



CHALLENGES IN STEM LEARNING IN AUSTRALIAN SCHOOLS

LITERATURE AND POLICY REVIEW

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INTRODUCTION

Over twenty years of reports and articles from government, business, think tanks and the media have drawn attention to the Science, Technology, Engineering and Mathematics (STEM) learning problem. This literature and policy review is informed by the key messages of the ACER 2016 Research Conference, 'Improving STEM Learning: What will it take?' The papers presented at this conference give a picture of current thinking in STEM education.

There is general agreement about the importance of STEM education in Australia and reports cite the need for a workforce with STEM skills to drive economic prosperity and the contribution that STEM can make in solving the 'wicked' problems of the world via science and technology.

Set against Australia's desire for strong, comprehensive and equitable STEM education is evidence that our education systems are not up to the challenge. Recent results on international assessments show a continuing decline in performance by Australian students. There are concerns that we do not have sufficient teachers who are qualified to teach STEM subjects. While the curriculum is being modified in an attempt to address changes in STEM, including the introduction of a Technologies curriculum, there is concern that the Australian Curriculum is packaged in discrete disciplines and is not future-facing.

There are suggestions that government and industry might partner to provide support for improvement in STEM education, but this raises the question of where to invest in programs to stimulate change.

This literature and policy review outlines the complex context related to STEM learning and focuses on student outcomes, the teacher workforce and the curriculum.

This paper also sheds light on possible policy directions by examining lessons from other countries. STEM education is a broad enterprise that starts in early childhood education, continues through the years of schooling and extends into tertiary education supported by contributions from extra-curricular and enrichment activities, science centres and museums. However, the focus in this document is on primary and secondary schooling.

CONTEXT

Policy papers emanating from industry and government, reviews of STEM learning and media channels have delivered a constant message that there is a STEM problem, and that it is an urgent one.

This spotlight on STEM is not just occurring within Australia. Education systems and sectors in many countries have an economic and educational focus on STEM. This section provides a brief overview of the context in which STEM learning is situated in Australia and globally, through a review of recent STEM education research literature and policy documents.

What do we mean by STEM?

To investigate questions related to change in STEM literacy and curriculum requires agreement on exactly what is meant by STEM (Blackley & Howell, 2015; English, 2016; Rosicka, 2016; Siekmann & Korb, 2016; Wall, 2016). It appears either STEM education has several different definitions, or it encompasses a continuum of concepts under the roof of what Siekmann and Korb (2016) refer to as the 'house of STEM'.

What are the flavours of STEM education?

Science

Science on its own is not usually considered as an official definition of STEM, but too often science and STEM are used interchangeably, or as shorthand for each other. It is not uncommon to hear conference presenters, journal writers, sales representatives and teachers talk STEM but mean science.

The four disciplines of STEM

Science, technology, engineering and mathematics are the most common disciplines linked to the STEM acronym within the school sector (compared to the tertiary sector which increasingly uses STEMM to include medicine). As well as working scientifically, STEM involves students working mathematically, working digitally or technologically, and working like an engineer.

Integrative STEM

STEM has come to mean the integration of these disciplines, either in any dyad, triad or ideally all four disciplines. In other words, the goal is to see students working in an integrative way.

STEM with attitude

STEM education in its ideal form addresses more than simply academic and economic outcomes. Personal, social and economic development all require more than STEM knowledge and skills. There is an understanding that STEM education should develop a set of personal attributes that are variously known in the education sector as 21st century skills, soft skills or general capabilities. To employers they are also known as employability skills, and include competencies such as problem solving, collaboration, creativity and innovation. This is often associated with an inquiry-based pedagogy.

Jobs of the future

Two arguments are commonly put forward about why STEM learning is particularly crucial at this point in history.

One argument is that STEM learning is a predominantly social imperative. STEM is necessary to solve real-world challenges, and we need people with strong STEM literacy in order to address the complex problems facing the world.

The other is that STEM literacy is a pressing economic issue. Future national productivity demands workers able to fill STEM-related jobs in order to withstand global competition. Australia faces the challenge of ensuring that young people develop the level of STEM expertise required to confidently address these concerns. While Australia appears in the list of countries that are leading their regions in gaining technology-related skills (World Economic Forum, 2016) there is an ongoing fear of ‘brain drain’ related to losing too many of the best graduates.

A theme running through the STEM rhetoric is that STEM jobs are ‘jobs of the future’ (Andrews, 2015). The World Economic Forum (2016) counts STEM literacy as a measure of the future-readiness of countries. The challenge of STEM learning in this context is building capacity in learners to thrive in the ‘known unknown’ of future careers and communities.

Not surprisingly, the commentary on ‘jobs of the future’ comes predominantly from employer groups and the business sector. The Deloitte Access Economics (2014) survey of employers, *Australia’s STEM workforce*, is an often-cited study in this space. The Australian Industry Group (2015) report on its survey of employers’ perspectives recommends ‘school-based STEM activity needs to occur in a coordinated manner and in conjunction with increased industry participation’. The Australian Bureau of Statistics (2014) reported growth in STEM-related jobs to be 1.5 times the growth rate of other jobs (14% compared to 9%) between 2006 and 2011.

Investing in research

Investment in research and development (R&D) is one indicator of how much value a country places on preparing for its future. According to the OECD’s *Main Science and Technology Indicators* (2017), Australia’s spending on research and development (R&D) is below the OECD average and below that of countries such as the United States, Japan and Korea.

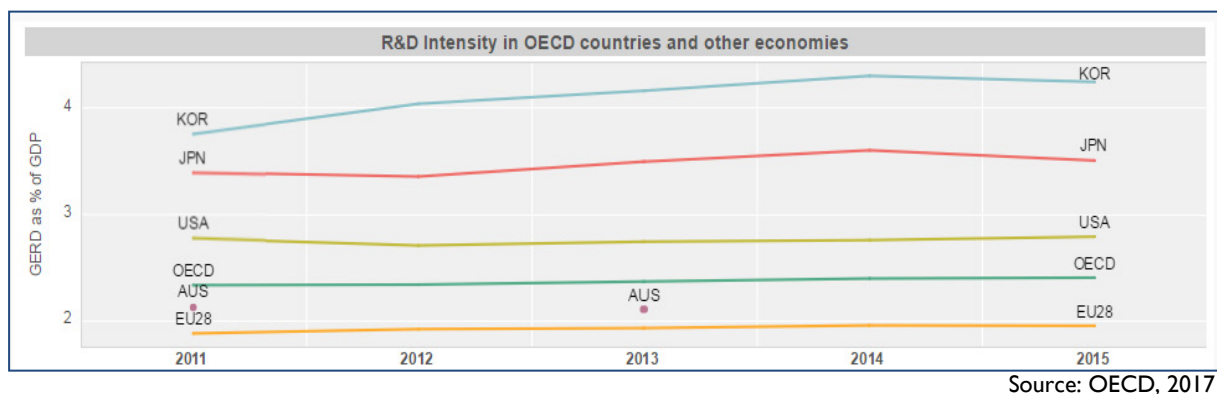


Figure 1 Expenditure on R&D, as a percentage of gross domestic product

For a challenge so urgent, it would seem a priority to ensure research is being maintained at a level comparable to other nations, and that investment in research be shared across government and industry. The OECD indicators show that Australian research is predominantly performed in the higher education sector, with the already low expenditure in the government sector decreasing between 2013 and 2014. The absence of reported business expenditure on R&D for Australia is a concern.

Is it up to education to bear the responsibility and cost of R&D on behalf of the nation's businesses and industries? Is it clever to lay blame for the problem, and the obligation to fix it, entirely on the education sector?

Growing STEM literacy

The need to develop higher levels of STEM literacy in the population is repeated in debates on how to solve the STEM challenge. Falling levels of achievement in STEM and falling numbers of people studying STEM at advanced levels become a downward spiral, at the very time when the demand for STEM literacy is spiralling upward.

