation Council

QCE	Queensland Certificate of Education
R&D	Research and Development
ROSE	Relevance of Science Education
RTO	Registered Training Organisation
S&T Law	Science and Technology Basic Law (Kagaku Gijutsu Kihon Hō)
SAASTEC	South African Association for Science and Technology Education Centres
SACE	South Australian Certificate of Education
SAF	Securing Australia's Future
SAYES	Singapore Academy of Young Engineers and Scientists
SCOTESE	Standing Council on Tertiary Education Skills & Employment
SES	Socio-Economic Status
SET	Science, Engineering and Technology
SiAS	Staff in Australia's Schools
SSHRC	Social Sciences and Humanities Research Council
STEAM	Science, Technology, Engineering, Arts and Mathematics
STELR	Science and Technology Education Leveraging Relevance
STEM	Science, Technology, Engineering and Mathematics
STEMNET	Science, Technology, Engineering and Mathematics Network
STEP	STEM Talent Expansion Program
TAFE	Technical and Further Education
TCE	Tasmanian Certificate of Education
TIMSS	Trends in International Maths and Science Study
UNESCO	United Nations Science, Education and Cultural Organization
VCAL	Victorian Certificate of Applied Learning
VCE	Victorian Certificate of Education
VET	Vocational Education and Training
WACE	Western Australian Certificate of Education
WATCH21	Women's Academy for Technology Change in the 21st Century
WCU	World Class University
WISET	Korea Advanced Institute of Supporting Women in Science, Engineering and Technology

Bibliography

ACARA 2012, *Australian Curriculum Implementation Survey*, Australian Curriculum, Assessment and Reporting Authority, Sydney, viewed 11 January 2013, http://www.acara.edu.au/curriculum_1/learning_areas/mathematics.html

ACARA 2012, *NAPLAN Achievement in Reading, Persuasive Writing, Language Conventions and Numeracy: National Report for 2012,* Australian Curriculum, Assessment and Reporting Authority, Sydney, viewed 6 January 2013, http://www.nap.edu.au/verve/_resources/NAPLAN_2012_National_Report.pdf

Ainley, J, Kos, J & Nicholas, M 2008, *Participation in science, mathematics and technology in Australian education,* Research Monograph no. 63, ACER, Melbourne.

Ainsworth S, Prain V & Tytler R 2011, 'Drawing to Learn in Science', *Science*, vol. 333, pp. 1096 – 1097.

AMSI 2012a, *Discipline Profile of the Mathematical Sciences*, Australian Mathematical Sciences Institute, Melbourne.

AMSI 2012b, *Forum Communique* (press release), Australian Mathematical Sciences Institute, Melbourne.

ANAO 2012, *Audit Report No.41 2011–12 Performance Audit National Partnerships Agreement on Literacy and Numeracy*, Australian National Audit Office, Canberra, viewed 5 January 2013, http://www.anao.gov.au/~/media/Uploads/Audit per cent20Reports/2011 per cent2012/201112 per cent20Audit per cent20Report per cent20No41.pdf

ATN-G08 Symposium 2011, *Excellence in Innovation: Measuring the Dividend,* viewed 22 March 2013, http://www.go8.edu.au/__documents/go8-policy-analysis/2012/atn-go8-report-web-pdf.pdf

Au, W 2007, 'High Stakes Testing and Curricular Control: A Qualitative Metasynthesis', *Educational Researcher,* vol. 36, no. 5, pp. 258-267.

Australian Government 2009, *Powering Ideas: An Innovation Agenda for the 21st Century*, viewed 6 January 2013 http://www.innovation.gov.au/Innovation/Policy/Documents/PoweringIdeas.pdf

Australian Government 2009, *Transforming Australia's Higher Education System*, Australian Government, Canberra, viewed 11 January 2013, http://www.innovation.gov.au/HigherEducation/Documents/TransformingAusHigherED.pdf

Australian Government 2012, *National Plan for School Improvement – FAQs*, Australian Government, Canberra, viewed 31 December 2012, http://www.schoolfunding.gov.au/node/148#how-long-will-it-take-to-implement

AWPA 2012, *Future focus: Australia's skills and workforce development needs Discussion paper*, Australian Workforce and Productivity Agency, Canberra, viewed 1 March 2013 http://www.awpa.gov.au/publications/documents/Future-Focus-Australias-skills-and-workforce-development-needs-Discussion-Paper.pdf

Banner, I, Donnelly, J, Homer, M & Ryder, J 2010, 'The impact of recent reforms in the KS4 science curriculum', *School Science Review,* vol. 92, no. 339, pp. 101-109.

