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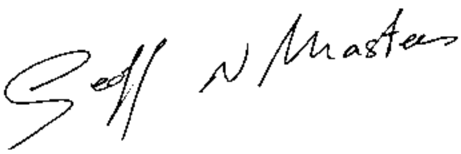
Conference papers: Tuesday 9 August

Foreword

Levels of science, technology, engineering and mathematics (STEM) will be important determinants of a nation's future productivity and economic competitiveness. Future STEM levels will determine a nation's ability to contribute to, rather than simply consume, scientific and technological breakthroughs and advances. At the same time, a growing percentage of future occupations will require high levels of STEM learning and skill. And beyond this, higher levels of scientific literacy will be required in society if citizens are to make informed decisions about environmental, health, technological and privacy issues that will impact them directly.

In this context, it should be of concern that there has been a steady decline in the mathematical and scientific literacy levels of Australian 15 year olds since at least the turn of the century. The decline in mathematical literacy has been dramatic. Australia has declined from being one of just a handful of very high performing countries in 2000 to performing little better than the OECD average in 2012. An indicator of this decline is the observation that the performance gap between Australia and South Korea increased by the equivalent of a full year of school between 2000 and 2012.

It also should be of concern that there has been a steady decline over several decades in the percentage of Australian Year 12 students choosing to study advanced mathematics and science subjects. This decline has been particularly marked in the subjects Advanced Mathematics and Physics.



And in parallel with these declines has been a decline in the attractiveness of teaching as a career among Australia's most able school leavers and a growing shortage of highly qualified STEM subject teachers.

These are some of the challenges we will be addressing at this year's Research Conference. The focus will be on what we are learning from research about ways of improving levels of STEM learning.

Australia faces significant challenges in promoting improved science, technology, engineering and mathematics (STEM) learning in our schools. Research Conference 2016 will showcase research into what it will take to address these challenges, which include:

- the decline in Australian students' mathematical and scientific 'literacy'
- the decline in STEM study in senior school
- a shortage of highly qualified STEM subject teachers, and
- curriculum challenges.

You will hear from researchers who work with teachers to engage students in studying STEM-related subjects, such as engineering in primary school, and science and maths at all levels. You will learn how to engage both girls and boys in STEM learning, through targeted teaching, activities like gaming, and applying learning from neuroscience.

Professor Geoff Masters AO, CEO
Australian Council for Educational Research

Keynote papers

Must try harder: An evaluation of the UK government's policy directions in STEM education

Pauline Hoyle
STEM Learning, United Kingdom

Pauline Hoyle is the Associate Director of STEM Learning, the organisation that provides continuing professional development in STEM across the United Kingdom. She manages the National Science Learning Network, including the National Science Learning Centre in York and more than 50 Science Learning Partnerships, the National STEM Centre and a range of other government and employer-funded continuing professional development programs supporting STEM education. Pauline has more than 40 years' experience as a teacher, advisor, researcher, professional development facilitator, author, examiner and accredited school inspector for the Office for Standards in Education, Children's Services and Skills in England. She has particular expertise in science teaching and learning, school improvement, monitoring and evaluation of the impact of programs on teacher development and student achievement. She is currently chair of the Expert Advisory Group in Science in England, which provides guidance and support to teachers and teacher trainers on the implementation of the national curriculum in science.

Background

STEM subjects in schools and colleges have received continuous support from the UK government and the devolved administrations for decades. There have been government-backed teacher training and continuing professional development of science and mathematics teachers, STEM employers have developed their own individual approaches to supporting curriculum materials and enrichment projects for students, and the scientific and learned bodies and STEM charities have supplied a range of support for STEM education and scientists. Despite all this action, during the past 30 years there has been a decline in the number of young people taking STEM subjects in the later stages of school, and a subsequent lack of STEM graduates and people with sufficient STEM background available for employment. So in the light of the continuous support already provided, what is the UK doing to address this situation?

Abstract

There is a common issue across Europe and the UK that vexes governments, employers and educationalists: the need for more young people to choose to study STEM subjects, become graduates in STEM subjects and then take up STEM careers. In addition, there is an urgent need for more STEM skills in the total workforce. For decades, the UK government has been committed to addressing this issue with a range of activities and strategies. Since the influential UK Government report conducted by Sir Gareth Roberts (2002), there have been policy and funding commitments by the various UK governments to improve outcomes for young people. These commitments have included incentives for people with industry experience and for graduates with good degrees to enter teaching; adopting accountability measures for schools to improve outcomes for young people, including better progression to STEM subjects at student milestones of 16 and 19 years of age; developing the STEM curriculum, including bringing a more cohesive approach to the vast array of curriculum enrichment by industry, charities and government; using national strategies for school improvement; and providing national continuing professional development for teachers and support staff, particularly through the National STEM Learning Centre and Network. This presentation will consider the evidence of the impact of the various strategies and the implications for other jurisdictions.

Government policy and action

The UK is made up of four different countries, and although most strategic planning for STEM is at UK-level, there are different education policies in each of the four countries – England, Scotland, Wales and Northern Ireland. Each country has interpreted the overall STEM policy initiative differently, although all four remain committed to improving the supply of home-grown talent in science and engineering.

Like Australia, the UK government has had a commitment and vision for improving STEM over a number of years. The UK government's commitment is summarised in the Science and Innovation Investment Framework 2004–2014 (HM Treasury, 2004) and a subsequent STEM strategy (2014–2024) (Department for Business Innovation and Skills, 2014), which both reiterate the aim for the UK to be the best place in the world for science and business.

In 2004, education was given a key role in achieving immediate and significant improvement in:

- 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 for General Certificate of Secondary Education (GCSE) levels in science
- the numbers choosing science, engineering and technology subjects in post-16 education and in higher education
- the proportion of better qualified students pursuing research and development careers
- the proportion of minority ethnic and women participants in higher education.

In 2006, targets were derived from these changes. It is these targets that provide the framework for this paper.

Changes in educational policy context

This commitment to improving the support for STEM research and development, as well as STEM education, has had cross-party political collaboration and support from industries and charitable trusts committed to STEM. The implementation of the STEM strategy was initially successful, with a cohesive program throughout 2004–2010; however, progress was slowed by the economic recession from 2007 onwards and by a number of changes in education policy in England. The recent systemic reform to a 'school-led self-improving' system introduced by the coalition government in *The importance of teaching* (Department of Education, 2010) has impacted on the implementation of the STEM policy, and at times conflicted with it. The leadership of the curriculum, assessment and school improvement is now the responsibility of school leaders. The responsibilities for schools in England were transferred from 153 locally elected local education authorities to individual schools and self-appointed school groupings called academies, with many being part of multi-academy trusts; around 1200 organisations are now responsible for schools.

There continues to be a commitment to supporting professional learning for teachers of STEM subjects through continued government funding for Maths Hubs, Computing Hubs and Science Learning Partnerships. However, individual schools/multi-academy trusts need to provide some funding towards the continuing professional development of their staff; and with austerity budgets beginning to bite now in UK education, some head teachers are unable/unwilling to prioritise support for improvements in teaching in STEM subjects, which jeopardises the quality of teaching.

Initial teacher education is now mainly school-based and led by teaching schools that collaborate with university teacher training programs (for more information, see Gov.UK, 2016). This has resulted in a reduction of recruitment of teachers of STEM subjects, which is impacting on the quality of teaching.

The government introduced in 2010 a revised national curriculum, which is a more knowledge-based curriculum. In science, there is less emphasis on inquiry-based learning and an increased requirement for mathematics skills. In mathematics, there is more emphasis on problem-solving in unfamiliar situations and making connections between different areas of mathematics. Consequently, this affects students' knowledge and understanding of the use and application of STEM skills. Nowhere is the detrimental effect of this policy change more evident than in the international test results for UK pupils.

There have been changes to the assessment of student attainment and progress that have affected evidence of the long-term impact of the STEM strategy. In 2009, the testing of students at ages 7 and 14 was removed, and testing at age 11 was reduced to English and mathematics only, science being assessed only through non-moderated teacher assessment. This has reduced the status and teaching of science in primary schools. In 2013, all national examinations for 16 year olds were changed from modular to terminal examinations, which has affected the uptake of triple science.

Changes to the accountability framework for schools have affected the assessment of the long-term impact of the 2004 STEM strategy. From 2006, schools were required to offer access to 'triple science' (biology, chemistry and physics) for higher-attaining students, to increase the likelihood of them progressing to sciences post-16. However, from September 2015, all 11 year olds have to take EBacc[1] subjects, and the different pathways in science work against more students taking triple science, and have reduced the uptake of design and technology. This could have an impact on students taking STEM pathways and careers.

Impact of policy changes in Europe and the UK

To ascertain the impact of the UK government's STEM policy since 2004, it is important to have a robust evidence base. With the shift of the locus of control to schools, a removal of standardised comparators of student progress and the dispersal of the national curriculum, it is challenging to find a consistent baseline by which to judge the outcomes of the policy. Given this difficulty, this paper reviews the available evidence of impact against the targets set in 2006, namely:

- changes in student attainment and progress data, nationally and internationally
- the uptake of science and progression to study and career pathways post-16 science
- the impact on the quality of teaching as indicated by the findings from the inspection system in England by the Office for Standards in Education, Children's Services and Skills
- impact on teacher recruitment, retention and continuing professional development programs.

Attainment progress and uptake of STEM subjects by young people

National results

Overall, the 2006 target to increase year-on-year the number of young people (16 to 18 year olds) taking General Certificate of Secondary Education A levels in physics, chemistry and mathematics has been met with increases since 2009 in the number of students entered for A levels in mathematics, further mathematics, physics and chemistry, and an increase in the number of students attaining grades of A* to C in each of these subjects. There is a gender issue, with fewer girls taking physical science and mathematics.

There were targets set to improve take-up and attainment in science for 16 year olds (General Certificate of Secondary Education level):

- an entitlement from 2008 for all higher-attaining students to study triple science[2]
- to continually improve the number of students achieving A* to B and A* to C grades in two General Certificate of Secondary Education science subjects.

There was an increase in the numbers of students taking triple science up to 2013, though a decrease in attainment. Conversely, there was a decrease in the numbers and attainment of those taking double science, but this has been reversed recently since the introduction of the EBacc.