One common way to view this challenge, particularly through an economic lens, is the STEM pipeline (Tytler et al., 2008; Watt, 2016). The pipeline describes a flow of engaged students in primary school leading to recruitment of students to secondary and senior secondary STEM subjects. This in turn means skilled students are retained into post-school STEM learning, including into teacher education courses, and also into STEM careers. A key benefit is building the flow of STEM-literate parents who pass on curiosity and engagement to the next generation. Identifying and then plugging the potential points of leakage along the pipe becomes the priority. While the pipeline provides a useful metaphor for this multifaceted issue, its linear imagery does not adequately address what is actually a vicious circle. What educators and policymakers are looking for is a starting point, and how to increase the flow of STEM capacity throughout the system.

Teacher quality is one point in the pipeline that has received significant attention. Ingvarson et al. (2015) sum up the impact of teacher quality on student learning, stressing the importance of recruiting, developing and retaining high quality teachers. Lloyd (2013) cites evidence that raises questions about the academic level of students choosing to enter teaching, and this is a particular issue for STEM subjects. A common response is to point the finger at primary school teachers, seen as generalist teachers with minimal science, technology and engineering discipline knowledge, a proportion of whom also have mathematics anxiety (Buckley et al., 2016).

Has something changed in the primary education workforce, the primary curriculum or the primary school students that explains the decline in performance and interest in STEM?

One policy response to this perceived area of weakness has been to recommend placing specialist STEM teachers into primary schools (Caplan, Baxendale & Le Feuvre, 2016; Prinsley & Johnston, 2015). Pezaro (2017), however, warns that science specialist teachers in primary schools are not the answer if they simply provide release time for class teachers who then don't have to worry about science teaching. Professional development that enables generalist teachers to build skills and confidence in STEM teaching is seen as a more sustainable strategy.

STEM EDUCATION POLICIES

Given how recently many of the STEM policy initiatives across Australia have been announced, there is very little monitoring literature available by which to evaluate their effectiveness. Australia must therefore look to other places to inform a STEM education policy review.

Global STEM education policies

Hoyle's keynote address to the 2016 Research Conference presented an overview of 30 years of STEM education policy in the United Kingdom. This paper describes a rich set of policies and programs, many of which have been evaluated, and most of which involved partnerships between government, education providers, scientific and learned bodies, charities and employers. Hoyle's list provides a starting point for other countries to use to look at policy interventions to address STEM literacy challenges. The initiatives have been categorised as policies that relate primarily to students, to teachers or to curriculum.

| Students | Teachers | Curriculum |
|--|---|---|
| <ul style="list-style-type: none">• Selection of senior STEM subjects• Focus on performance in senior secondary• Choosing careers• Equity initiatives addressing gender and ethnic representation | <ul style="list-style-type: none">• Quality of science teachers and lecturers• STEM specialist teachers• Continuing professional development for teachers• National STEM Learning Centre and Network | <ul style="list-style-type: none">• STEM curriculum development• Coordination of 'a vast array of curriculum enrichment' |

STEM assessment does not appear on Hoyle's list, but she does note that in the UK 'removal of national testing of science at age 11 has reduced the teaching of primary science' (p. 7).

A major report by Marginson, Tytler, Freeman and Roberts (2013) contains an extensive analysis of 22 studies of STEM globally, and identifies 27 key findings, which range from STEM-specific tracking in secondary education (p. 19) to models of national STEM coordination (p. 27).

How does this wealth of possible responses compare to the current Australian STEM education policy landscape?

Australian STEM School Education Strategy 2016–2026

On 11 December 2015, a 10-year National STEM School Education Strategy 2016–2026 was endorsed by Australian education ministers. The rationale was that 'a renewed national focus on STEM in school education is critical to ensuring that all young Australians are equipped with the necessary STEM skills and knowledge that they will need to succeed' (Education Council, 2015). It centres on two goals:

- to ensure all students finish school with strong foundational knowledge in STEM and related skills
- to ensure that students are inspired to take on more challenging STEM subjects.

To meet these goals, there are five strategies for action:

1. increase student STEM ability, engagement, participation and aspiration
2. increase teacher capacity and STEM teaching quality
3. support STEM education opportunities within school systems
4. facilitate effective partnerships with tertiary education providers, business and industry
5. build a strong evidence base.

Australian Government STEM policies

Recent Australian Government policies (2015a, 2015b, 2016) have promoted STEM education initiatives in the following areas.

| Students | Teachers | Curriculum |
|---|--|---|
| <ul style="list-style-type: none"> • Pathways in Technology (P-TECH) A pilot providing secondary students with an industry supported pathway to a STEM-related VET qualification. • Summer schools for STEM students and national competitions, ICT Summer Schools initiative (digIT), and Curious Minds • Improved career and post-school advice in collaboration with industry • At least one maths or science subject as a prerequisite for an Australian Tertiary Admission Rank (ATAR) | <ul style="list-style-type: none"> • reSolve: Mathematics by Inquiry project (Australian Academy of Science in collaboration with the Australian Association of Mathematics Teachers) developing mathematics curriculum resources focusing on inquiry • CSER Digital Technologies Education programs (The University of Adelaide) • Let's Count Maths program for parents and early years educators • Digital literacy school grants | <ul style="list-style-type: none"> • Primary Connections and Science by Doing programs • Early Learning STEM Australia (ELSA) pilot of app-based STEM • Digital technologies curriculum and computer coding • Australian Digital Technologies Challenges for Year 5 and 7 |

A selection of state STEM policies in 2017

Each Australian state and territory government has initiated some form of STEM education policy, and initiated programs that range across the three priorities of student outcomes, teacher workforce and the curriculum. The following section provides a selective snapshot of policies that reference STEM in education, identified from Australian states and territory websites during 2017.

| State/ Territory | Government policies and programs | Addressing students | Addressing teachers | Addressing curriculum |
|---------------------|--|---|--|--|
| ACT | CBR Innovation Development Fund (CBRIDF) 2016–17 funds programs in schools | Mount Stromlo Space and STEM Education Centre (MSEC) to inspire public high school and college students into STEM, in particular as it relates to space sciences \$5.9m Centre for Innovation and Learning at Caroline Chisholm School, opening 2018 | | MeriSTEM producing modular, secondary-level classroom materials for flipped learning |
| NSW | STEM NSW promotes an Integrated STEM Framework, and some integrated curriculum units, and holds that, 'STEM education is for all students and should be incorporated throughout all stages of learning from preschool through to Year 12'. (NSW Department of Education, 2016) | Raising expectations and enhancing the quality of student learning in STEM | Fostering quality teaching and leadership in STEM Illustrating innovative ways of delivering STEM education | Integrated STEM Framework, and some integrated curriculum units |
| NT | Department of Education Strategic Plan 2016–18 To build partnerships with professional organisations and industry to support student access to high quality programs about science, technology, engineering and mathematics | Darwin High School is a Centre for Excellence in STEM Essington School Darwin has a school-wide Year 1 to 12 focus on STEM | | Science, Technology, Engineering and Maths (STEM) week in May 2017 |

| State/ Territory | Government policies and programs | Addressing students | Addressing teachers | Addressing curriculum |
|---------------------|---|--|---|---|
| QLD | <p>A Strategy for STEM in Queensland will lift participation of students, including girls and Aboriginal and Torres Strait Islander students</p> <p>http://www.education.qld.gov.au/stem/pdfs/s-trategy-for-stem.pdf</p> | <p>A STEM Girl Power Camp 2016 for 22 Queensland Year 10 girls</p> <p>A STEM hub with resources and career information for students and parents</p> <p>116 state primary and secondary schools to receive \$16 600 grant to nurture the next generation of digital entrepreneurs</p> | <p>Give every state school access to a specialist STEM teacher</p> | <p>A review of STEM education in Queensland state schools</p> <p>Ensure every state school offers the Digital Technologies curriculum, including coding and robotics.</p> |
| SA | <p>STEM Learning Strategy 2017–2020</p> <p>139 STEMWorks schools building projects to upgrade school STEM facilities (\$250 m)</p> <p>https://www.decd.sa.gov.au/teaching/curriculum-and-teaching/stem-learning-strategy</p> | <p>STEMPlay preschools</p> | <p>Professional development for 500 primary school teachers to become STEM specialists by 2019</p> | |
| TAS | <p>The LearnersFirst 2017 update includes a focus on ‘delivering high quality teaching and learning that connects young people to the world of work.</p> <p>2016–17 budget factsheet allocates \$375 000 over two years to develop resources</p> | <p>Enrichment programs for gifted and talented students</p> | <p>Resources for government schools to provide all students with engaging and challenging STEM learning</p> | <p>Science Technology Engineering and Maths Framework and Agricultural Education</p> |
| VIC | <p>VicSTEM</p> <p>STEM in the Education State strategy is to equip all Victorian learners with STEM capabilities</p> | <p>\$128m to invest in 10 new tech schools</p> | <p>Professional development for 200 primary teachers and 60 secondary teachers</p> | <p>Early years programs ‘Let’s Count’ (maths) and Taking Small BYTES (digital technologies)</p> |