Barrington, F 2011, *AMSI Interim Update on Year 12 Mathematics Student Numbers*, 2011, Australian Mathematical Sciences Institute, Melbourne.

Barro, R 2001, 'Human capital and growth', *American Economic Review,* vol. 91, no. 2, pp. 12-17.

Bell, S 2010, 'Women in science: The persistence of gender in Australia', *Higher Education Management and Policy,* OECD Publishing, vol. 22, no. 1, pp. 1-19.

Blenkinsop, S, McCrone, T, Wade, P, & Morris, M 2006, *How do young people make choices at 14 and 16?*, Department for Education and Skills, viewed 19 March 2013, http://dera.ioe.ac.uk/6449/1/RR773.pdf

Breakspear, S 2012, *The policy impact of PISA: An exploration of the normative effects of international benchmarking in school system performance*, OECD Education Working Papers, vol. 71 pp. 1-30.

Broadbridge, P & Henderson, S 2008, *Mathematics Education for 21st Century Engineering Students,* Australian Mathematical Sciences Institute, Melbourne, viewed 26 February 2013, http://scholar.google.com.au/scholar?cluster=18143973785765796401&hl=en&as_sdt=0,5&as_vis=1

Bush, V 1945, *Science, the Endless Frontier*, United States Government Printing Office, Washington, viewed 20 March 2013, http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm

Congress of the United States of America 2010, *America COMPETES Act*, viewed 20 March 2013, http://thomas.loc.gov/cgi-bin/query/z?c111:H.R.5116:

Coupland, M 2006, *A critical analysis of selected Australian and international mathematics syllabuses for the post-compulsory years of secondary schooling*, Report prepared for the NSW Board of Studies, Sydney, viewed 19 March 2013, http://www.boardofstudies.nsw.edu.au/manuals/pdf_doc/maths_st6_lit_curr_rev_pt1.pdf

Cutler and Company 2008, *Venturous Australia – building strength in innovation*, viewed 6 January 2013, http://www.innovation.gov.au/Innovation/Policy/Documents/NISReport.pdf

DEEWR 2012a, *Skills Shortage List Australia,* Department of Education, Employment and Workplace Relations, Canberra, viewed 7 January 2013, http://deewr.gov.au/skill-shortages

DEEWR 2012b, *Skills Shortages New South Wales,* Department of Education, Employment and Workplace Relations, Canberra, viewed 7 January 2013, http://deewr.gov.au/skill-shortages

DEEWR 2012c, *Skills Shortages Queensland*, Department of Education, Employment and Workplace Relations, Canberra, viewed 7 January 2013, http://deewr.gov.au/skill-shortages

DEEWR 2012d, *Skills Shortages Tasmania*, Department of Education, Employment and Workplace Relations, Canberra, viewed 7 January 2013, http://deewr.gov.au/skill-shortages

DEEWR 2012e, *Skills Shortages Northern Territory*, Department of Education, Employment and Workplace Relations, Canberra, viewed 7 January 2013, http://deewr.gov.au/skill-shortages

Department for Business Innovation and Skills 2011, *STEM graduates in non STEM jobs*, Department for Business, Innovation and Skills, London.

DfES 2004, *Science & innovation investment framework 2004-2014,* Department for Education and Skills and Treasury, London, viewed 19 March, 2013, http://news.bbc.co.uk/nol/shared/bsp/hi/pdfs/science_innovation_120704.pdf

DIISRTE 2012, *Australian Innovation System Report 2011*, Australian Government, viewed 21 March 2013, http://www.innovation.gov.au/Innovation/Policy/Pages/AustralianInnovationSystemReport.aspx

Dobson, IR 2012, *Unhealthy Science? University Natural and Physical Sciences 2002 to 2009/10*, Report prepared for the Office of the Chief Scientist, viewed 11 January 2013, http://www.chiefscientist.gov.au/wp-content/uploads/Unhealthy-Science-Report-Ian-R-Dobson.pdf

Duggan, S, & Gott, R 2002, 'What sort of science education do we really need?' *International Journal of Science Education*, vol. 24, no. 7, pp. 661–679.