Results in General Certificate of Secondary Education mathematics have shown a steady increase from 2007 to 2013, though changes to entry policies and introduction of terminal examinations have had some negative effect on attainment levels.

On the whole, the government STEM policy to increase attainment and progress in science pre- and post-16 was reasonably successful until 2013, when there was a decrease in take-up of triple science. A recent evaluation of the Triple Science Support Programme (STEM Learning, 2016) provides evidence that this is caused by the introduction of terminal assessment and the EBacc accountability measure. This is exacerbated by many post-16 providers only accepting students with A* to A grades in triple science to progress onto post-16 courses. Ultimately, this could reduce the numbers of students progressing to STEM study post-19, and hence to STEM careers and pathways. This is an example of two government policies that appear to conflict and give rise to unintended consequences.

International results

In contrast to the national attainment data, the outcomes of international tests show no positive increase. Students' performance in mathematics, science and reading in England has remained stable in PISA, with students performing at a level similar to the OECD average in mathematics and reading, and significantly better than the OECD average in science.

The results in the Trends in International Mathematics and Science Study (TIMSS) and the Progress in International Reading Literacy Study (PIRLS) 2011 show that at age 10, England has fallen in science but risen in reading, it has plateaued in mathematics at ages 10 and 14 between 2007 and 2011, and it has plateaued in science at age 14. The removal of national testing of

1 The English Baccalaureate (EBacc) is a school performance measure. It allows people to see how many students get a grade C or above in the core academic subjects at key stage 4 in any government-funded school. To pass the science element of the EBacc, pupils need to do one of the following: (1) get an A* to C in core and additional science GCSE (in core and additional science, pupils take 2 modules in each of the 3 main sciences: biology, chemistry and physics); (2) take 3 single sciences at GCSE and get an A* to C in at least 2 of them (the single sciences are biology, chemistry, computer science and physics); (3) get an A* to C in GCSE science double award (in science double award, pupils take 2 GCSE exams that cover the 3 main sciences: biology, chemistry and physics).

2 All pupils aged 14 to 16 have to take science, but it can be taught as triple science – encompassing biology, chemistry and physics taught separately in substantial depth – worth three GCSEs. Alternatively, the three sciences can be taught as integrated or combined science, called 'core and additional science' or 'double science', worth two GCSEs.

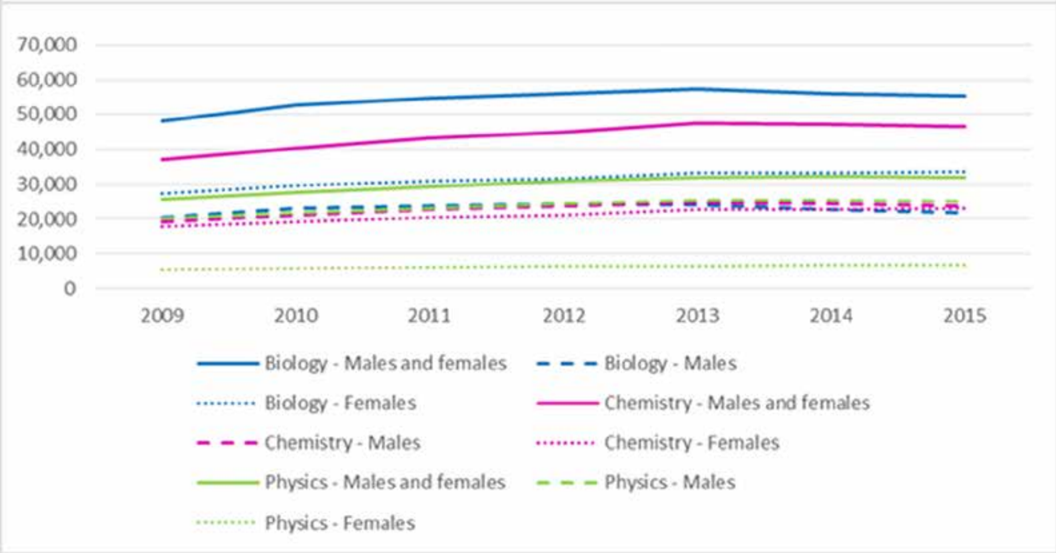


Figure 1 Year-on-year A level entries – Science

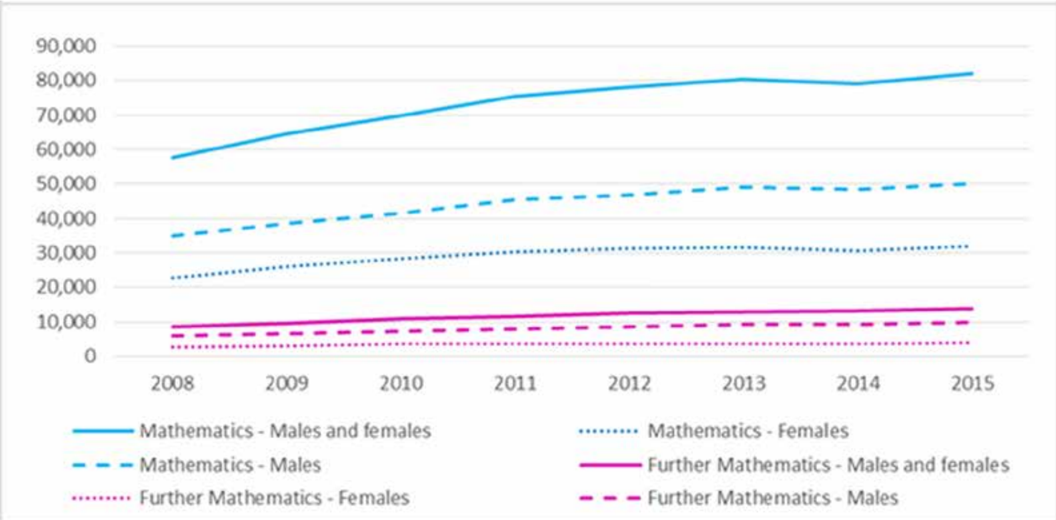


Figure 2 Year-on-year A level entries – Mathematics and Further Mathematics

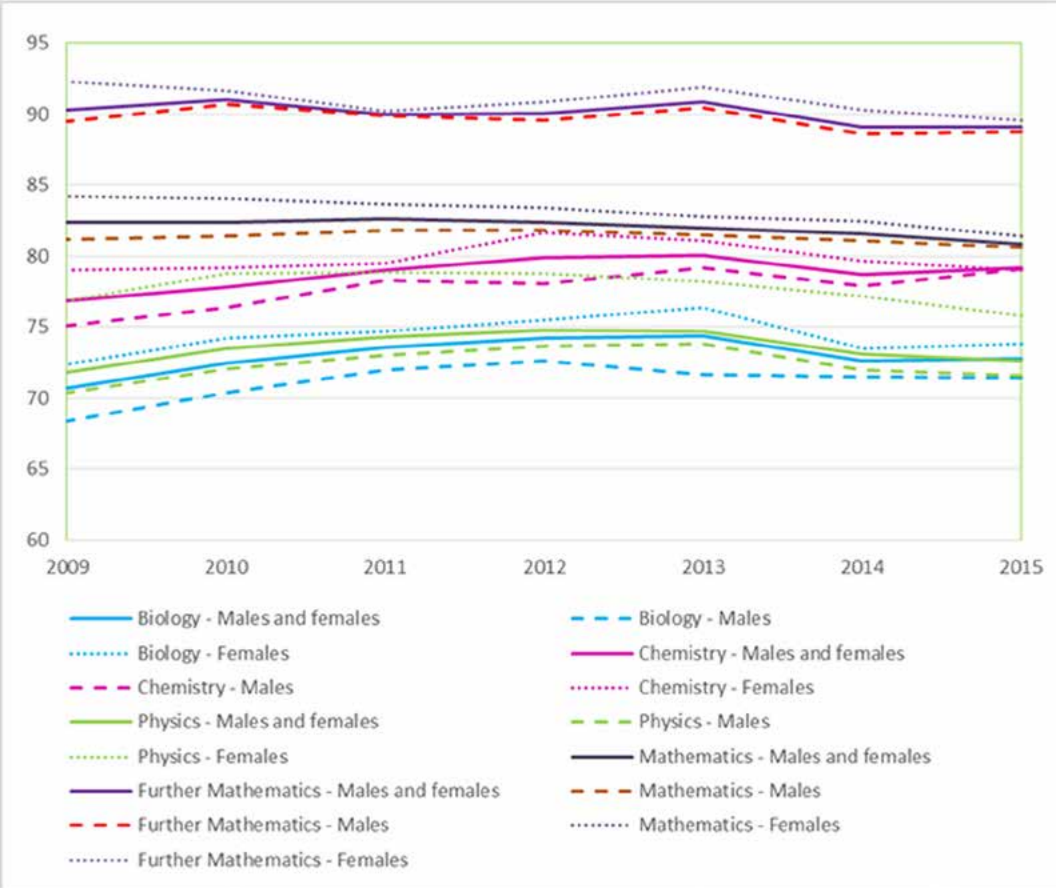


Figure 3 A level results: Percentage of cohort achieving A* to C in science and mathematics