| State/ Territory | Government policies and programs | Addressing students | Addressing teachers | Addressing curriculum |
|---------------------|--|---|--|--|
| WA | <p>Focus 2017: Directions for Schools</p> <p>May 2017, \$4m over 3 years for the STEM Learning Project managed by a consortium comprising the Educational Computing Association of WA (ECAWA), the Mathematical Association of WA (MAWA), the Science Teachers Association of WA (STAWA) and Scitech</p> | Increase percentage of senior secondary students studying challenging levels of maths and science | Strengthen teacher development and school support for STEM education including increased online support. | <p>Focus on STEM in the early years, particularly numeracy, creative problem solving and coding skills</p> <p>Software for secondary schools, including Wolfram Technologies</p> |

HOW CAN THE SCHOOL SECTOR MAKE A DIFFERENCE?

The size of the STEM elephant can either paralyse policymakers or promote an approach that attempts to solve the whole, and as a result spreads resources too thinly to be effective. This section discusses three specific areas in which the school sector has its strongest chance of making a difference, namely to student outcomes in STEM, the STEM teacher workforce and STEM curriculum.

Nearly 15 years ago, a review of teaching and teacher education called *Australia's Teachers, Australia's Future*, looked into the advancement of innovation, science, technology and mathematics. This 2003 report noted that:

- a declining proportion of students completed Year 12 studies in physics, chemistry, biology and advanced mathematics
- there were insufficient numbers of highly trained teachers in science, technology and advanced mathematics
- there was uncertainty among primary school teachers about how best to teach science, accompanied by primary teachers' relatively low levels of interest and academic attainment in science and mathematics
- teaching did too little to stimulate curiosity, problem solving, depth of understanding and continued interest in learning among students, or to thus encourage them to undertake advanced study in science and mathematics at school and beyond (Department of Education, Science and Training, 2003, p. xviii).

There have been further reviews and some changes since 2003, notably the implementation of a national curriculum, which itself has been reviewed since it was implemented. A great deal has been written on the importance of STEM to Australia's future. It is therefore concerning that a report written this long ago still accurately portrays the present state of affairs.

Challenge 1: Improve student outcomes in STEM

The literature on student outcomes in STEM raises several areas of concern to be addressed.

Students in provincial and rural areas perform at a lower level than students in metropolitan areas (Thomson, De Bortoli & Underwood, 2017; Thomson, Wernert, O'Grady & Rodrigues, 2017). Growing disparities in Australian schools are increasingly associated with socioeconomic background (Ainley & Gebhardt, 2013). Most students who receive low numeracy achievement scores in Year 3 never catch up with their peers, falling further behind by Year 9 (Wienk, 2015).

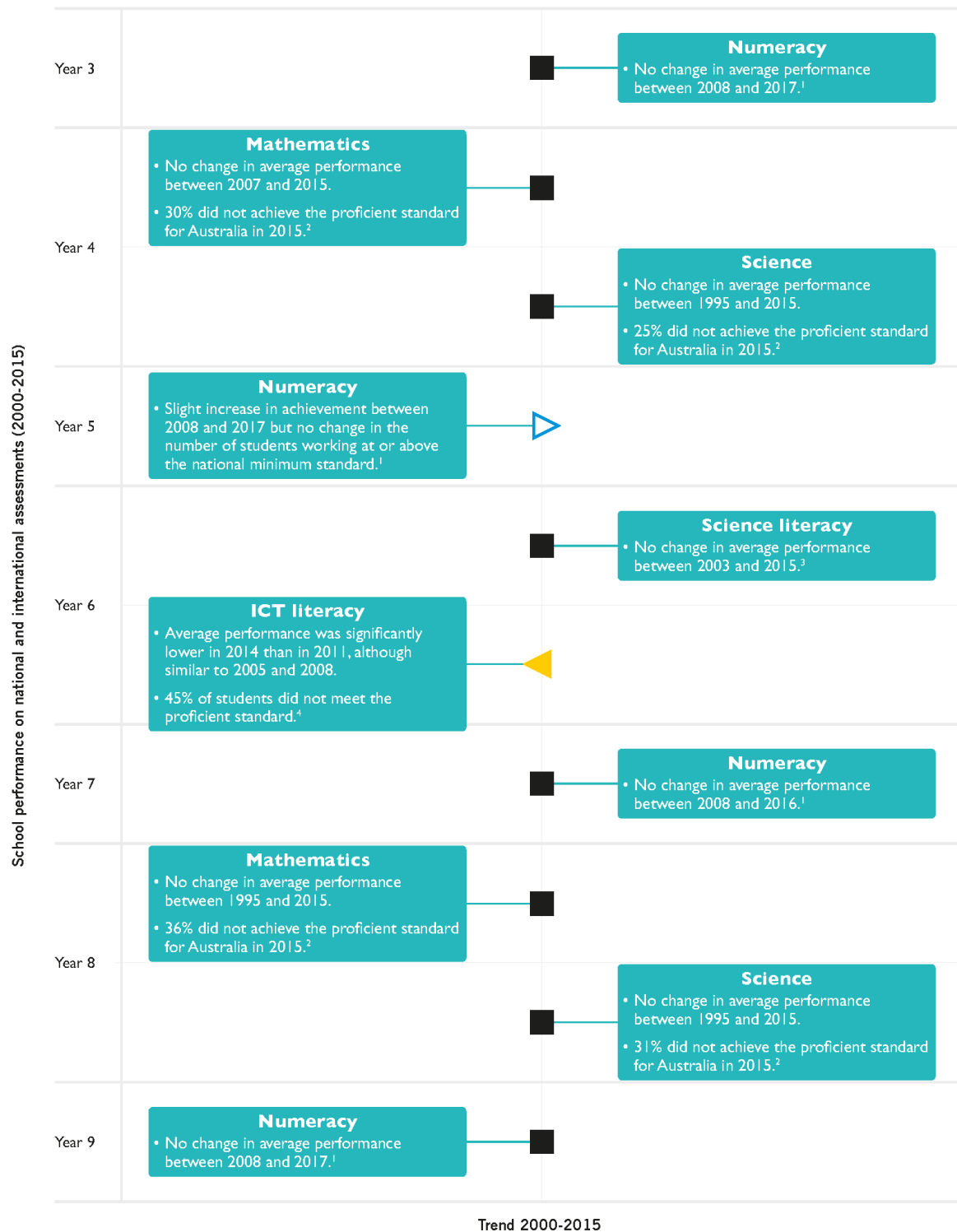
The percentage of Year 12 students enrolled in higher-level STEM subjects has been in decline for many years (Wienk, 2015; Kennedy, Lyons & Quinn, 2014). One in ten Year 12 students completed an advanced maths subject in 2015 (Barrington & Evans, 2016). A greater number of students are enrolling in elementary mathematics and a rising proportion of high-achieving Year 12 students, particularly females, undertake no maths at all (Marginson, Tytler, Freeman and Roberts (2013).

Between 1992 and 2012, there was a steady decline in participation rates in physics, chemistry and biology at Year 12 (Kennedy, Lyons & Quinn, 2014). Beyond secondary school, entry into university mathematical sciences degrees in Australia is half the OECD average. The number of universities that require at least intermediate maths for entry into science degrees remains low and many engineering degrees do not include maths as a prerequisite.

Australia's performance on national and international assessments in mathematics, science and ICT has not changed in one to two decades.

Figure 2 summarises student performance across STEM-related subjects across different year levels.