European Centre for the Development of Vocational Training (CEDEFOP) 2012, *RESEARCH PAPER No 26: Future skills supply and demand in Europe: Forecast 2012*, Research Paper no. 26, Publications Office of the European Union, Luxembourg.

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.

European Union 2012, *EU Skills Panorama Analytical Highlight*, viewed 21 March 2013, http://euskillspanorama.ec.europa.eu/docs/AnalyticalHighlights/EngineeringProfessionals_en.pdf

Eurydice 2011, *Science Education in Europe: National Policies, Practices and Research*, European Commission, Brussels.

Federal Coordination in STEM Education Task Force Committee on STEM Education National Science and Technology Council 2012, *Co-ordinating Federal Science, Technology, Engineering and Mathematics 2012, Education Investments: Progress Report*, viewed 19 March 2013, http://www.whitehouse.gov/sites/default/files/microsites/ostp/nstc_federal_stem_education_coordination_report.pdf

Goodrum, D, Druhan, A & Abbs, J 2012, *The Status and Quality of Year 11 and 12 Science in Australian Schools*, Australian Academy of Science, viewed 24 April 2012, http://www.science.org.au/publications/documents/Year11and12Report.pdf

Gonski, D, Boston, K, Greiner, K, Lawrence, C, Scales, B & Tannock, P 2011, *Review of Funding for Schooling – Final Report*, Australian Government, Canberra, viewed 28 December 2012 http://foi.deewr.gov.au/node/30439/

Grek, S 2009, 'Governing by numbers: The PISA 'effect' in Europe', *Journal of Education Policy*, vol. 24, no. 1, pp. 23-37.

Hanushek, E, & Kimko, DD 2000, 'Schooling, labour-force quality and the growth of nations', *American Economic Review,* vol. 90, no. 5, pp. 1184-1208.

Hanushek, EA & Woessmann, L 2008, 'The role of cognitive skills in economic development', *Journal of Economic Literature*, vol. 46, no. 3, pp. 607-668.

Hanushek, EA & Woessmann, L 2009, Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation, *Institute for the Study of Labour Discussion Paper*, no. 4575.

Hanushek, EA & Woessmann, L 2012, 'Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation', *Journal of Economic Growth*, vol. 17, no. 4, pp. 267-321.

Henry et al. 2012, White Paper on *Australia in the Asian Century*, report prepared for the Department of the Prime Minister and Cabinet, viewed 19 March 2013, http://asiancentury.dpmc.gov.au/white-paper

Hobbs, L 2012, Teaching 'out-of-field' as a boundary-crossing event, *International Journal of Science and Mathematics Education*, 1-31.

Hong, S, Hwang, Y, Bae, Y, Hong, S-B, Jung, S, Lee, S, … Huh, H 2010, *Role of science and technology in leading the economic development of Korea and its implications for developing countries*, Science and Technology Policy Institute, Seoul.

House of Lords 2012, *Higher Education in Science, Technology, Engineering and Mathematics*, Select Committee on Science and Technology 2nd Report of Session 2012–13, House of Lords, London.

Jensen, B, Hunter, A, Sonnemann, J, & Burns, T 2012, Catching up: learning from the best school systems in East Asia, Grattan Institute, viewed 21 April 2013, http://grattan.edu.au/publications/reports/post/catching-up-learning-from-the-best-school-systems-in-east-asia/

Kearney, C 2011, *Efforts to increase students' interest in pursuing science, technology, engineering and mathematics studies and careers*, European Schoolnet.

Keating, J, Annett, P, Burke, G & Hanlon, C 2011, *Mapping funding and regulatory arrangements across the Commonwealth and state and territories*, report prepared by the University of Melbourne, commissioned by the Victorian Department of Education and Early Childhood Development on behalf of the Ministerial Council for Education, Early Childhood Development and Youth Affairs, viewed 19 March 2013, http://www.mceecdya.edu.au/verve/_resources/Mapping_Funding_and_Regulatory_Arrangements_-July_2011.pdf

Kingdon, J 1995, *Agendas, Alternatives, and Public Policy*, (2nd ed.) Harper Collins, New York.