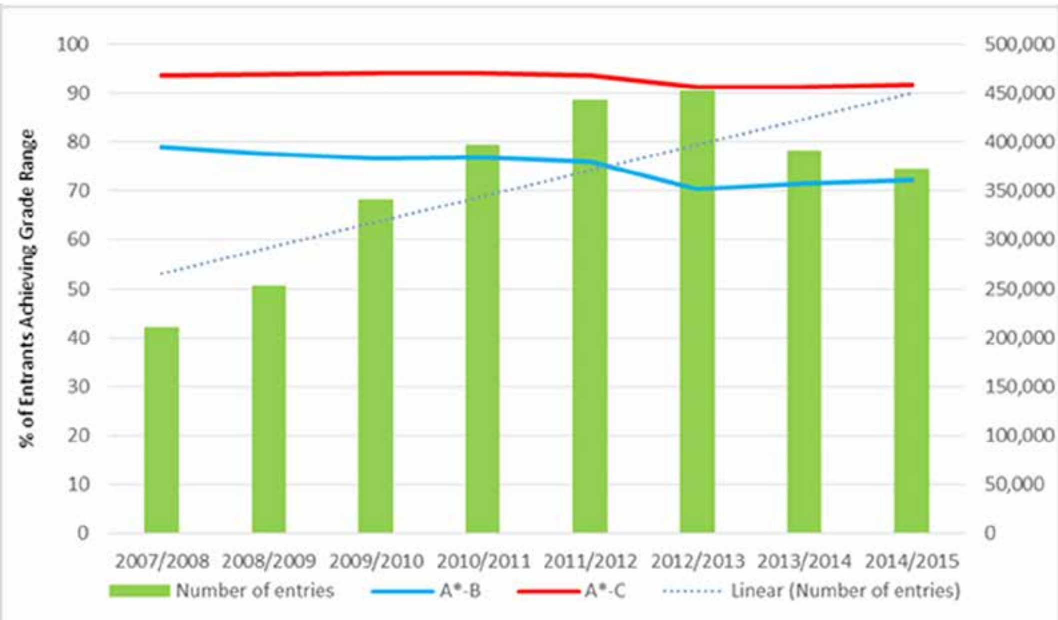


Figure 4 Biology, chemistry and physics combined – GCSE entrants and grade attainment

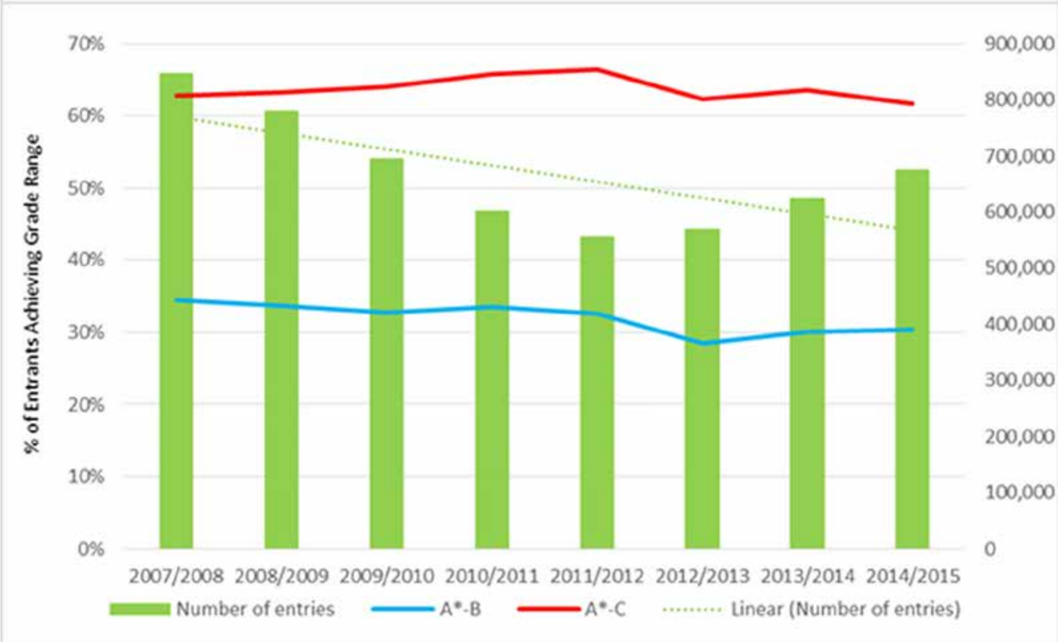


Figure 5 Core and additional sciences combined – GCSE entrants and grade attainment

Figure 6 Mathematics GCSE entrants and grade attainment

science at age 11 has reduced the teaching of primary science, which could partly account for these decreases. Also, more than national tests, international assessments test students' ability to use and apply knowledge, skills and processes in unfamiliar contexts. Coupled with the 2011 policy change from an enquiry-based to a knowledge-based curriculum, this is another example of unintended consequences resulting from policy change.

Take-up of degrees, apprenticeships and employment

There has been mixed improvement in the take-up of degrees, apprenticeships and employment in STEM areas. There is a very slight increase in the take-up of undergraduates studying STEM subjects, with around 45 per cent of undergraduate numbers in STEM subjects (Gatsby Foundation, 2014).

There has been minimal increase in uptake of STEM apprenticeships and vocational pathways. Of the three categories of apprenticeships (levels 2 to 4), the expansion in government-funded apprenticeships at level 2 has not been in STEM subjects. There has been an increase in science, engineering and technology (SET) apprenticeships from 20 950 in 2002/03 to 38 950 in 2012/13, while non-SET apprenticeships have risen sixfold in the same period.

Despite government policy and commitments in STEM, there continues to be a skills gap in the STEM area, with a year-on-year increase (12 to 19 per cent) of UK employers reporting difficulties in finding suitable STEM graduate recruits (UK Commission for Employment and Skills, 2014). The increase in attainment pre- and post-16, and the increased take-up of STEM subjects at A level, suggests that the STEM policy to increase the number of UK young people progressing to STEM careers and pathways has yet to be totally successful and is in jeopardy of delinking due to conflicting government policies.

Recruitment, retraining and retention of STEM specialist teachers

The government prioritises recruiting, retraining and retaining of teachers in STEM subjects so as to improve the quality of teaching in those subjects. By recruiting the best people into teaching, training them well initially and maintaining their skills and effectiveness through professional development, it is intended that the outcomes for young people will improve too.

There are yearly targets for teacher recruitment, and support for the recruitment and training of specialist teachers in maths and science, with scholarships for top graduates (Department for Education, 2015) and

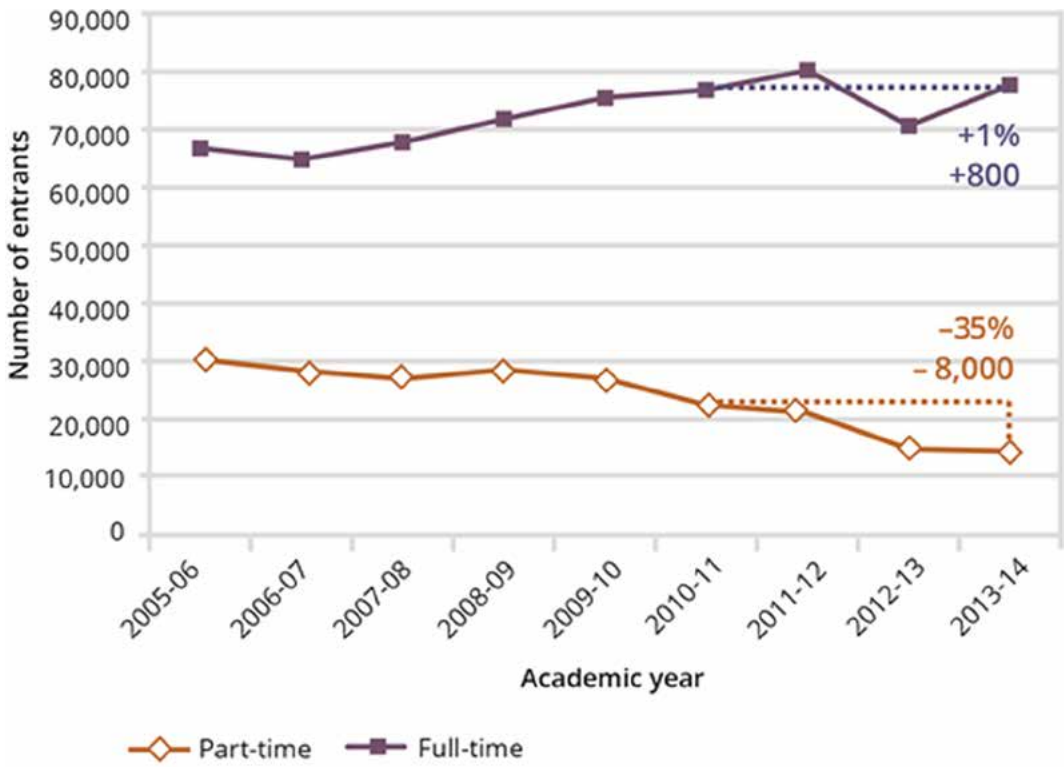


Figure 7 UK and other EU entrants to undergraduate STEM courses registered at English higher education institutions, 2006–07 to 2013–14

additional funding to retrain existing teachers on subject knowledge enhancement programs.

During the global recession (2007 to 2010), when more people entered teaching, the targets were almost reached. However, the recruitment of teachers with STEM qualifications has declined in recent years. There has been an improvement in the British economy, which has made it harder to attract people into teaching, and, as mentioned earlier, changes to teacher training, with the introduction of a school-based training program, which appear to have severely affected the take-up in STEM subjects. Again, there is an indication of conflicting government priorities having a negative effect on STEM education.

Teacher recruitment, retention and student outcomes

It is clear from the recent position paper (Office of the Chief Scientist, 2015) that the Australian government is taking measures to transform STEM teaching in Australian primary schools, focusing on initial teacher education and professional development. The English government has provided extensive continuing professional development for teachers of STEM subjects over many years (see Appendix 1). Employers support STEM education by funding programs including single employer-based activities and continuing professional development for teachers. A group of STEM employers, the Wellcome Trust and the UK government contribute to Project ENTHUSE,[3] which provides teachers with bursaries for sustained career-enhancing continuing professional development through the National STEM Learning Centre in York.

Given this plethora of continuing professional development available to teachers, the question is this: does it make an impact on the STEM outcomes the government has set? To answer this, we can examine the evidence from the evaluation of continuing professional development projects and from the inspection of schools in England carried out by the Office for Standards in Education, Children's Services and Skills.

The most recent inspection report in science by the Office for Standards in Education, Children's Services and Skills (2013) indicates that the majority of the teachers observed were skilful in teaching interesting science lessons, with the majority of the lessons (69 per cent) rated as good or outstanding.

3 Project ENTHUSE is a unique partnership of government, charities and employers that have come together to bring about inspired STEM teaching through the professional development of teachers, technicians and support staff across the UK. Current ENTHUSE participants include the Department for Education, Wellcome Trust, BAE Systems, Biochemical Society, BP, Institution of Engineering and Technology, Institution of Mechanical Engineers, Rolls-Royce, and the Royal Society of Chemistry.