CHALLENGES IN IMPROVING STEM LEARNING IN AUSTRALIAN SCHOOLS



¹ ACARA, 2017a

² Thomson, Wernert, O'Grady & Rodrigues, 2017

³ ACARA, 2017b

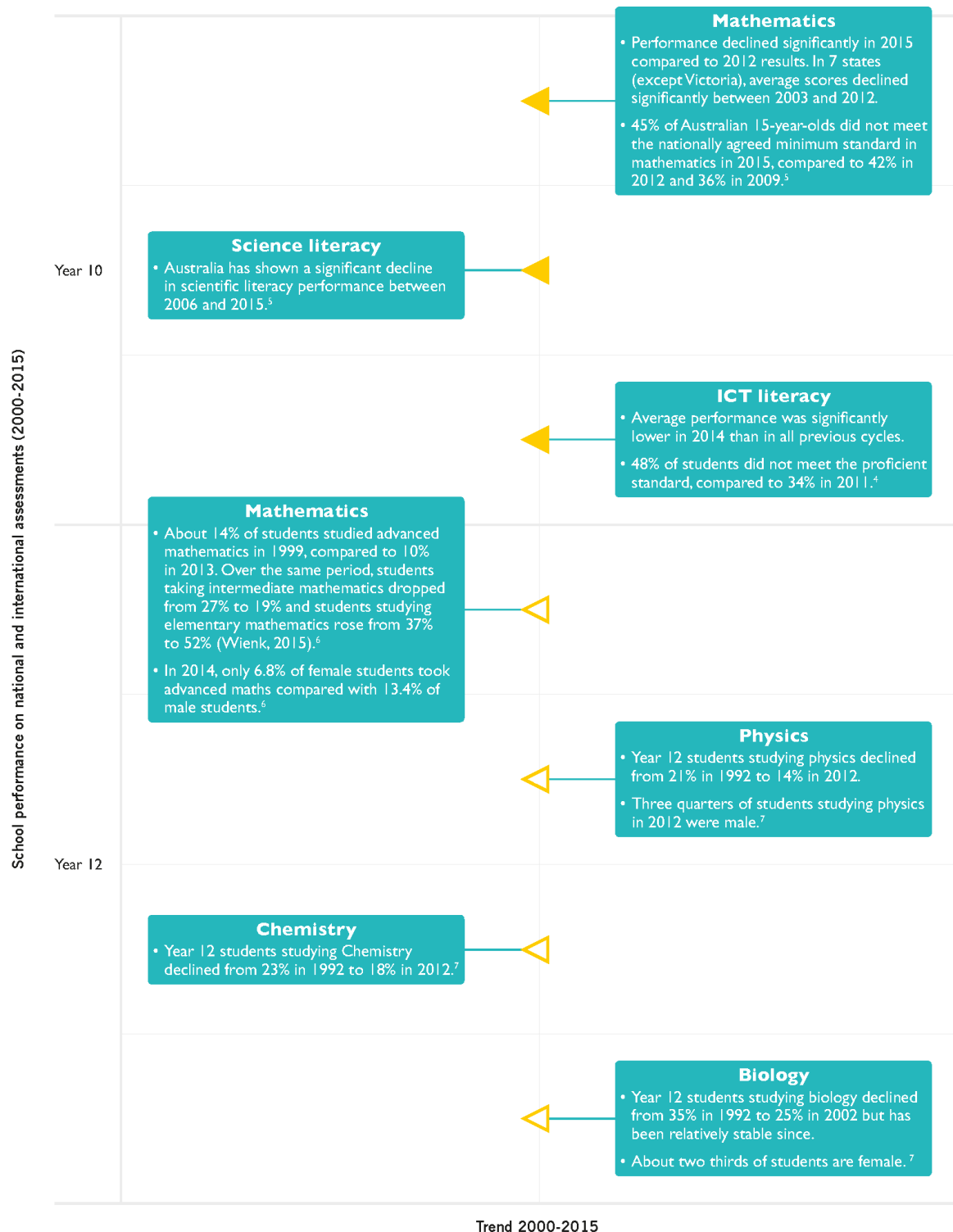
⁴ ACARA, 2015

Key

▶ Large decrease
 ◀ Small decrease
 ■ No change
 ▶ Small increase
 ▶ Large increase

Figure 2 Summary of student performance on national and international assessments, by year level

CHALLENGES IN IMPROVING STEM LEARNING IN AUSTRALIAN SCHOOLS



⁵ Thomson, De Bortoli, & Underwood, 2017

⁶ Wienk, 2015

⁷ Kennedy, Lyons & Quinn, 2014

Key

▶ Large decrease
 ▶ Small decrease
 ■ No change
 ▶ Small increase
 ▶ Large increase

Figure 2 continued

Policy initiatives to improve student outcomes

Widespread improvement of student outcomes in STEM cannot be achieved through a single intervention. It will require a strategic combination of approaches, each carefully evaluated.

Smart monitoring

In mathematics in Australia, we see achievement gaps between students from different socioeconomic backgrounds persist across year levels. Australia only conducts a sample assessment in science at Year 6 and then uses PISA as its measure for secondary school, so we cannot examine how the achievement gaps for science persist over time. However, from the PISA 2015 results we do know that students in the highest socioeconomic background quartile achieved an average score of 559 points, which was significantly higher than students in the lowest socioeconomic quartile, who achieved 468 points. This difference represents around three years of schooling.

The kinds of skills that need to be learned and applied in STEM are complex. While conventional assessments of multiple-choice and written response items can assess knowledge and some of the skills, they are limited. It can be hard to assess science inquiry skills, the ability to write code or the application of engineering principles, using static assessment items. Full appraisal of those skills can only be achieved through practical assessments or through the use of technology via simulations and other interactive assessments. While there has been considerable research into the use of technology-enhanced assessments and products (Quellmalz, Silbergitt, Buckley, Loveland & Brenner, 2016; Sao Pedro, Jiang, Paquette, Baker & Gobert, 2014), there is still no widespread implementation of such assessments. A promising avenue is to embed the assessments into the learning materials to provide continual feedback to learners and summaries of progress to teachers in what has been called 'third generation assessments' (Bennett, 2015). This approach has the capability of measuring core skills and producing reliable and valid formative and summative assessments (Quellmalz, Timms, Silbergitt & Buckley, 2012).

Early intervention and access for all

A study conducted in the United States by Morgan, Farkas, Hillemeier & Maczuga (2016) showed that science achievement gaps begin very early in life and persist over time. From a longitudinal study of over 7000 students, they found that some groups of students entering school were far less knowledgeable about the natural and social sciences than their peers. These general knowledge gaps strongly predicted poor performance through the first four years of school. From that point on, other factors such as reading and mathematics achievement were predictive of science performance. Once these gaps were set, they persisted throughout schooling, emphasising the need to intervene as early as possible. The conclusion to their longitudinal study echoes Evans' (2005) recommendation:

... policymakers and practitioners may need to increase the provision of early intervention efforts in science – particularly for at-risk populations – if science achievement gaps are to be narrowed or closed.

An Australian government project working toward this is the Early Learning STEM Australia (ELSA) project. ELSA is a play-based digital learning program for children in preschool to explore STEM. It uses tablet-based apps that encourage active play that supports STEM practices, such as creativity and problem solving. The apps are designed to act as a springboard for children to explore the natural world and a pilot of ELSA in 100 preschools will take place in 2018.

Females continue to be underrepresented in STEM-related courses and careers. Females' motivation to pursue STEM in senior secondary can be determined by their exposure to STEM prior to and during school. This coupled with societal values can mean they are less likely to enter STEM-related careers. Lessons can be learned from the 'Science in Australia Gender Equity' (SAGE)

program that facilitates gender parity initiatives in higher education. There is a need to get girls enthusiastic about STEM prior to and throughout their schooling. Female role models in STEM are one enabler, through school visits by women working in STEM, female STEM teachers and researchers. The University of New South Wales facilitates 'Science 50:50', which engages girls through school visits, online resources, facilitating mentoring experiences and access to STEM facilities on-campus. The University of Melbourne's 'Girl Power' program for Year 9 students, established in 2016 hosts a camp for girls on campus where they hear from speakers and participate in interactive workshops.