Kitazawa, Koichi 2010, Kagaku Gijutsu wa Nihon o Sukuu noka: 'Dai Yon no Kachi' o Mezashite [*Can Science and Technology Save Japan?: Toward the creation of the 'forth value'*], Tokyo: Discover Twenty-One (in Japanese).

Krueger, AB & Lindahl, M 2001, 'Education for growth: Why and for whom?', *Journal of Economic Literature*, vol. 39, no. 4, pp. 1101-1136.

Leiden University 2012, *Leiden Ranking 2011/2012*, viewed 19 March 2013, http://www.leidenranking.com/ranking.aspx

Lyons, T 2006, 'The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together', *Research in Science Education,* vol. 36, no. 3, pp. 285-311.

Lyons, T & Quinn, F 2010, *Choosing Science: understanding the declines in senior high school science enrolments*, National Centre of Science, ICT and Mathematics Education for Rural and Regional Australia, University of New England, Armidale.

Mack, J & Walsh, B 2013, *Mathematics and science combinations NSW HSW 2001-2011 by gender*.

Marginson, S 2011, 'Higher education in East Asia and Singapore: Rise of the Confucian model', *Higher Education,* vol. 61, no. 5, pp. 587-611.

McKenzie, P, Rowley, G, Weldon, P & Murphy, M 2011, *Staff in Australia's Schools 2010: Main Report of the Survey*, Report prepared for the Department of Education, Employment and Workplace Relations by Australian Council for Educational Research, DEEWR, Canberra.

MEXT 2002, *Annual Report on the Promotion of Science and Technology 2002*, Ministry of Education, Culture, Sports, Science and Technology, Japan.

Mullis, IVS, Martin, MO, Foy, P & Arora, A 2012a, *TIMSS 2011 International Results in Mathematics*, International Association for the Evaluation of Educational Achievement, Boston.

Mullis, IVS, Martin, MO, Foy, P & Arora, A 2012b, *TIMSS 2011 International Results in Science*, International Association for the Evaluation of Educational Achievement, Boston.

National Academies' Committee on Science, Education and Public Policy 2007, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* Committee on Science, Engineering and Public Policy, viewed 19 March 2013, http://www.nap.edu/openbook.php?isbn=0309100399

NCVER 2012,Tertiary education and training in Australia 2010, Department of Industry, Innovation, Science, Research and Tertiary Education, viewed 19 March 2013, http://www.ncver.edu.au/publications/2489.html

National Governors' Association 2011, *Building a Science, Technology, Engineering and Maths Education Agenda: An Update of State Actions,* viewed 19 March 2013, http://www.nga.org/files/live/sites/NGA/files/pdf/1112STEMGUIDE.PDF

National Science Board 2009, *STEM Education Recommendations for the President-Elect Obama Administration,* viewed 19 March 2013, www.nsf.gov/nsb/publications/2009/01_10_stem_rec_obama.pdf

OECD 2006, *Evolution of student interest in science and technology studies: Policy report,* OECD and Development Global Science Forum, Paris.

OECD 2010a, *The high cost of low educational performance: The long-run economic impact of improving PISA outcomes*, OECD Publishing, Paris.

OECD 2010b, *PISA 2009 Assessment framework: Key competencies in reading, mathematics and science,* OECD Publishing, Paris.

OECD 2010c, *PISA 2009 Results – What students know and can do: Student performance in reading, mathematics and science*, OECD Publishing, Paris. Volume 1.

OECD 2010d, *PISA 2009 Results – Learning Trends: Changes in student performance since 2000*, OECD Publishing, Paris. Volume 5.

OECD 2010e, Expectations for science-related careers by gender, *OECD Factbook 2010: Economic, Environmental and Social Statistics*, OECD Publishing, Paris.

OECD 2011, *Science, Technology and Industry Scoreboard 2011*, OECD Publishing, Paris.

OECD 2012, *Education at a Glance 2012: OECD Indicators,* OECD Publishing, Paris.