They found that:

- 'A very low proportion of the subject leaders in the survey had received specific professional development in providing leadership for science. However, schools that had provided science-specific professional development were much more likely to be judged as outstanding in their overall effectiveness of science.' [page 6 summary]
- 'There was a strong correlation between a school's provision of continuing professional development (CPD) for teaching science, and the overall effectiveness of science.' [paragraph 28]
- The mathematics report indicates a much more mixed view of the improvements in the teaching of mathematics, while the achievement and provision in design and technology in 2011 were good in about two-thirds of the primary schools and just under half of the secondary schools, particularly where up-to-date technologies were used and explained accurately to students. However, a lack of subject-specific training for teachers undermined efforts to develop students' knowledge and skills, particularly in using electronics, developing control systems and using computers to aid in designing and making.

The government in England has funded subject-specific continuing professional development science through the National Science Learning Network for 10 years, and it is here that the best effects of strong and strategic policy directions can be seen. The Network has considerable evidence that those teachers who access sustained subject-specific professional development:

- improve teaching and learning, thus increasing uptake and achievement in science
- improve in their subject and pedagogical knowledge, skills and confidence, resulting in better outcomes for young people
- develop strong leadership in science
- help to recruit and retain excellent teachers
- enrich teaching, and support young people's engagement, progression and awareness of STEM careers (National Science Learning Network, 2015).

This evidence concurs with the hypothesis that professional development in science has positive results on improving teaching and learning. The government funding for professional development in mathematics and design technology has been less sustained and not yet fully evaluated for its impact.

InGenious, a European project across 26 European countries, also found that continuing professional development had an impact on improving students' interest in STEM careers and increased their likelihood of take-up (Stem Learning, 2014; see also InGenious and the Science Learning Network, 2014). The evaluation of the project identified four factors that improved teaching and influenced students' future choice of career:

- interesting classroom and extra-curricular activities
- inputs from experts, through learning resources as well as direct interaction with teachers and students
- embedding real-life applications of STEM knowledge and STEM career information within teaching materials
- sustained professional development for teachers through interactive and online resources as well as face-to-face opportunities.

Impacts of continuing professional development

The UK government policy to support STEM education has had some positive impact on the attainment and progress of students in science. There has been an increase in the uptake of sciences pre- and post-16, and some limited increase in up-take of STEM degrees, but less improvement in vocational areas. There is clear evidence that to increase students' attainment and interest in STEM pathways and careers, teachers of STEM subjects need sustained subject-specific continuing professional development to improve their subject and pedagogical knowledge, their confidence, their competence, and their leadership, to motivate them to stay in teaching and make good career progression.

There are still insufficient people available for employment in STEM companies in the UK, and people with STEM degrees entering and staying in teaching, which is partly due to the age profile of the country, the economic recession and, possibly, some conflicting government policies. You can pose the question: if the government had not had the STEM strategy, would the situation be worse?

What can Australia learn from UK approaches?

There are a range of strategies and approaches used in the UK to increase the interest and take-up of young people into STEM study and career pathways that Australia might like to consider.

It is helpful to have a clear, sustained, long-term government vision, strategy and funding for STEM research and development, strategies to increase citizens' awareness of the importance of STEM to the economy, and strategies for inspiring young people to take up STEM pathways.

Learning from UK and Europe, it is clear that constant fluctuations and changes in government education policies and funding have not been helpful in providing consistent and cumulative improvements. The best outcomes for young people and for sustainability in the STEM arena will come through an integrated approach that has all political party agreement for implementation and evaluation of impact over a sustained period. Setting realistically timed outcomes and targets in partnership with the teaching profession will bring about sustained change.

An effective partnership between government, industry (particularly STEM employers) and charitable trusts focused on STEM is vital to providing sustainable commitment and funding for STEM development. Together, these organisations can enrich the STEM curriculum, provide teachers with opportunities to learn about STEM knowledge and skills in context, and gain up-to-date knowledge about careers, which will entice more students into STEM career pathways. Funding teacher continuing professional development is very cost-effective – one teacher can influence a minimum of 250 students per year, or more than 10 000 students during a teaching career.

There are a range of measures with proven impact that, with sustained funding, will increase the likelihood of young people taking STEM study pathways. These include:

- culturally valuing an interest in and expertise in STEM subjects, on par with success in sports and cultural pursuits
- making teaching financially and culturally appealing, and attracting and keeping the highest calibre of teachers in STEM subjects
- the support of school leaders for teachers of STEM subjects to receive regular, high-quality subject-specific professional development to improve subject content and pedagogical knowledge, subject-specific leadership development and their knowledge of career pathways for young people
- teachers having access to up-to-date online information and curriculum-based resources about cutting-edge developments in STEM subjects, which help embed information about career pathways in the curriculum
- access to experts from the world of STEM for both teachers and students, to enhance the curriculum and teaching
- a clear pathway of STEM knowledge and skills across the curriculum, so students develop them and understand how they are used in context
- sufficient time for teachers to prepare, implement and evaluate the impact of the changes to the curriculum, assessment and accountability measures
- a coordinated and cohesive approach to enrich and enhance the experiences of ALL young people in

STEM subjects, through formal and informal learning opportunities

- training teachers, schools leaders and professional development providers in effective strategies for the evaluation of the impact of continuing professional development.

It is a combination of these strategies and partnerships that are likely to make a difference to attracting sufficient young people to take up STEM pathways and careers in the future.

Appendix 1

Current government-funded continuing professional development projects in England

- The National Science Learning Network, consisting of around 45 Science Learning Partnerships, mainly based in teaching schools
  http://www.stem.org.uk
- A national network of 34 Maths Hubs based in schools, coordinated by the National Centre for Excellence in the Teaching of Mathematics
  http://www.ncetm.org.uk
- The Further Maths Support Programme, focused on A level mathematics for 16 to 18 year olds
  http://www.furthermaths.org.uk
- Core Maths, aimed at increasing the number of post-16 students studying the subject, and designed to maintain and develop real-life maths skills
  http://www.core-maths.org
- A national network of Master Teachers in computing, coordinated by the British Computer Society and through Computing at School (CAS)
  http://www.computingatschool.org.uk
- STEM Ambassador program enabling employees with STEM expertise to provide support in STEM subjects and activities in schools
  http://www.stemnet.org.uk/ambassadors
- The National STEM Clubs Programme, support for out-of-school STEM meetings
  http://www.stemclubs.net
- Your Life campaign, aimed to increase the number of boys and girls progressing to A level maths and physics and beyond
  http://yourlife.org.uk
- Stimulating Physics Network, through the Institute of Physics, providing support and resources for schools struggling to deliver high-quality physics lessons
  http://www.stimulatingphysics.org

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What's all the fuss about coding?

Professor Tim Bell
University of Canterbury, New Zealand

Professor Tim Bell is a professor in the Department of Computer Science and Software Engineering at the University of Canterbury in Christchurch, New Zealand. His main current research interest is computer science education; in the past he has also worked on computers and music, and data compression. His Computer Science Unplugged project is widely used internationally, and its books and videos have been translated into more than 18 languages. He has received many awards for his work in education, including the ETH Zurich ABZ International honorary medal for fundamental contributions in computer science education in 2013, and the Institute of Information Technology Professionals New Zealand Excellence in IT Education award and President's Award for Contribution to the IT Profession in 2014. Recently he has been actively involved in the design and deployment of new computer science curriculum in New Zealand high schools.

Abstract

The idea of teaching 'coding' to school students has become popular, and the term appears in the names of many initiatives, such as Hour of Code and Code Club. But what do we really mean by 'coding', and why would you want every child to learn it? Won't it be outdated soon? This paper looks at these issues, and why topics such as computer science are being taught to all students. This includes an assessment of misunderstandings around the idea of compulsory programming for every student, and the challenges that accompany the introduction of such topics into schools.

Introduction

The term ‘coding’ has become a catchword for an international movement to give school students the opportunity to explore technical computing topics. Using the word ‘coding’ gives an air of mystery to the topic, and this can be useful for attracting students’ attention. In this paper we will unpack what is really meant by the term, and why it is being introduced into curricula around the world.

One of the drivers of exposing students to coding is to help them be *creators* of software, rather than just *users*. There are several motivations for this, but a key point is that being a mere ‘user’ in an increasingly digital world means that one is completely dependent on others to provide suitable software, which takes away individual freedom, since you can only consume what others choose to provide. Rushkoff uses the phrase ‘program or be programmed’ to capture this issue (Rushkoff, 2010). Lee et al. (2014) also highlight the sense of ownership that students get when they know how to modify and create technology. Furthermore, a country that doesn’t produce and sell software is missing out on an important export market, which provides an economic incentive to increase the exposure to coding in schools.

Understanding the nexus of human life and the discipline of programming is essential; in the 21st century, computer programs (also referred to as apps or software) permeate daily life. Programs bring life to smartphones, provide access to information online, mediate much of human communication, run our transport, monitor our fitness, track our health, and protect our finances. Hence, computing is primarily about people, rather than computers. The computer is just the general-purpose tool we use to solve human issues, whether for something as noble as supporting democracy, or simply for pure entertainment in the form of games.

Not only do programs need to be written to address human needs, the process of writing programs involves an awareness of what those needs are. For all but the smallest projects, programming involves collaborating with others to deliver the software in a timely fashion; putting all this together explains why ‘many skills of a professional programmer are related to social context rather than the technical one’ (Blackwell, 2002). Coding, whatever it is, is more about people than about computers.

What is coding?

The term ‘coding’ has become widely used in recent years, largely through the names of websites that promote programming (for example, Code.org, Codecademy.com, Codeclub.org.uk). Coding has become a brand, relating to moving students from consuming digital technology to producing digital technology, and giving them a sense of agency.

Coding in popular culture has come to mean what is more accurately called programming, and, more generally, software development. The term ‘coding’ has traditionally referred to only a small part of the whole process of software development. Creating new software involves several aspects, including:

- analysis: identifying the needs for which a solution will be developed
- design: sketching how the solution will work
- coding: converting the proposed solution to a computer language
- testing: checking that the solution works as intended, including being reliable and usable
- debugging: tracking down why parts of it don’t work as intended.