Amid the broad range of policies, programs and problems associated with STEM education is a perceived tension between equity and excellence. Is STEM education important enough to be compulsory for all teachers and students, or should priority be given to specialist programs tailored to selected groups? Blackley and Howell (2015) ask:

Should there be a scattergun approach from which all students will experience some STEM education – or could some students receive all of the focus on STEM education?

It seems that the first scenario is what has been tried; maybe the latter is truly the way forward.

The Office of the Chief Scientist's STARportal (2017) links to a multitude of clubs and challenges for students interested in robotics, coding and engineering. The majority of these are extension activities, offered out of school hours, to engage participants who generally have an existing interest and capacity to pay. Policymakers and providers face a dilemma in scaling these kinds of initiatives to ensure equitable access, particularly for those who are already absent from STEM activities, such as girls, Indigenous students, those from rural and remote areas and from low socioeconomic backgrounds.

The real challenge is to invest in creating the same level of engagement and excitement about STEM as part of the standard program in all early childhood centres, schools across the community, for all students.

The opportunity to be directed towards STEM should not depend on access to extracurricular enrichment activities.

Specialist STEM schools

Ensuring equity of access to STEM for all students includes offering opportunities and encouraging those students who wish to specialise in STEM. Across Australia, the introduction of specialised STEM schools has been one policy aimed to increase student engagement in STEM and provide a targeted education, a path taken by other countries. According to American researchers Erdogan and Stuessy (2015), specialised STEM schools have been around for over 100 years and they fall into three categories:

1. selective STEM schools
2. inclusive STEM schools
3. schools with STEM-focused career and technical education.

In Australia, examples of specialist STEM schools include the John Monash Science School in Melbourne, associated with Monash University; the Queensland Academies – Science, Mathematics and Technology Campus (QASMT) which has credit arrangements with the University of Queensland, and the Australian Science and Mathematics School established on the Flinders University campus in Adelaide in 2003 (Bissaker, 2014).

A recent example of the establishment of schools with STEM-focused career and technical education can be seen in a \$128 million program to construct ten Tech Schools on TAFE and university campuses across Victoria. The schools aim both to attract students to STEM and to provide smooth pathways into post-secondary education and training (Department of Education and Training Victoria, 2017).

Erdogan and Stuessy's (2015) review of studies exploring college and career readiness of students attending specialised STEM

schools shows that these students did perform slightly better on high-stakes mathematics and science tests in comparison with students in traditional schools. They also confirmed that those students showed more interest in STEM, were more willing to attend classes, were more likely to pass state tests, and more likely to obtain a degree.

Another way to encourage students to specialise in STEM is to create a career academy – what has been described as a ‘school-within-a-school’. About 2550 high schools in the United States have created career academies, some of which focus on STEM subject areas. The career academies are multi-year programmes with integrated academic and career technical content organised around broad career themes (Institute of Education Sciences, 2006). Academy students take classes together and remain with the same group of teachers over time. Academies also maintain relationships with local businesses and industries as a way to provide contextual learning opportunities (Kemple, 2001).

There are existing Australian schools with specialist STEM programs. Darwin High School is a Centre for Excellence in science and mathematics. In 2017, South Australia had six metropolitan secondary schools and one area school designated as STEM specialists, with a new \$100m STEM and health science focused school planned to open in Adelaide in 2019. New South Wales has 13 technology high schools.

Community connections

Student and teacher interest in STEM is one of the challenges facing schools. Strategies that focus on engagement with ‘real-world’ STEM can contribute to increased levels of motivation through informal learning opportunities. A plethora of programs promote this connection with industry, with STEM-related institutions, and involvement in community initiatives. These include citizen science activities, coding clubs such as CoderDojo, and challenges such as the STEM Video Game Challenge.

Organisations offer summer schools such as STEM X Academy for teachers, and the Aboriginal Summer School for Excellence in Technology and Science (ASSETS) for students. Work experience, STEM incursions and mentoring programs such as In2Science and Scientists in Schools connect industry and promote higher education STEM offerings. Zoos, museums and STEM centres such as Scitech (WA), Questacon (ACT), the Powerhouse Museum (NSW), and ScienceWorks (VIC) are a key element in this agenda of engagement in STEM beyond the classroom. Galleries, Libraries, Archives and Museums (GLAM sector) also provide accessible and cross-generational STEM activities across the community. Ensuring that all children have access to quality enrichment activities from a young age is a priority to stimulate the curiosity so important in STEM, and to inform ongoing education and career choices.

Recommendations: Student outcomes

Improving student outcomes across the full range of STEM will take a combination of approaches and four things that might be addressed include

- monitoring STEM learning skills more broadly over time rather than just testing knowledge in summative assessments
- developing early intervention programs to close the gaps that will otherwise persist over time
- encouraging broader participation through specialised STEM schools and career academies
- stimulating interest in STEM through out-of-school activities.

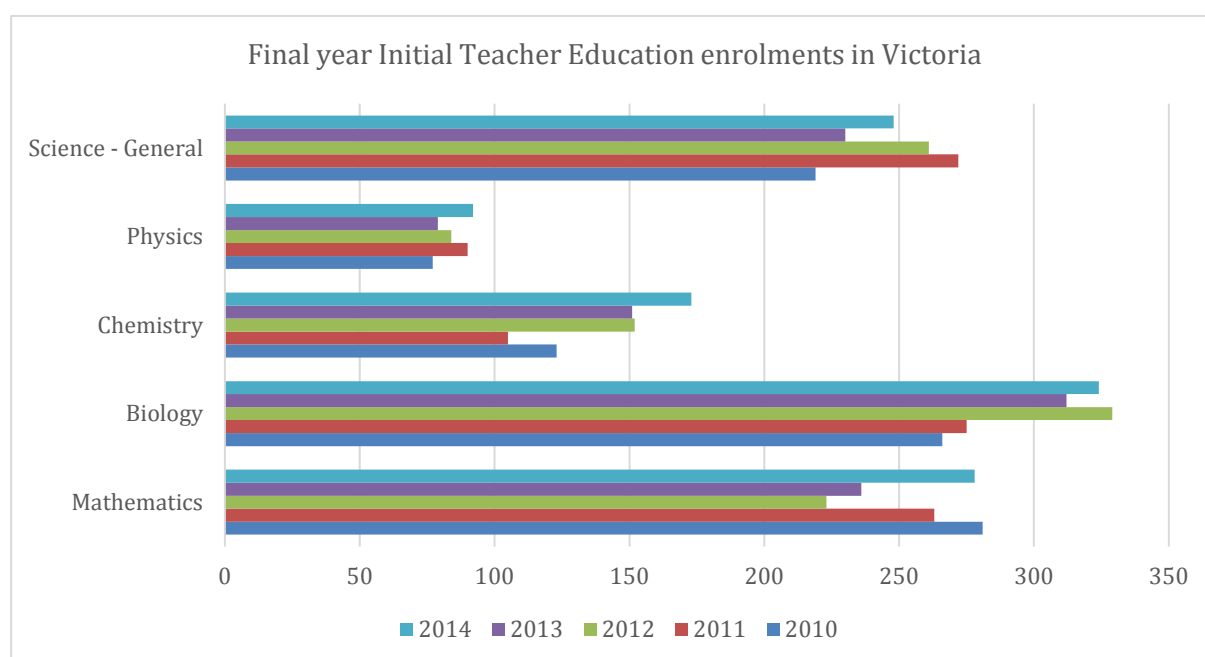
Challenge 2: Build the STEM teacher workforce

The Organisation for Economic Co-operation and Development (OECD) (2012) and the Productivity Commission (2012) have noted the undersupply of science and mathematics teachers in Australia, and previous studies show that this is not a new problem (e.g. DEST, 2003; Eacott & Holmes, 2010; McKenzie, Rowley, Weldon, & Murphy, 2011; Stokes & Wright, 2007).

About 60 per cent of secondary teachers are women; however, in most sciences (except biology and general science), there are still greater numbers of male teachers, which is also the case for mathematics and computing/IT. In science and mathematics, a greater proportion of male teachers is retiring from the profession at the same time as the proportion of men entering it continues to decline. Male-dominated subjects are likely to suffer teacher shortages, especially in the context of a booming primary student population about to enter secondary schooling (Weldon, 2015).