Office of the Australian Qualifications Framework Council 2012, AQF Qualifications, viewed 18 February 2013, http://www.aqf.edu.au/AbouttheAQF/AQFQualifications/tabid/98/Default.aspx

Office of the Chief Scientist 2012a, *Health of Australian Science*, Australian Government, viewed 19 March 2013, http://www.chiefscientist.gov.au/2012/05/health-of-australian-science-report-2/

Office of the Chief Scientist 2012b, *Mathematics, Engineering and Science in the National Interest*, Australian Government, viewed 21 March 2013, http://www.chiefscientist.gov.au/wp-content/uploads/Office-of-the-Chief-Scientist-MES-Report-8-May-2012.pdf

President's Council of Advisors on Science and Technology 2010, *Report to the President Prepare and inspire: K-12 education in science, technology, engineering and math (STEM) for America's future,* viewed 19 March 2013, http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stem-ed-final.pdf

President's Council of Advisors on Science and Technology 2012, *Engage to Excel,* viewed 19 March 2013, http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf

SACE Board of SA n.d., *About the SACE*, viewed 18 February 2013, http://www.sace.sa.edu.au/the-sace/students-families/about-the-sace

Sainsbury, LoT 2007, *The Race to the Top: A Review of Government's Science and Innovation Policies*, HM Treasury, London.

Salmi J 2009, *The Challenge of Establishing World-class Universities*, World Bank, Washington, viewed 19 March 2013, http://siteresources.worldbank.org/EDUCATION/Resourc es/278200-1099079877269/547664-1099079956815/547670-1237305262556/WCU.pdf

SCOTESE 2012, *National Foundation Skills Strategy for Adults*, Standing Council on Tertiary Education Skills & Employment, Canberra.

Sianesi, B & Reenen, JV 2003, 'The returns to education: Macroeconomics', *Journal of Economic Surveys*, vol. 17, no. 2, pp. 157-200.

Smith, DV & Gunstone, RF 2009, Science curriculum and the market liberal society of the 21st century: 'Re-visioning' the idea of Science for All, *Research in Science Education*, vol. 39, pp. 1-16.

Sjøberg, S & Schreiner, C 2010, The ROSE Project: An overview and key findings, Naturfagsenteret, Oslo.

Stacey, K 2003, The need to increase attention to mathematical reasoning. In Hollingsworth, H, Lokan, J & McCrae, B, *Teaching mathematics in Australia: Results from the TIMSS 1999 video study* (pp. 119-122), Australian Council for Educational Research, Melbourne.

Tasmanian Qualifications Authority n.d. *Tasmanian Certificate of Education,* viewed 18 February 2013, http://www.tqa.tas.gov.au/1906#stand

The Science and Technology Basic Law (Chapter 1, Article 1), Law No. 130 of 1995.

Thomson, S, De Bortoli, L, Nicholas, M, Hillman, K & Buckley, S 2010, Challenges for Australian education: results from PISA 2009, Australian Council for Educational Research, Melbourne, viewed 11 January 2013, http://research.acer.edu.au/ozpisa/9

Thomson, S, Hillman, K & Wernert, N 2012a, *Monitoring Australian year 8 student achievement internationally: TIMSS and PIRLS 2011*, Australian Council for Educational Research, Melbourne.

Thomson, S, Hillman, K, Wernert, N, Schmid, M, Buckley, S & Munene, A 2012b, *Monitoring Australian year 4 student achievement internationally: TIMSS and PIRLS 2011*, Australian Council for Educational Research, Melbourne.

Tomei, A, Dawson, E & Dillon, J 2013, *A study of Science, Technology, Engineering and Mathematics education in the United Kingdom*, unpublished.

Tytler, R 2007, *Re-imaging Science Education Engaging students in science for Australia's future*, Australian Education Review, Australian Council for Educational Research, Melbourne.

Tytler, R, Osborne, J, Williams, G, Tytler, K & Cripps Clark, J 2008, *Opening up pathways: Engagement in STEM across the Primary-Secondary school transition*, Department of Education, Employment and Workplace Relations, Canberra, viewed 19 March 2013, http://pandora.nla.gov.au/tep/88047

Tytler, R, Symington, D, Darby, L, Malcolm, C & Kirkwood, V 2011a, 'Discourse Communities: A model for considering professional development for teachers of science and mathematics', *Teaching and Teacher Education,* vol. 27, no. 5, pp. 871-879.

Tytler, R, Symington, D, & Smith, C 2011b, 'A curriculum innovation framework for science, technology and mathematics education', *Research in Science Education,* vol. 41, pp. 19-38.

UNESCO 2007, *Science, technology and gender: An international report,* Science and Technology for Development Series, UNESCO, Division for Science Policy and Sustainable Development.