Those who advocate teaching ‘coding’ are invariably intending to refer to the broader ideas of software development listed above, but even this is a smaller part of the wider field of computer science. Programming is a key tool in computer science, but the bigger issues are knowing how to develop (rather than just use) fast algorithms, usable interfaces, intelligent systems, reliable networks, computer vision, innovative graphics software, and so on. New curricula appearing internationally take account of these broader issues, and in this context we can see that coding is simply a small but critical part of the whole idea of developing software to meet a human need. It has been compared to the telescope in astronomy; one could be forgiven for thinking that astronomy is about telescopes, since they are such a key tool, but that would be missing the point (Fellows, 1991).

While ‘coding’ has become common as a sound bite term to advocate for this new discipline, official curricula tend to use broader terminology. In the US, the term ‘computer science’ is more commonly used (for example, one of the main organisations is the Computer Science Teachers’ Association). In the UK, ‘computing’ has been chosen. In Europe, the German term ‘Informatik’ (and various translations[1]) describes the field well, and in Australia and NZ, ‘digital technologies’ is the name of the new curriculum. A key point is that

1 Note that the English term 'informatics' doesn't have the same meaning as the European 'Informatik', and, confusingly, is closer to traditional curricula that are focused on using computers rather than developing new software.

all of them have moved away from very broad terms like 'information and communications technology' (ICT). A 2012 report from the Royal Society (UK) pointed out that a focus on learning to be a computer *user* rather than a *developer* 'has led to many people holding a very negative view of "ICT", to the extent that terminological reform and careful disaggregation is required.' (Furber, 2012). Traditional ICT in schools might be easier to teach, but is often focused on learning to use particular software, which means the knowledge could date rapidly. Of course, the new curricula don't throw out the baby with the bathwater; it's still important for students to learn to use existing systems effectively.

A concept that has become widely used to capture the idea of a more empowering computing curriculum is 'computational thinking' (CT). Rather than focus on particular technical skills, it captures ways of thinking that students should develop, such as decomposing large problems, designing algorithms, and abstracting concepts (Voogt et al., 2015; Wing, 2006). In principle, these concepts can be applied without even using a computer, but computer programming is a very direct way of exercising these ideas, and quickly exposes any weaknesses in a student's expression of how to solve a problem.

Why teach coding?

As discussed earlier, when popular culture talks about adding 'coding' to a curriculum, we should expand this to the general idea of computational thinking and the corresponding disciplines (for example, computer science or digital technologies). Guzdial (2015) gives several reasons that students benefit from learning computing.

- Jobs: For some students it will be important to discover early that this is in fact a rewarding career for them; at present, many students miss out on this opportunity simply because they don't know what it involves, and this has created a desperate shortage of suitably qualified software engineers. However, this shouldn't be the main driver; the goal is not to prepare all students for the software industry, in the same way that teaching art isn't intended to prepare all students to become artists.
- Learning about their world: Now that society is so digital-centric, we have created many issues such as risks involving privacy, security, artificial intelligence, intellectual property and computer reliability; but there are also positive opportunities such as access to information, efficiency gains and better communication. In the same way that some understanding of biology helps us to be informed about controversies such as genetic modification, understanding computing will help us be informed about drivers behind our changing society.
- Computational thinking: The skills learning through CT can generalise to non-computing problems that we face.
- Productivity: Understanding and being in control of the devices we use enables us to use them more effectively.
- Broadening participation: Women and minority ethnic groups are notably absent from the business of software development, and yet the industry is crying out for diversity in order to produce better products. Increased participation can largely be traced to stereotypes created by society that are very hard to overcome if a student hasn't tried the discipline for themselves. There is evidence that it is particularly helpful for students to gain experience in programming before their adolescent years (Duncan et al., 2014), which crudely translates to learning 'coding' in primary/elementary school.

Each of the above reasons have an impact on a student's self-efficacy: the idea that they can understand and even control or change their digital world is important, to avoid developing a society of technocrats and their users.

As noted earlier, programming isn't an end in itself. Programming is used to make the world a better place for humans (and understanding programming helps us to evaluate better if each program that is written actually does improve our world, be it a social network, encryption, or artificially intelligent system). This view is particularly important for engaging women in computer science; Margolis points out that 'for most women students, the technical aspects of computing are interesting, but the study of computer science is made meaningful by its connections to other fields' (Margolis & Fisher, 2003).

Much of what is already available in school curricula is foundational to computer science, and includes skills and dispositions around interpersonal communication, teamwork, mathematical reasoning, understanding society, and creative thinking. Introducing 'coding' to a curriculum should not push out these existing subjects, and, in particular, experience in areas like music has a positive impact on the ability of a student to function effectively in a creative team.

Of course, this raises the question of what might be removed from an overcrowded curriculum, but in our experience, adding computer science concepts to a primary classroom can help to teach other areas faster. For example, with students programming in Scratch, one of the initial exercises is often to draw a square, with 90-degree angles. Students soon want to find out how to draw other shapes, and end up demanding to know how to work out the angle for a three- or five-sided figure, and soon encounter the idea that a full turn is 360 degrees. We have seen this happen with a variety of topics; the mathematical links are more obvious (coordinate geometry, arithmetic, number representation and so on), but topics like interface evaluation require some concepts from psychology and sociology, and since output from a computer is sensed by human beings, this leads to considering how eyes and ears work (for example, red/green/blue cones in the eye explain the use of red/green/blue (RGB) colour models on computers; and the 20 kilohertz (kHz) limit of human hearing explains why 44.1kHz is a common audio sampling rate).

The challenge of introducing computer science

We are living through a digital revolution that has impacted almost every aspect of our lives. Many aspects of education have been through change in parallel with other changes in society; there is an increasing use of mobile devices, use of the internet to access information, and use of productivity software to improve the way we work with information. However, these are all significant changes in education, and although 'e-learning' has made a significant impact, it is primarily used to teach the same subjects that we would have taught without it, and teachers are mainly having to develop their pedagogical knowledge rather than their subject knowledge. In contrast, computer programming and related topics are (for most schools) a completely new curriculum subject, and will require considerable professional development for teachers to gain both content knowledge *and* pedagogical knowledge. This is often overlooked, or confused with e-learning; a school might mistakenly think that because students are now bringing their own devices for all classes, then they are learning computer science, whereas this often means the opposite and reinforces the notion of being a user rather than a creator.

Digital technology has had a huge impact on society, and introducing programming – while urgent and important – is a large transition for schools and staff. Relying on the idea that students have devices and that teachers can simply start teaching programming can lead to the initiative backfiring.

For example, computer programming in industry is generally done on large desktop machines with multiple screens. It is particularly unfortunate that programming is being introduced into schools at a time when computer labs are being removed, and students are getting devices with smaller screens! Furthermore, programming involves running completely untested programs on a computer (that is, the students' own programs), and with one-to-one devices, often school policies or even device manufacturers make it difficult to run such programs!

There is also an unfounded concern that these ideas might be too difficult for young students. This would be equivalent to saying we shouldn't teach maths, science or music based on how complex those topics are at an advanced level, when of course they need to be adapted to be age-appropriate so that a foundation can be built early. Engaging tools for teaching computer science have been developed for teaching programming and related subjects to primary-aged students. There are dozens of programming languages designed for children (Duncan, 2014). Students can also engage with many of the concepts of computing and computational thinking without using a computer; approaches like Computer Science Unplugged (Bell et al., 2012) can provide students with the opportunity to think deeply about issues in computing without having to learn to program first. Unplugged exercises aren't enough on their own – after all, students need to find out how programming actually works first-hand – but programming on its own isn't enough either, since it isn't an end in itself, but a tool for implementing new ideas.

Another issue is around the choice of a programming language to teach students. There are many factors to consider here, but a key point is that we should be teaching *programming*, not a particular language. The issue is similar to choosing a car for a student to learn to drive in; while the typical career expectations for a professional driver might involve a bus, truck or courier van, the first principles are easily learned in a small hatchback. Similarly, programming is best taught in languages that have good pedagogical support, including books or websites, and are motivating in an age-appropriate way.

Conclusion

Digital technologies now permeate our lives, and it is important that we grow a diverse generation of students who are empowered to understand what is really going on, are able to make informed decisions, and have the opportunity to pursue the remarkable career opportunities that we have. There are deep ideas that students need to understand that haven't been taught previously in schools. Fortunately there are age-appropriate ways of engaging students with these ideas, so long as we are clear about what the key concepts are, we are clear about our purpose in mandating that they be taught, and we resource the transition to teaching this engaging subject.

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Conference papers

Monday 8 August

The STEM Teacher Enrichment Academy: Evaluating teachers' approaches to implementing STEM education in secondary school contexts

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Abstract

Amidst calls for a greater focus on STEM education in schools, attention is inevitably drawn to the quality of teaching and to appropriate means of supporting the teaching workforce so that more young people are engaged and interested in STEM subjects. This presentation describes the development and implementation of a STEM Teacher Enrichment Academy at the University of Sydney, and presents some of the outcomes from teachers' efforts to implement STEM education across a variety of school systems. The findings draw on survey and interview data from two cohorts of participant teachers and their STEM mentors as they progressed through the Academy program. One of our goals was to establish a professional learning community for enhancing STEM teaching in schools. We had mixed success, but each new Academy program builds on findings from earlier efforts so that we develop teachers' capacity to design and implement STEM curriculum to meet the needs of their students.

Currently, there is a global decline in students enrolling in mathematics and science subjects at the senior secondary and tertiary levels (Kennedy, Lyons & Quinn, 2014). In New South Wales, there has been a 13 per cent decline since 2001 in students electing to take a calculus-based mathematics course (Mack & Walsh, 2014; MANSW, 2014). Similar patterns occur with physics and chemistry, computing science, and engineering subjects in the senior secondary years. Research suggests that students who choose not to take a calculus-based course in senior years are less likely to succeed in mathematics and science programs at the tertiary level (McPhan et al., 2008). Associated with these trends is a decline in the number of mathematicians and scientists in the workforce, and predictions that we will need many more to meet workplace demands of STEM (science, technology, engineering and mathematics) professionals into the future (Office of the Chief Scientist, 2016).