Data on the subject specialisations of graduate teachers have not been collated nationally, although there is some information in Victoria and NSW. Final year enrolments in initial teacher education (ITE) show that teachers with a specialisation in mathematics make up about 6 per cent of enrolments year on year, compared to 13–14 per cent for teachers who specialise in English (Weldon, Shah & Rowley, 2015). The NSW Education Standards Authority keeps records of teachers who have been accredited. The ratio is similar with about 1000 maths teachers to over 3000 English teachers (Centre for Education Statistics and Evaluation, 2014).

Figure 3 shows that biology and general science are the most popular science specialisations for pre-service teachers; biology has almost twice as many final-year enrolments as chemistry, and over three times as many as physics (Weldon et al., 2015).



Source: Weldon, Shah & Rowley (2015, p. 35)

Figure 3 Final year Initial Teacher Education enrolments, Victoria

In NSW, Wilson and Mack (2014) looked at Year 12 participation in maths among prospective teachers, who received Initial Teacher Education undergraduate university offers (at all levels, primary and secondary) between 2001 and 2013. The proportion with no mathematics at Year 12 tripled from 4.8 per cent in 2001 to 15.6 per cent in 2013. Those with general maths rose from 55 per cent to 65 per cent; those with intermediate level maths declined from 31 per cent to 14 per cent and those with advanced maths declined from 10 per cent to 5 per cent (Wilson & Mack, 2014).

In 2012, the Victorian Auditor-General's report argued:

The availability and distribution of science and mathematics teachers continues to be an area of challenge. Schools, regions and other stakeholders report that quality – not quantity – of teachers is their most significant issue. Schools in rural and regional areas and socioeconomically disadvantaged areas have the most difficulty attracting good quality science and mathematics teachers (p. ix).

Lack of teachers with subject specialisations leads to teachers teaching outside their specialisation, which is known as teaching out of field. Out-of-field teaching is common in Australia (Queensland Audit Office (QAO), 2014; Weldon & Ingvarson, 2016). TIMSS data for Australia found that in 2011, 34 per cent of participating Year 8 students had an out-of-field mathematics teacher compared to an international average of 12 per cent (Thomson et al., 2012). In the most recent TIMSS, that proportion had dropped to about 22 per cent (Thomson, Wernert, O'Grady & Rodrigues, 2017). Data from the Staff in Australia's Schools (SiAS) survey in 2013 found that of Year 7–10 teachers, about 15 per cent of chemistry and physics teachers were teaching out-of-field with less than five years of experience, as were about 12 per cent of mathematics teachers and 25 per cent of ICT teachers. Early career teachers were more likely to be teaching out-of-field than their more experienced colleagues (Weldon, 2016).

According to SiAS data, 23 per cent of primary teachers have no tertiary studies in either mathematics or numeracy, and 26 per cent say they have no method studies in either area¹. TIMSS found similar results: 80 per cent of Australian students had mathematics teachers with no major or specialisation in mathematics, compared to 46 per cent of students, on average, across countries (Thomson, Wernert, O'Grady & Rodrigues, 2017). According to the ABS (2014) only 19 per cent of Australian secondary school teachers employed in 2010–11 had university level STEM qualifications.

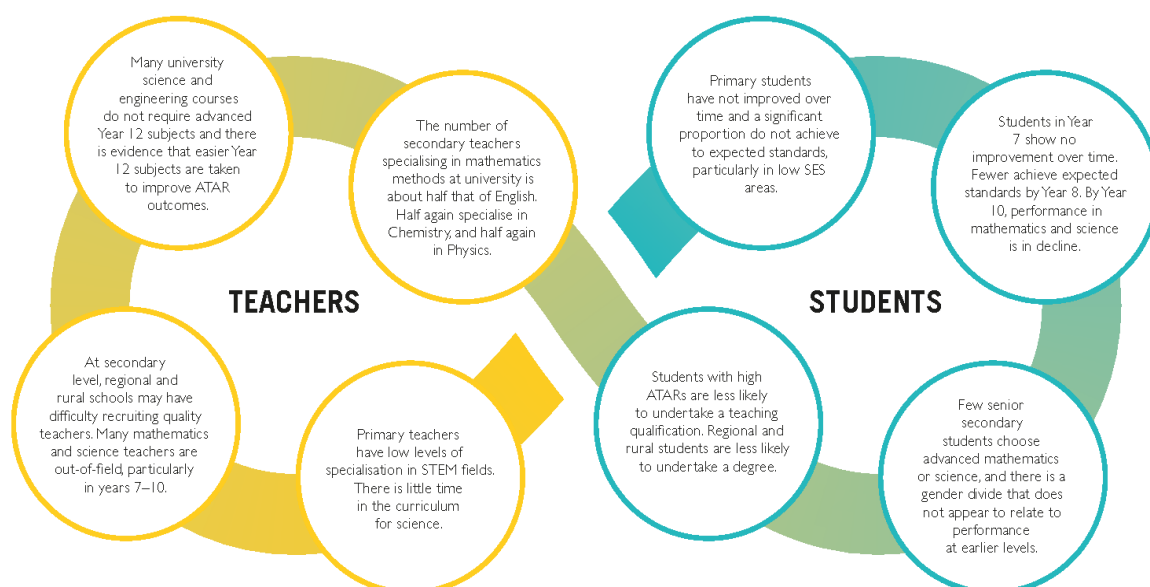


Figure 4 Interplay of challenges in building the STEM teacher workforce

¹ Additional analysis of SiAS 2013 data for this report show mathematics and numeracy separately, so it was not clear whether primary teachers who did not study methods in mathematics did so in numeracy.

Policy initiatives to build the STEM teacher workforce

Australia is not going to be able to deliver the STEM curriculum it envisages or raise student outcomes unless it has the qualified teachers to deliver it. But, to better target workforce policies to appropriate areas, we need to know where the issues lie. Teacher workforce data collection in Australia is limited and leaves considerable gaps in our knowledge. Universities have records of the subject areas teacher education graduates specialise in; these data are not routinely collected nationally. Teacher registration bodies do not appear to record teacher subject specialisations and there is minimal data on the number of specialist teachers in STEM subjects nationally. Governments in Australia have no direct control over the supply of qualified teachers as the number of places in initial teacher education courses is determined by individual providers. It is possible, however, to influence supply at a number of different points.

Incentives to qualify as a STEM teacher

Providing incentives is a common method to attract people to STEM teaching. Specialists in shortage subject areas are offered incentives to enter teaching. Schools that are hard to staff also use similar tactics. These can be financial incentives in the form of scholarships, payment of tuition fees or bonus payments for working in a location for a given amount of time (Weldon et al., 2015). Another incentive might be to offer a permanent or ongoing position – a guarantee of work.

Reports from England and Australia suggest that these incentives are generally successful, although there is little evaluation of the extent to which incentives attract teachers who would not otherwise have entered or returned to teaching. In England, there is an attempt to meet a large shortfall of STEM teachers by retraining about 15 000 teachers who have either left teaching or are not specialists (i.e. those interested in teaching STEM, or currently teaching out-of-field). However, these teachers are unlikely to have the deep subject understanding that comes from having studied it as a tertiary degree (Royal Academy of Engineering, 2016).

This may also include international recruitment and funding for A-level students (Year 12 equivalent) in maths or physics, which includes financial support through an undergraduate maths or physics-related degree and a guaranteed place in an employment-based initial teacher education program, in return for a commitment to teach for a further two years upon graduation.

Better data to power better policy

We need better data in order to target better policy in Australia, and better evidence on where the issues are. High quality teachers make a difference: teachers who have a deep knowledge of their field, deep understanding and extensive experience of how to teach it. Some data are available telling us:

- it is common for more experienced teachers to teach senior secondary level
- there is more out-of-field teaching at Years 7–10
- few primary teachers have a strong background or tertiary qualification in science or mathematics
- fewer teachers in STEM subjects graduate each year compared with English, social studies and health and physical education.

But we do not know where these teachers go, what they do or how long they stay.