UNESCO 2010, *Engineering: Issues, challenges and opportunities for development*, UNESCO, the World Federation of Engineering Organisations, the International Council of Academies of Engineering and Technological Sciences, and the International Federation of Consulting Engineers.

Wiseman, AW 2010, Introduction: The advantages and disadvantages of national education policy making informed by international achievement studies. In A.W. Wiseman *The impact of international achievement studies on national education policy making*. Emerald Group Publishing Limited, Bingley.

Expert Working Group

Professor Simon Marginson FASSA (Chair)

Professor Marginson is Professor of Higher Education in the Centre for the Study of Higher Education (CSHE) at the University of Melbourne. He is Joint Editor-in-Chief of *Higher Education*, the principal world scholarly journal in higher education studies. Professor Marginson works in sociology and policy studies in relation to higher education, and comparative and international education. He has held continuous Australian Research Council support for basic research since 1995, including an ARC Australian Professorial Fellowship awarded in 2002. He directed the 2002 ASSA Project on 'The contribution of postgraduate training in the Social Sciences to Australia' and has prepared three OECD policy reports on aspects of higher education and globalisation.

Professor Russell Tytler (Deputy)

Professor Tytler is the Chair in Science Education at Deakin University, deputy director of the Centre for Research in Educational Futures and Innovation (CREFI) and heads the very productive Science, Technology, Environmental and Mathematics Education group. He is also 'hub cap' of the Victorian SiMERR rural and regional network. He has had considerable involvement with science curriculum development in Victoria and nationally, and science education initiatives of the AAS and ATSE. He has been CI on a range of ARC and government funded research and development projects focusing on student learning in science and teacher pedagogy and professional learning. Professor Tytler has been a visiting professor in Universities in Hong Kong and in Sweden.

Professor Stephen Gaukroger FAHA

Professor Gaukroger is currently Professor of History of Philosophy and History of Science at the University of Sydney. He has served as President of the Australasian Association for the History, Philosophy, and Social Studies of Science; President of the Australasian Society for the History of Philosophy; Chair of the Australian Academy of Science National Committee for the History and Philosophy of Science and he is currently President of the International Society for Intellectual History. He is editor of the series Studies in History and Philosophy of Science published by Kluwer, and on the editorial boards of the Australasian Journal of Philosophy, and the British Journal for the History of Philosophy.

Mr David Hind FTSE

David Hind is Chair of Skills Tasmania, an angel investor and Chair of Barefoot Power Pty Ltd, a board member of the childhood cancer charity Redkite and is Director of External Relations at the University of Sydney's School of Chemical and Biomolecular Engineering. He is a past President of the Business Higher Education Round Table (B-HERT) and was a vice Chair of the Education Forum of ATSE. In 2005, David retired as Managing Director of BOC South Pacific following CEO/Chair positions in the UK, Thailand and Japan. He was a member of the Business Council of Australia from 1998 to 2005.

Professor Nalini Joshi FAA

Professor Nalini Joshi is Professor of Applied Mathematics at the University of Sydney. Nalini has taught mathematics at ANU, UNSW, the University of Adelaide and the University of Sydney. She has been a Visiting Professor at Kyoto University in Japan and the University of Leeds, UK. She was Head of the School of Mathematics and Statistics (2007-09), President of the Australian Mathematical Society (2008-10), and is now Chair of the National Committee for Mathematical Sciences and a member of the Council of the Australian Academy of Science. In 2012, she was awarded the Georgina Sweet Australian Laureate Fellowship, to focus on creating new mathematical methods to describe critical solutions of nonlinear mathematical systems, and provide activities to promote and support women and early career researchers in science.

Professor Geoff Prince

Since 2009 Professor Prince has been Director of the Australian Mathematical Sciences Institute (AMSI). Geoff has taught at RMIT, the University of New England and La Trobe. He worked at AMSI in 2004 through to 2006 in part as executive director to Garth Gaudry and he oversaw the introduction of the AMSI/ICE-EM Access Grid Room project. AMSI aims to support research at all levels including mathematics in cross-disciplinary areas, business and industry; enhance the undergraduate and postgraduate experience of students in the mathematical sciences and cognate disciplines; and to improve the supply of mathematically well-prepared students entering tertiary education.