There are many factors influencing subject choice and subject engagement in secondary schooling. Of the four main factors in the lower participation of students in senior mathematics identified by McPhan et al. (2008), pedagogical practices, perceived level of difficulty, and relevance are key. One strategy to counteract these issues suggests mathematics should be taught using rich tasks that develop problem-solving skills related to real-life contexts, allowing students to see the relevance of the content they are learning. Others have identified the influence of maximising ATAR scores (MANSW, 2014), as well as a lack of understanding of the importance of 'assumed knowledge' when embarking on tertiary studies in the mathematical sciences (King & Cattlin, 2015). Some of these factors are difficult to address, but one approach to promoting relevance and engagement is through subject integration in Years 7 to 10 (Bybee, 2013).

Integrating the STEM subjects forges connections and highlights real-world applications (Vasquez, Sneider & Comer, 2013). Integrated learning can be implemented in classrooms in a multitude of ways; by drawing connections to other subject domains, or by adopting a multidisciplinary approach, where teachers from two or more of the STEM subjects design integrated tasks, lessons or units of work so that students have a synthesised, integrated approach to learning STEM content. To date, there has been little research conducted into the efficacy of STEM integration and application in secondary classrooms (Bruder & Prescott, 2013; English, 2016), but there is some evidence to suggest that STEM integration is successful in increasing student engagement within mathematics classrooms (Stohlmann, Moore & Roehrig 2012; Venville, Wallace, Rennie & Malone, 1998). Based on the assumption that students benefit from opportunities to connect knowledge across the curriculum, a professional learning approach was developed to support teachers in planning and implementing connected approaches in secondary schools. This paper presents early findings from the professional learning of two cohorts of teachers.

The STEM Teacher Enrichment Academy: Setting the context

Since 2014, the Faculty of Education and Social Work has been collaborating with the faculties of Science, and Engineering and Information Technology, to build the nation's STEM capacity through teacher enrichment and professional development with the establishment of the STEM Teacher Enrichment Academy. The academy's flagship is a multi-day residential program for up to 70 teachers of Years 7 to 10 mathematics, science and technology designed to be foundational in enhancing teachers' knowledge of content and pedagogy, inspiring them to reinvigorate their classroom practice and improve student engagement in STEM subjects. The overall Academy aims were to:

- introduce and support exciting and effective approaches to learning, enhance teachers' knowledge of content and approaches to teaching mathematics, science and digital technologies in Years 7 to 10 of the Australian Curriculum for NSW
- develop a community of practice for participating STEM teachers, with ongoing support and engagement through mentoring, online forums, newsletters, seminars and events
- develop teachers' knowledge of STEM-related research and industry as well as knowledge of STEM programs at university and in career pathways.

Modelled on commonly agreed core features, the Academy professional learning approach incorporated a content focus, active learning, coherence, duration and collective participation (Desimone, 2009). With a focus on examining content and processes from the STEM subjects, Academy sessions were facilitated by the University's academic specialists and STEM leaders, as well as teacher/peer-led sessions. The program involved a three-day residential program at the University followed by up to two full school terms working on developing, planning and implementing STEM strategies in school-based teams. Teachers then returned for a further two-day program at the University to share their experiences, present evidence of teacher and student learning, discuss issues and challenges, and consider future initiatives. Each cross-disciplinary school team of two mathematics, two science and two technology teachers worked together to develop inquiry-based learning approaches to teaching both within their subject discipline as well as across the subject disciplines (Maaß & Artigue, 2013).

A unique feature of the STEM Teacher Enrichment Academy is its mentoring and support provision.

Table 1 School sector representation for the first two STEM Academies including school gender composition

	Department of Education	Catholic Systemic	Independent	Total
2014/15	8 (1 female)	1	4 (2 male, 2 female)	13
2015/16	7 (1 male)	2 (1 female)	3 (1 male, 1 female)	12

Throughout the Academy, professional mentors worked with participating teachers in their schools, providing support and assistance to plan and implement STEM strategies. Mentors visited participating teachers prior to, during, and in-between the two workshop sessions. An online platform was used to facilitate continuing discussion and sharing of resources between teachers across schools. This community of practice developed through interactions in the online community, information updates about STEM initiatives via a newsletter, and STEM one-day conferences to further facilitate sharing of approaches and resources from the wider community of schools in NSW.

Outcomes and recommendations from the STEM Academies

For the first Academy, 60 teachers from 13 schools visited the University in November 2014 and returned in March 2015 (see Table 1 for sector representation) – schools were invited to participate based on engagement with the University. While most schools were based in Sydney, four were clustered near Mudgee in the central west of NSW. This small country hub of schools enabled greater opportunity for collegiality, an essential ingredient given the small size of these schools, with some teachers reporting feeling isolated and with limited access to quality professional learning. Similar to the first Academy, the second involved 70 teachers from 12 schools, with a country hub of two larger schools from Wagga Wagga (see Table 1), and took place in November 2015 with a subsequent return to the University in May 2016. When selecting each group of schools, we sought diversity in socio-economic status, gender composition, and size, to promote sharing and to provide a diversity of experiences.

While overall the feedback from teachers has been positive, the key issues to be addressed based on the first two Academies included implementing inquiry-based learning approaches in regular classrooms, understanding the connections between the separate STEM subjects, working effectively in school teams, designing a STEM strategy most suitable for particular school contexts, and building the community of practice.

An external evaluation of the program revealed the features most supportive of teachers' STEM efforts included the provision of planning time, mentor input, and the structure and content of the program, which began with a focus on the separate subjects, allowing teachers to develop new skills and pedagogical strategies before exploring cross-disciplinary approaches. Focusing on the individual STEM subjects was adopted because mathematics and science teachers make more limited use of inquiry-based learning approaches in lessons than is recommended in curriculum documents and in research into meaningful learning (Anderson, 2005; Barron & Darling-Hammond, 2008).

However, teachers requested more examples of STEM integration, including sample tasks, projects and lessons – interestingly, when we did provide such examples, it was not always evident to teachers how they might use them and how the tasks connected with syllabus requirements. Indeed, there appears to be a need to make the connections between the STEM subjects more transparent for teachers (English, 2016), particularly when they are presented with already-prepared multidisciplinary tasks. These observations further highlighted the siloed nature of secondary school teaching, with teachers being most comfortable with their subject specialisation; to adopt a STEM curriculum perspective, teachers require horizontal expertise and they need to 'boundary cross – stepping into unfamiliar domains' (Clarke, 2014). Clarke also recommends that we need to construct STEM education around practices which could include discourse, artefacts, reasoning and evidence. Such an approach might help to address the issues associated with inconsistency in language as highlighted by English (2016), although some have addressed this by focusing on the engineering design process or systems thinking (Bybee, 2013).

Our experiences from both academies revealed some schools moved more quickly to developing integrated STEM approaches because of earlier experiences of writing integrated units of work, and working together as a team. This highlighted the diversity of teachers' knowledge and experiences of integrated STEM before coming to the Academy. It was clear that we needed to conduct school audits of their STEM work as well as take into account teachers' experiences of working together as a team. Some teams were cohesive and had already worked on projects together; others were dominated by one or two teachers who already had a plan that would be implemented regardless, while others had never worked together on creative programming and curriculum design.

Team building and effective whole-school planning have now become critical components of the Academy, and these begin with each school before they attend the first session at the University. Preliminary planning meetings include the school principal and other school leaders who need to play a key role in supporting the development of STEM initiatives, which frequently have implications for timetabling, teacher allocation to classes, alignment of STEM subjects on particular timetable lines, and resourcing. Schools have adopted a wide variety of approaches to implementing STEM education – frequently these decisions have been based on available personnel, teacher interest and resources, but school structures can act as impediments to innovative practices.

Because the schools were so diverse, particularly in relation to teachers from different subjects working together, the approaches they initially adopted were equally diverse. Some of the approaches used by Academy schools have included:

1. embedding more cross-curriculum applications within regular lessons (for example, exploring half-life in mathematics lessons and using virtual worlds in science to collect data to model and investigate real-world ecological problems)
2. conducting cross-disciplinary investigations in several STEM subject lessons to design solutions to problems (for example, improving the recycling system at the school, designing a new grandstand for the school football field)
3. undertaking an extended investigation over several weeks or school terms to design an artefact (for example, a plan for an energy efficient home for the school principal on a nearby plot of land)
4. redesigning the STEM curriculum program for a whole-year group around themes or big ideas (for example, mission to another planet, human diseases and prosthetics, better parks and gardens)
5. creating a STEM elective for Year 9 and 10 students
6. inviting STEM speakers to the school to share their experiences.

While this list may appear to be a rather eclectic set of approaches without any real cohesion, it recognises and accepts that schools are at different places in designing integrated curriculum and in embracing substantial change to curriculum design and delivery. Our acceptance of such diversity acknowledges that schools need to consider the needs of their students, the competence and interest of teachers, the overwhelming influence of siloed assessment in many schools, and the fact that real change takes time.

Building the community of practice has been a challenge. While on campus, teachers willingly discussed ideas with teachers from other schools, and engaged in worthwhile sharing of ideas, but the busyness of work back at school frequently meant little ongoing sharing in the online community. In some schools, finding time to meet as a school team was enough of a challenge and proved to be an inhibiting factor in moving plans forward. For schools to become STEM Academy participants, we had requested principals provide time for teachers to work on their projects, but this was not always achieved and remains another challenge to be addressed.

Future STEM Academy programs

There has been considerable interest in the program across NSW and Australia, so there is clearly a role for such an academy in supporting schools in implementing integrated STEM approaches. Our next program will have a similar number of schools from NSW, including another regional hub, but we will also be expanding to include a country-based program. We also plan to track students as they move through their secondary school to gather data about the efficacy of the program in relation to promoting the study of the STEM disciplines in senior school and beyond.

There is also a need to consider developing a STEM program for primary school teachers, as many are not confident teaching mathematics and science in the upper grades of primary school. We have evidence that some students enter secondary school already expressing anxiety and disengagement in mathematics and science. This needs to be addressed if we are to improve engagement in the STEM disciplines across all of the secondary school years.

Finally, Williams (2009, p. 31) cautions:

> The problem for educators here is that the consequent absence of a sound educational rationale for this combination of subjects inhibits its development. There needs to be a reason for integrating these subjects which relates to quality learning outcomes for students. As an educator, it is not difficult to be attracted by the logic and research that an integrated curriculum approach would be more appropriate for secondary schooling than a discipline silo approach in that it is more reflective of the society for which students are being prepared.