Contrary to some academic and popular reporting, we do not know how many early career teachers leave teaching – most estimates are based on rates in other countries and Australian references are usually over a decade old (AITSL, 2016; Weldon, 2018). We do know that despite report after report recommending change in how early career teachers are treated and supported; they are still more likely to be teaching outside their field than their more experienced colleagues. There is evidence that STEM teachers may have more opportunities outside teaching than some of their colleagues, and may therefore be more likely to leave teaching.

Recommendations: Teacher workforce data

Australia, like other countries, has a history of using a variety of incentives to encourage participation in teaching. We need more data to understand where in the teacher supply pipeline we might best target such incentives, and data over time to enable us to gauge to what extent those incentives or policies are working.

Options include policies that target:

- school leavers with strong STEM results to undertake a STEM degree and then a teaching qualification
- STEM degree graduates to undertake a teaching qualification (some states are doing or have done this)
- mature-age potential career changers from STEM areas to undertake a teaching qualification

- newly qualified STEM teachers to enter low SES schools, hard-to-staff schools and schools in rural and remote areas (some states are doing or have done this)
- experienced STEM teachers to teach in low SES schools, or to teach younger students
- STEM teachers from overseas to teach in Australia (regional and low SES schools).

Other options include policies that focus on:

- lowering the rate of students dropping out of STEM subjects at senior secondary level
- lowering the rate of initial teacher education students who drop out of teaching degrees
- lowering the attrition rate of early career teachers.

Challenge 3: Rethink the STEM curriculum

A third element of the STEM education equation is the curriculum. The Australian Curriculum is not based on a modern conceptualisation of STEM. It is structured around discrete learning areas and does not integrate explicit STEM learning progressions across the school years.

There are a number of challenges for planning STEM curricula.

First, if the concept of STEM is embraced as a meaningful interdisciplinary approach to learning, then schools should be addressing all parts of STEM. To date in Australia, the emphasis has been on the 'M' (mathematics), which is reinforced by the choice in NAPLAN to assess all students in numeracy at Years 3, 5, 7 and 9. In contrast, science literacy and information and communication technology (ICT) literacy are only assessed in a sample of schools every three years. In addition, ICT literacy assessments are only given to students in Years 6 and 10, while science assesses only Year 6. There is no curriculum or assessment of engineering.

The pattern of Australian curriculum and assessment sends a message to schools that STEM is not fully embraced and so teaching will reflect that. The NAP-ICT Literacy 2014 Report (ACARA, 2015), in explaining possible reasons for the fall in performance, speculates that there may be less emphasis placed on the teaching of skills associated with ICT literacy or that the development of ICT literacy competencies has been taken for granted in Australia where the level of access to ICT in schooling is extremely high.

The second challenge is in choosing what to include from each discipline and where to place the emphasis. Each area of STEM comprises multiple sub-disciplines. Within science, there are the traditional divisions of biology, chemistry, physics and earth sciences, but these can be fragmented into a multiplicity of sizeable fields. For example, biology contains molecular biology, cell biology, genetics at the small scale and zoology, ecology and evolutionary biology at the larger scale. Further, biology combines with other parts of science in things like biochemistry or with other STEM disciplines in biotechnology and bioengineering. This complex pattern of disciplines and sub-disciplines applies to all four components of STEM.

A third challenge is that knowledge building proceeds at a tremendous rate across STEM and particularly in science and technology. Whole new sub-disciplines emerge quite rapidly. Bioinformatics, for instance, was first used as a term in 1970 but has really taken off in the last two decades due to advances in genetic research, technology and mathematics. Disciplinary knowledge can change, too, as our understanding of the world around us expands.

A fourth challenge that is related to those outlined above is how to fit a modern and more inclusive version of STEM into an already crowded curriculum (Lloyd, 2013).

In summary, if STEM is to be truly implemented curriculum designers will have to address how to ensure that all four parts of this challenge are addressed and cope with defining the knowledge and skills necessary for each discipline in a durable way that is able to accommodate future changes in disciplinary knowledge and scope. The designs will have to account for the limited space in the overall curriculum and assessment systems will have to reflect the breadth of STEM.

Policy initiatives to re-think the STEM curriculum

Devise a new definition of STEM curriculum

To make progress on planning an integrated STEM curriculum, we need a new, shared definition of what STEM is. Much of the academic literature addresses how STEM subjects are linked, without providing a rationale as to why they belong together. A way to look at STEM is to define it as the set of disciplines that work together to understand and model the universe so that people can solve problems through harnessing and manipulating the world around them. Figure 5 represents the main linkages among the disciplines in this approach.

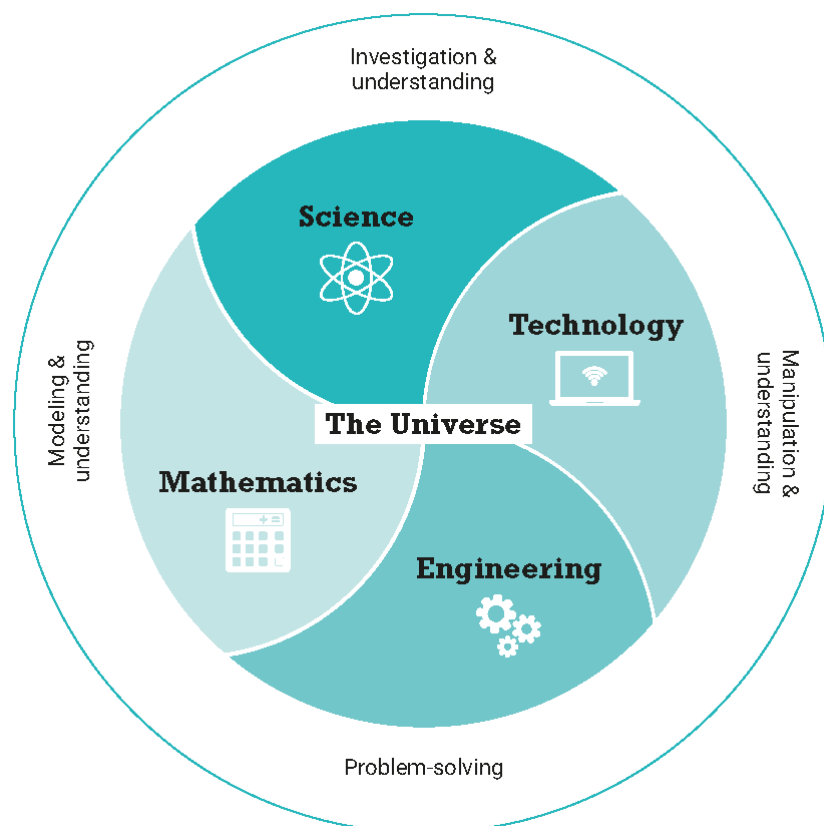


Figure 5 A model of how STEM disciplines are connected

In this model, the major focus of science is to investigate and understand the universe, while engineering's is to solve the problems we experience living in the world (such as harnessing and using energy in clean and efficient ways). Mathematics is also part of understanding the universe, and it provides ways to represent and model in ways that are applied in the other disciplines. Technology is involved in understanding but is also focused on manipulation of the matter and energy around us in order to solve problems. This model is intended to provide a framework for the integrated teaching of STEM. The model shifts the focus away from disciplinary knowledge to the practices and ways of thinking in each area and also places understanding and problem solving as the overarching purpose of STEM. Although in this representation each discipline touches only two others, it is accepted that all disciplines are connected.

Shift to an emphasis on practice

Adopting the model shown in Figure 5 gives a way of arriving at a cohesive, integrated STEM curriculum, but to do so, the educational emphasis needs to be on learning and applying the practices and ways of thinking in a discipline. That is not to say that disciplinary knowledge is not important but it should not be the main focus in an integrated STEM curriculum. Internationally, there are examples of curricula that have made this shift.

Science: Next Generation Science Standards (NGSS) (United States)

The United States of America has created the Next Generation Science Standards to set out what young people should know and be able to do in science. It does not specify what should be taught or how it should be taught, only the standards that should be achieved. The NGSS are based on an earlier Framework for K–12 Science Education (National Research Council, 2012) that emphasised the practices, cross-cutting concepts and core ideas for the discipline rather than the subject areas within science. The framework also takes a step towards an interdisciplinary approach because it incorporates the ideas and practices of engineering.