Professor Sue Richardson FASSA

Professor Richardson is Principal Research Fellow and deputy Director of the National Institute of Labour Studies, Flinders University. Her principal research interests are in the fields of the labour market, the ageing workforce, immigration, income distribution and the economic resources devoted to children. She has a part-time appointment as a Member of Fair Work Australia (Minimum Wage Panel). In recent years she has been a member of a number of Boards including the Council for the Humanities, Arts and Social Sciences, the National Academies Forum, the South Australian Certificate of Education, the SA Population Advisory Committee and she led a foresighting group to advise the Prime Minister's Science, Innovation and Engineering Council.

All EWG members have declared any relevant interests.

Acknowledgements

Evidence gathering

Country, regional and special interest reports

The evidence included country, regional and special interest reports:

Anthony Tomei, Emily Dawson and Justin Dillon
King's College London
A study of Science, Technology, Engineering and Mathematics education in the United Kingdom

Adam Maltese, Indiana University
Florin Lung and Geoff Potvin, Clemson University
Craig Hochbein, University of Louisville
STEM Education in the United States

Anna Smolentseva
National Research University – Higher School of Economics, Moscow
Science, Technology, Engineering and Mathematics: Issues of Educational Policy in Russia

Brigid Freeman
University of Melbourne
Science, Technology, Engineering and Mathematics (STEM) in Australia: Practice, policy and programs

Brigid Freeman
University of Melbourne
Snapshots of 23 Science, Technology, Engineering and Mathematics (STEM) consultants' reports: Characteristics, lessons, policies and programs

Cathy Buntting and Alister Jones,
University of Waikato
Liz McKinley and Mark Gan,
University of Auckland
STEM initiatives and issues in New Zealand

Cynthia Fernandez Roich
University of Melbourne
Study of Science, Technology, Engineering and Mathematics (STEM) and STEM-related issues in Argentina

Elodie de Oliveira, OECD
Kelly Roberts, University of Melbourne
Literature Review: STEM Education in France

Gili Drori and Avida Netivi
The Hebrew University of Jerusalem
STEM in Israel: The Educational Foundation of 'Start-Up Nation'

Glen Aikenhead
University of Saskatchewan
Science, Technology, Engineering and Mathematics Education and Related Employment for Indigenous Students and Citizens of Saskatchewan

Hugo Horta
Technical University of Lisbon
Education in Brazil: Access, quality and STEM

Hugo Horta
Technical University of Lisbon
STEM education in Portugal: Education, policies and labor market

Ian Dobson
University of Ballarat
… a critical examination of existing solutions to the STEM skills shortage in comparable [European] countries

Ian Dobson
University of Ballarat
… a critical examination of existing solutions to the STEM skills shortage in comparable [European] countries: Finland Country Report

Jae-Eun Jon, Korea University and
Hae-In Chung, University of Minnesota
STEM Report – Republic of Korea

Josh Healy, Kostas Mavromaras and Rong Zhu
Flinders University
The STEM Labour Market in Australia

Julian Weinrib and Glen Jones
University of Toronto
Canada's Approach to Science, Technology, Engineering and Mathematics (STEM): Context, Policy, Strategy and Programs

Kelly Roberts
University of Melbourne
Literature Review – A selection of the work
of international organizations on STEM
education and STEM-related issues

Noraini Idris, Mohd Fadhil Daud, Chew Cheng
Meng, Leong Kwan Eu and Ahmad Dzohir Ariffin
@ Maarof
University of Malaya
Country Report Singapore STEM

Marilyn Cole
Deakin University
*Literature review update: Student identity in
relation to Science, Technology, Engineering and
Mathematics subject choices and career aspirations*

Mayumi Ishikawa, Shota Fujii and Ashlyn Moehle
Osaka University
STEM Country Comparisons: Japan

Michael Kahn
Stellenbosch University
*Science, Technology, Engineering and
Mathematics (STEM) in South Africa*

Sharon S. Nelson-Barber
Pacific Resources for Education and Learning
(PREL)
US Indigenous STEM Report

Yuan Gao
University of Melbourne
Report on China's STEM System

Yuan Gao
University of Melbourne
*Report on Taiwan: STEM (Science, Technology,
Engineering and Mathematics)*

National Workshop – Transforming STEM Capacity (21 February 2013), Canberra

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Robyn Aitken
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Review Panel

This report has been reviewed by an independent panel of experts. Members of the Review Panel were not asked to endorse the Report's conclusions and recommendations. The Review Panel members acted in a personal, not organisational, capacity and were asked to declare any conflicts of interest. ACOLA gratefully acknowledges their contribution.