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Lifting Australian performance in mathematics

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Dr Thomson has also fulfilled the roles of National Research Coordinator for Australia in the IEA Trends in International Mathematics and Science Study (TIMSS) since 2002, National Project Manager for Australia in the OECD Programme for International Student Assessment (PISA) since 2004, and National Research Coordinator for Australia in the IEA Progress in International Reading Literacy Study (PIRLS) since 2008. In these roles she has contributed to the development of the instruments and questionnaires, particularly for TIMSS, where she is a member of the Questionnaire Review Committee.

Dr Thomson's research at ACER has involved extensive analysis of large-scale national and international data sets – the Longitudinal Surveys of Australian Youth (LSAY) as well as TIMSS and PISA – and she is also involved in several projects involving analysis of the longitudinal data collection associated with the PISA surveys. She was engaged as an expert writer on the National Numeracy Review, and has consulted with a variety of government departments at both Commonwealth and state level, as well as with the Catholic Education Commission, on a variety of data analysis projects related to TIMSS and PISA.

Abstract

One in five Australian 15-year-old students was found to be failing to achieve what the OECD describes as a basic level of mathematical literacy to enable students to actively participate in 21st century life. In many cases, these students are also unmotivated and disengaged with schooling, perceive their school experience in a negative light, and have low aspirations for the future. In a disproportionate number of cases, low-achieving students come from low socio-economic backgrounds, have an Indigenous background, and live in rural areas. This paper investigates the relationship of these and other demographic and educational background variables with being a low achiever, using data from PISA 2012. Lifting achievement in mathematics may also improve motivation and engagement.

In late 2016, new reports on student performance in the 2015 Trends in International Mathematics and Science Study (TIMSS) and the 2015 Programme for International Student Assessment (PISA) will be released. TIMSS focuses on Year 4 and Year 8 and tests students in mathematics and science. PISA focuses on mathematics, science and reading literacy for students who are 15 years old. Both studies have now been carried out for a substantial period of time – TIMSS every four years since 1995 and PISA every three years since 2000. Both studies show that Australia's scores in maths and science are not what we would want them to be. TIMSS has shown scores that have stagnated over the past 20 years, PISA that there has been slow but significant decline in Australia's scores in maths and reading literacy. It has been argued that these results are due to Australia's long 'tail' of underperformance (for example, Masters, 2016), particularly in the area of STEM (Office of the Chief Scientist, 2013), and while this performance is not different to that of many other countries, Australia does have a substantial proportion of students who are not achieving a standard that the OECD deems is sufficient to ensure active participation in the 21st century economy (OECD, 2014, p. 68).

There are many costs to having a substantial pool of low achievers in a country. Students who perform poorly at school are more likely not to complete school at all and to have poorer outcomes in life. OECD and Australian research has found that poor proficiency in numeracy and literacy not only means a much lower likelihood of a well-paying and rewarding job, but also poorer health outcomes and a lower level of participation in social and political life (OECD, 2013). As well as these negative outcomes for the individual, economic modelling carried out for the OECD by Hanushek and Woessman (OECD, 2010) argued that poor performance in tests such as PISA carries negative consequences for the whole country. They argue, 'Nations with more human capital tend to continue to make greater productivity gains than nations with less human capital' (p. 11). One of the models they explore in their OECD report involves bringing all students in a country up to a minimum skill level of 400 PISA score points. If this were achieved, Australia would see an increase of 225 per cent in GDP, which would have a value to the economy of around 3 billion Australian dollars (OECD, 2010, p. 26).

What do high- and low-performing mean?

While the mean scores on PISA provide a comparison of student performance on a numerical level, proficiency levels provide a description of the knowledge and skills that students are typically capable of displaying in each of the assessment areas. The proficiency scales typically span Level 1 (the lowest proficiency level) to Level 6 (the highest). Descriptions of each of these levels are based on the framework-related cognitive demands imposed by tasks that are located within each level. The skills and knowledge required to successfully complete these tasks can then be used as characterisations of the substantive meaning of each level.

PISA reporting generally refers to 'high performers' as being those students achieving proficiency Level 5 or 6; 'low performers' as those not achieving proficiency Level 2. Level 2 has been defined internationally as a baseline proficiency level and defines the level of performance on the PISA scale at which students begin to demonstrate the competencies that will enable them to actively participate in life situations. Reflecting this, the current study assigned students into groups based on their mathematical literacy proficiency level, and this report looks at differences between the high and low performers. Table 1 shows summary descriptions for low and high performers. A full description of all six proficiency levels for all subject domains is available in Thomson, De Bortoli & Buckley (2013).

Table 1 Basic descriptors of high and low performance on PISA

Achievement level	What students can typically do at this level
High performers	Students are capable of complex mathematical tasks requiring broad, well-developed thinking and reasoning skills. They can work with models for complex situations, reflect on their work and can formulate and communicate their findings.
Low performers	Students can use basic mathematical algorithms, formulate procedures or conventions, and can reason mathematically. They can make literal interpretations of the results of their calculations.

Australia's high (and low) performers

Australian students' average score in mathematical literacy in PISA 2012 was 504 points. While this was significantly higher than the OECD average of 494 score points, it masks the fact that around 15 per cent of students are performing very well on PISA, and about 20 per cent of students are not meeting basic OECD standards. Compared to the highest-achieving countries, Australia has a much higher proportion of students not performing at the base level and, compared to most of the highest-performing countries, a substantially lower proportion of students performing at the high proficiency levels. Figure 1 shows the proportion of high, average and low performers for Australia and the top five performers in PISA 2012.

Figure 2 provides an example of a Level 2 PISA item that a low performer would be likely to not answer correctly. One in five Australian students would not be able to provide the correct answer, in comparison to just four per cent of students in Shanghai-China.

Helen the cyclist

Helen has just got a new bike. It has a speedometer which sits on the handlebar.

The speedometer can tell Helen the distance she travels and her average speed for the trip.

On one trip, Helen rode 4km in the first 10 minutes and then 2km in the next 5 minutes.

Which one of the following statements is correct?

A. Helen's average speed was greater in the first 10 minutes than in the next 5 minutes

B. Helen's average speed was the same in the first 10 minutes and in the next 5 minutes

C. Helen's average speed was less in the first 10 minutes than in the next 5 minutes

D. It is not possible to tell anything about Helen's average speed from the information given.

Source OECD, 2014

Figure 2 Example of a PISA item at proficiency Level 2

The PISA 2012 average represented a significant decline of 20 score points from when mathematical literacy was first measured in PISA 2003. This decline is shown in a combination of a significant decrease in the proportion of high achievers and a significant increase in the proportion of low achievers (see Figure 1). In terms of actual numbers, the bar for low achievers in 2012 in Figure 3 represents about 57 000 Australian students.

Who are Australia's low-performing students?

Who and where are Australia's low performers? Table 2 shows the proportion of students at each level for the background variables collected in PISA. What is evident from this summary is that while there are some gender differences, these pale into insignificance when compared to differences by Indigenous background, by geographic location, by socio-economic background, and by school sector.

It is clear from Table 2 that low performers come from all manner of backgrounds; however, they are disproportionally from an Indigenous background, from a low socio-economic background, attend rural schools, and attend government schools. Interestingly, students who have a language background other than English fall into two groups: a group of low performers, and another group of high performers.

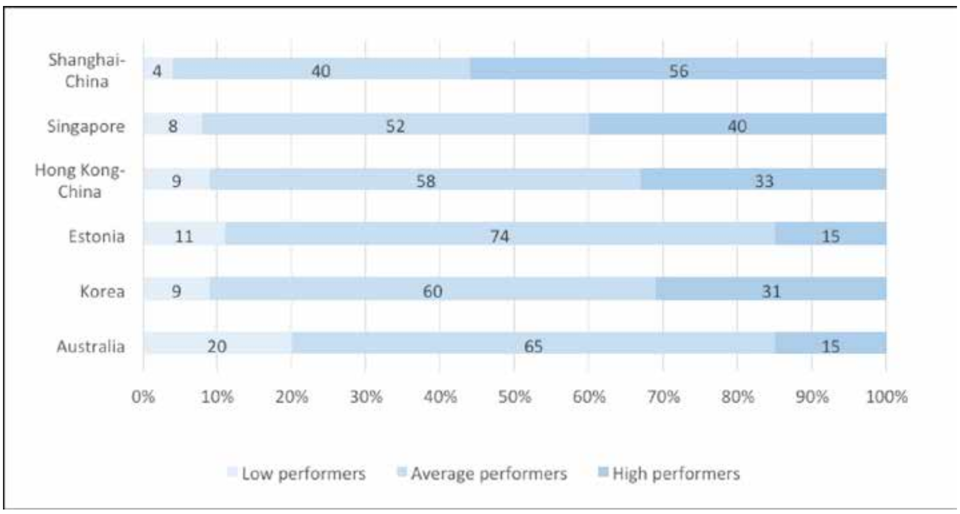

Figure 1 Proportion of low, average and high performers, PISA 2012

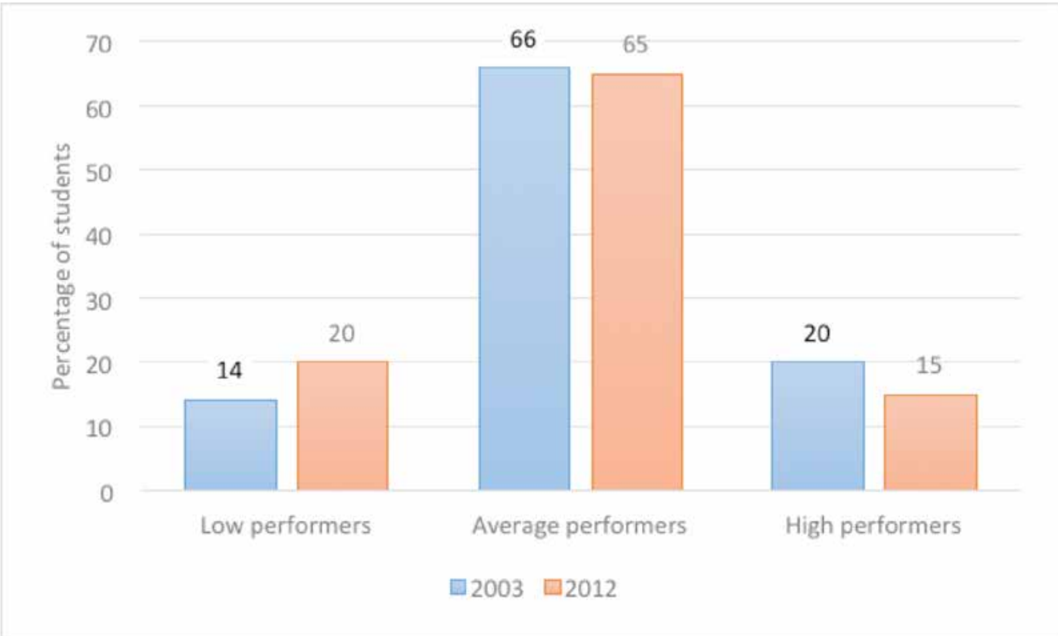

Figure 3 Percentage of students at mathematics proficiency levels, PISA 2003 and PISA 2012