Key features of the NGSS are as follows.

- Every standard has three dimensions: disciplinary core ideas (content), scientific and engineering practices, and crosscutting concepts.
- Scientific and Engineering practices and crosscutting concepts are designed to be taught in context – not in a vacuum.
- Science concepts build across grades in a coherent progression of knowledge.
- The NGSS focus on a smaller set of disciplinary core ideas (DCI) that focus on deeper understanding and application of content.

Science and engineering are integrated into science education by raising engineering design to the same level as scientific inquiry and by emphasising the core ideas of engineering design and technology applications.

Source: Next Generation Science Standards. (NGSS) Lead States, 2013.

Mathematics: KOM approach (Denmark)

An example from mathematics in which the curriculum focus was shifted away from the knowledge components of the discipline and placed on the skills needed to apply mathematics can be seen in the KOM curriculum approach taken in Denmark.

The Danes have organised their curriculum around a set of mathematical competencies rather than content area divisions. In the KOM approach – an acronym in Danish that stands for Competencies and the Learning of Mathematics – mathematical competence is defined as ‘the ability to understand, judge, do, and use mathematics in a variety of intra-and extra-mathematical contexts and situations in which mathematics plays or could play a role.’ The eight competencies fall into two groups. The first group is to do with the ability to ask and answer questions in and with mathematics, which include:

- 1 thinking mathematically (mastering mathematical modes of thought)
- 2 posing and solving mathematical problems
- 3 modelling mathematically (analysing and building models)
- 4 reasoning mathematically

The second group relates to the ability to deal with and manage mathematical language and tools and includes:

- 5 representing mathematical entities (objects and situations)
- 6 handling mathematical symbols and formalisms
- 7 communicating in, with, and about mathematics
- 8 making use of aids and tools (IT included).

This approach provides a more skills and application focused view of mathematics that makes it easier to integrate with other STEM disciplines.

Source: Højgaard, T. (2009)

Technology: Australian Curriculum: Technologies

Including the T (technology) and the E (engineering) from STEM in the already crowded school curriculum is a challenge because, unlike the S (science) and the M (mathematics), they have not been a traditional part of the curriculum. There has been a recent push to include technology in Australia via the introduction of *The Australian Curriculum: Technologies*.

In the same way that the NGSS in the United States focuses on the broader aspects of science across the discipline and year levels, the Australian Curriculum: Technologies focuses on systems thinking as a unifying approach so that students can develop the technologies knowledge, understanding and skills that are needed in modern society and the workplace of tomorrow. The curriculum describes systems thinking as ‘a holistic approach where parts of a system are analysed individually to see the whole, the interactions and interrelationships between the parts and how these parts or components influence the system as a whole’.

The technologies curriculum for Foundation to Year 10 assumes that all students from Foundation to Year 8 will study two subjects: Design and Technologies, and Digital Technologies. For Years 9 to 10, it assumes that school authorities will decide whether

students can choose to continue in one or both subjects and/or if technologies specialisations that do not duplicate these subjects will be offered.

A challenge for STEM curriculum in general and for technology in particular is how to remain current and relevant in a fast-moving discipline. The Australian Curriculum: Technologies addresses this by focusing on students developing their knowledge and understanding alongside experience in related processes and production skills. It is hoped that in this way students will develop a 'comprehensive understanding of the nature of traditional, contemporary and emerging technologies'.

Source: ACARA (2017). Technologies. F-10 Curriculum

Not many countries have developed a comprehensive school curriculum for Engineering. In Australia, engineering is typically featured as a choice for students in Years 11 and 12. The UK offers engineering as a subject choice for its General Certificate of Secondary Education (GCSE) assessment program that students usually take at age 16 but there is no curriculum for primary years.

Engineering: Technology and Engineering Literacy (TEL) (United States)

In the United States, the National Assessment Governing Body that operates the National Assessment of Educational Progress, developed a new Technology and Engineering Literacy (TEL) Framework and assessment. The framework focuses on the level of knowledge and competencies about technology and engineering needed by all students and citizens to function in a technological society. The pilot of the computer-based TEL assessment for Grade 8 was run in 2014 and a report on the outcomes was made available. Again, the approach of the 2014 NAEP Technology and Engineering Literacy Framework was to look more broadly at the skills and abilities that are required for technology and engineering literacy, rather than focus on subject matter knowledge. The framework defines TEL as 'the capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals'. The framework also covers both the T and the E from STEM in that it addresses students' knowledge and skills in the three interconnected areas of Technology and Society, Design and Systems and Information and Communication Technology.

Source: National Assessment Governing Board (NAGB). (2014)

Move toward an integrated STEM curriculum

An integrated STEM curriculum has been defined as 'an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems' (Moore & Smith, 2014).

An integrated STEM curriculum needs to be carefully designed. At present, we teach the content and skills of each discipline and hope that students will see the connections to real-life applications. An integrated approach needs to locate the connections between STEM subjects and create a relevant context in which skills can be developed and content can be learned. Of the four subjects, engineering seems to offer the best scope to create problem-based curriculum units that allow integration of the subject areas, but the other subjects also offer opportunities. Framing the projects in real-world contexts makes them more engaging and relevant. The STEM Connections Project (Australia) explores this.

STEM Connections Project (Australia)

ACARA and the Australian Association of Mathematics Teachers completed a national *STEM Connections Project* in June 2016 involving 13 schools. The objective of the project was to demonstrate ways in which the STEM disciplines could be integrated for Year 9 and Year 10 students to solve an authentic challenge. Connections between learning areas were emphasised, and the general capabilities such as numeracy, ICT capability and critical and creative thinking were addressed. There was also a focus on identifying connections between STEM learning and future work and learning opportunities (p. 6).

There were several different models of delivery. Overall findings from the project noted general enthusiasm about the real-world nature of the project and the collaboration required by participants, although less confident learners were inclined to get lost in open-ended tasks (p.19).

The project helped to identify the following obstacles to an integrated STEM approach:

- it needs a high degree of commitment and expertise from the staff involved, both during the planning and implementation phases
- it can have significant implementation issues in traditional school settings, as timetabling structures do not necessarily have the flexibility to accommodate such projects
- it can result in inconsistent content coverage of some learning areas within a single project if planning is not thorough. (p. 20)

Source: ACARA (2016b). *STEM Connections Project Report*

Recommendations: STEM curriculum

In summary, contemporary approaches to integrated STEM curriculum include:

- a definition of what is meant by an integrated STEM curriculum
- an integrated approach that combines at least two of the STEM strands
- a focus on the practices, skills and capabilities of the disciplines rather than on particular components of disciplinary knowledge
- a consideration of the long-term currency of the curriculum in the face of expansion and progression of the disciplines by focusing on core ideas
- a design for the acquisition and development of skills across the years of schooling by focusing on cross-cutting and recurring themes in the disciplines.

CONCLUSION

Australian STEM education seems caught in a whirlpool of factors that are contributing to one another. Student engagement and performance in STEM are declining, and we do not have the supply of qualified teachers we need to improve learning. The STEM curriculum is unbalanced and fragmented, leading to disinterest among students. It is not possible to break out of the downward cycle from within the current system and it requires policy changes that address the issues raised in this report. This means developing well-considered, systemic and joined-up policies that address the following challenges.

The following recommendations represent a starting point.

Challenge 1: Improve student outcomes

Recommended strategies:

- Monitor STEM learning skills more broadly over time rather than just testing knowledge in summative assessments.
- Develop universal and early intervention programs to close the gaps that will otherwise persist over time.
- Encourage broader participation through specialised STEM schools and career academies.
- Stimulate interest in STEM through affordable and accessible out-of-school activities.

Challenge 2: Build the STEM teacher workforce

Recommended strategies:

- Deliver better data on the teacher workforce to power better policy.
- Offer tangible incentives to qualify and work as a STEM teacher.

Challenge 3: Re-think the STEM curriculum

Recommended strategies:

- Work from an agreed definition of STEM curriculum.
- Shift to an emphasis on STEM practices.
- Move towards an integrated STEM curriculum.

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