Professor Lyn English

Professor English is a professor in the field of mathematics education at the Queensland University of Technology. Her areas of research expertise include mathematical modelling, problem solving, statistical reasoning, the psychology of mathematics education, and engineering education. She is currently the chief investigator on ARC projects addressing students' development of statistical literacy, mathematical modelling, mathematical learning of junior secondary school students, and primary and middle school students' knowledge and awareness of engineering. She is the founding editor of the international journal "Mathematical Thinking and Learning" (Taylor & Francis).

Professor Denis Goodrum

Professor Goodrum is an Emeritus Professor and Executive Director of Science by Doing at the Australian Academy of Science. He is former Dean of Education of the University of Canberra and has been involved in many national and international activities in science education. In 1998 he was a visiting scholar at the National Research Council in Washington DC working on a project examining inquiry and the National Science Education Standards. He is presently Chair of the ACT Teacher Quality Institute. Professor Goodrum has been involved in many national projects including Australian Science Curriculum, Primary Investigations and the Australian School Science Education: National Action Plan 2008–12.

Professor Richard Gunstone

Emeritus Professor Gunstone was previously Professor of Science and Technology Education, and Director (and founder) of the Monash-King's College (London) International Centre for the Study of Science and Mathematics Curriculum. He has extensive research, development and consultancy experience in learning, teaching, curriculum, assessment, and teacher development, in school and undergraduate science, physics, engineering (and to a lesser extent medicine) contexts. Professor Gunstone is a Life Member of the Science Teachers' Association of Victoria and is widely published, including 14 books, 45 book chapters and over 140 refereed research papers. He is frequently invited to address international research conferences.

Dr Doreen Clark AM FTSE

Dr Doreen Clark is a scientist with extensive experience in business. From 1969 to 1998 she was Managing Director of Analchem Bioassay Pty Ltd, she is also a founding director (1991) of Organic Crop Protectants Pty Ltd a firm which develops and markets environmentally friendly agricultural chemicals. This is her major business interest following her retirement from Analchem Bioassay. Doreen trained as an organic chemist, completing a BSc(Hons) degree at Sydney University and a PhD at the University of New South Wales. Dr Clark was a member of a Commonwealth Committee appointed to review Higher Education Financing and Policy which released its report "Learning for Life" in 1998. She was a member of the TAFE Commission of NSW from 1999 to 2007.

About Securing Australia's Future

In June 2012 the Australian Government announced Securing Australia's Future, a $10 million investment funded by the Australia Research Council in a series of strategic research projects for the Prime Ministers Science, Engineering and Innovation Council (PMSEIC), delivered through the Australian Council of Learned Academies (ACOLA) via the Office of the Chief Scientist and the Chief Scientist.

Securing Australia's Future is a response to global and national changes and the opportunities and challenges of an economy in transition. Productivity and economic growth will result from: an increased understanding in how to best stimulate and support creativity, innovation and adaptability; an education system that values the pursuit of knowledge across all domains, including science, technology, engineering and mathematics; and an increased willingness to support change through effective risk management.

PMSEIC identified six initial research topics:

   i.   Australia's comparative advantage

   ii.   STEM: Country comparisons

   iii.   Asia literacy – language and beyond

   iv.   The role of science, research and technology in lifting Australian productivity

   v.   New technologies and their role in our security, cultural, democratic, social and economic systems

   vi.   Engineering energy: unconventional gas production

The Program Steering Committee responsible for the overall quality of the program, including selection of the Expert Working Groups and the peer review process, is comprised of three Fellows from each of the four Learned Academies:

Professor Michael Barber FAA FTSE (Chair)

Mr Dennis Trewin AO FASSA (Deputy Chair – Research)

Professor Ruth Fincher FASSA

Professor Mark Finnane FAHA

Professor Paul Greenfield AO FTSE

Professor Iain McCalman AO FAHA FASSA FRHS

Professor Peter McPhee AM FAHA FASSA

Dr Graham Mitchell AO FAA FTSE

Dr Jim Peacock AC FAA FTSE FRS

Dr Susan Pond AM FTSE

Professor John Quiggin FASSA

Dr Leanna Read FAICD FTSE

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