Table 2 Proportion of low, average and high performing students, PISA 2012, by background variables

	Low performers	Average performers	High performers
Males	18	65	17
Females	20	67	13
Indigenous	48	49	3
Non-Indigenous	18	66	16
Metropolitan	18	65	17
Provincial	22	68	10
Rural	37	57	6
Government	25	63	13
Catholic	14	71	15
Independent	9	68	23
Lowest quartile SES	33	61	6
Second quartile SES	22	68	10
Third quartile SES	13	69	18
Highest quartile SES	8	66	27
Australian-born	19	68	13
1st Generation	16	64	20
Foreign-born	20	62	18
Single-parent family	21	67	12
Two-parent family	17	67	16
English spoken at home	18	68	14
Language other than English spoken at home	23	56	21

Relationships with achievement

Of course, a student's performance is affected by a combination and accumulation of factors and experiences at home and at school, and while social and demographic variables do not determine achievement, they provide opportunities that influence a student's success in the education system. Based on the data in Table 2, Table 3 shows the potential areas of risk for mathematical literacy, specifically for the Australian PISA data.

Binary logistic regression models were constructed to examine what factors differentiated the sample members who did not have a successful outcome (that is, low performers) from those sample members with more positive outcomes. Table 4 shows the results of the logistic regression.

Table 3 Student background and low performance – risk factors

Potential area of risk	PISA variable	Risk factors
Socio-economic background	ESCS	Socio-economic disadvantage
Demographic background	Gender	Being a girl
	Indigenous background	Being Indigenous
	Immigrant background	Immigrant background
	Language spoken at home	Not speaking English at home
	Location	School in a rural area
	Family structure	Single-parent family
Educational background	Participation in pre-primary education	No pre-primary education
	School sector	Government school
	Grade repetition	Repeated at least one grade
	Absence from school	Away from school for at least 2 months in primary or secondary school or both

Table 4 Logistic regression model for low achievement

Predictor	Comparison group	B	SE(B)	eB
Low ESCS***	High ESCS	-1.43	0.10	4.2
Girl***	Boy	-0.34	0.08	1.4
Indigenous***	Non-Indigenous	-0.99	0.11	2.7
Immigrant background	Born in Australia	-0.11	0.12	-
Language at home not English	English spoken at home	-0.08	0.11	-
Single-parent family	Two-parent family	0.05	0.12	-
Rural school	Metropolitan or provincial school	-0.07	0.32	-
Did not attend pre-primary***	Attended at least one year of pre-primary	-0.63	0.16	1.9
Repeated at least one grade***	Never repeated a grade	-0.92	0.12	2.5
Attends a government school***	Attended an independent or Catholic school	-0.56	0.11	1.8
Absent for 2 months at least once***	Never absent for large block of time	-0.61	0.08	1.8

Asterisks denote significant results

In this model, having an immigrant background, speaking a language other than English at home, attendance at a rural school and being a member of a single-parent family did not have a significant influence on being in the low achievement group. Seven of the factors described in this model were significant. Holding other factors constant:

- Disadvantage was found to have the strongest relationship with performance, with a socio-economically disadvantaged student more than four times as likely as a socio-economically advantaged student to be a low performer.
- Girls were about one and a half times as likely as boys to be low performers.
- Indigenous students were almost three times as likely as non-Indigenous students to be low performers.
- Students who did not attend pre-primary education were about twice as likely to be in the low performers group than those who had attended pre-primary education for at least one year.
- Students who had repeated at least one grade were two and a half times as likely to be a low performer than those who had not.
- Students who attended a government school were almost twice as likely to be a low performer than those who attended an independent or Catholic school.
- Students who had missed at least two months of school at some stage of their school lives were also almost twice as likely to be a low performer than those who had never done so.

Relationships with engagement and motivation

On every indicator of motivation and engagement used in PISA, low-performing students are much more negative than their high-achieving counterparts. They are less likely to aspire to university study, more likely to truant or skip classes, and perceive their classrooms and schools in a different light.

Conclusions

These findings are important for policy. One in five 15-year-old students in Australia fails to achieve the level described by the OECD as the minimum needed for active participation in 21st century life. The benefits of substantially decreasing the proportion of students at this level vastly outweigh the cost of doing so. At the individual level, higher achievement leads to better job opportunities and better life outcomes. For the community as a whole, raising achievement for the lowest achievers brings many benefits, including higher levels of GDP. A number of countries – Brazil, Germany, Italy, Mexico, Poland, Portugal, Russian Federation, Tunisia and Turkey – all decreased their proportion of low achievers in mathematics, showing that it is possible, with the will and the right policies, to change things.

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Sharing the stories of near novices to impact mainstream change

Dr Bronwyn Stuckey
Independent consultant

Dr Bronwyn Stuckey has been engaged in educational community and gameful practices in learning development for the past 15 years. She has worked to explore virtual worlds, games in learning and how we can cultivate identity, agency, citizenship, leadership and community. Bronwyn earned her PhD in researching the core factors supporting successful online communities of practice. In that research, she examined in-depth the development of communities across many sectors: e-government, enterprise, military and not-for-profit. She has applied those research findings when consulting in the design of adult learning communities and workplace communities of practice. Since leaving lecturing and l earning design in the higher education sector (at the University of Wollongong, Queensland University of Technology and the University of Western Sydney), her research, consultation and design have been in gamification and game-inspired designs for professional learning and communities of practice.

Most prominent of this work was the gamification (badges) and community design of the PLANE professional community. PLANE was a flagship of the Australian Digital Education Revolution. Bronwyn also co-designed and coached in the Foundations of Communities of Practice online workshop with Étienne Wenger, founder of the concept. This workshop inspired new community designs and supported workplace community developers to bring their personal projects from idea to viable product, and to address concerns and roadblocks.

Bronwyn is a co-facilitator of the Open Badges Australia and New Zealand community and has for the past two years researched the efficacy of open badges in re-imagining and re-framing academic learning programs and contexts. She is a postdoctoral research fellow of the Arizona State University Center for Games & Impact and is a global leader in gamification for community and identity cultivation. Bronwyn is also lead member of the Sydney Educational Technology Group working to support edutech start-ups and to make Sydney the hub of educational entrepreneurship.

Abstract

This case study research is designed to examine the ways in which teachers are bringing gameful practices into their classrooms as part of a STEM learning agenda. It is hypothesised that one of the best persons to inform or improve the practice of novices is a near novice; someone who was most recently themselves a novice. In many case study programs, we hold up exemplary practitioners as models, but these experts may be too far removed in their levels of expertise to impact the practice of true novices. Experts and evangelists might be useful in creating vision for change, but the actual steps toward change in practice might lie with educators 'more like ourselves'. This research sets out to examine the work of educators starting out in various forms of gameful practices in teaching and learning. Telling the stories of these near novices has the potential to support, influence and impact the next wave of innovators, those beyond the early adopters. This is a work in progress and will report on the case studies collected and nascent feedback on their impact early in 2017.

What is the relationship of games and gameful practices to STEM learning?

Conventional mathematics mini-game content management systems like *Mathletics* have found a ready place in classrooms for demonstration and assessment of domain knowledge. But games may take a much more transformational role in learning. Simulations and virtual worlds have allowed learners to be immersed in contexts, roles and experiences. Immersive games like *Murder under the Microscope* (Nielsen, 2011), *Quest Atlantis* (Barab et al., 2010a, 2010b), *Whyville* (Kafai, 2010), *WolfQuest* (Goldman, Koepfler & Yocco, 2009) and *ecoMUVE* (Metcalf et al., 2013) have demonstrated how virtual world games can be used to support an abstraction of participation in a field or study (behave as a vector or practitioner in a field).

Gameful or gamified learning experiences like Hour of Code (https://code.org/learn) and Scratch (https://scratch.mit.edu) are being used to build a positive disposition to fields of STEM new to primary education (like computational thinking), while the mobile game *Water Bears EDU* (https://itunes.apple.com/us/app/water-bears-edu/id964924572?mt=8) engages learners in spatial awareness and systems thinking.

Commercial or 'off-the-shelf' games (commercial games not designed specifically for educational use) have been appropriated and adapted successfully by teachers for specific learning contexts. Games such as *Minecraft* (https://minecraft.net/en) and *Portal 2* (http://www.thinkwithportals.com) have reported success in supporting STEM learning topics as diverse as momentum, potential energy, circuitry, Rube Goldberg machines and city planning.

Game design tools are being used for students to evidence their own research and learning by embodying STEM concepts in games to teach others. Leveraging this constructivist pedagogy (Piaget, 1977), competitions in Australia like the ACER STEM Video Game Challenge (https://www.stemgames.org.au) and ACMI Screen It (https://www.acmi.net.au/education/student-programs/screen-it), while relatively new to the scene, clearly are drawing teacher attention. They promote STEM learning agendas while providing an authentic context and audience for student-designed products.

What do we know about the diffusion of gameful practices?

Everett Rogers (1962; 1983) described the diffusion of innovation as being a bell curve of adoption. It seems reasonable to assume that over time, innovations such as video games would follow a similar pattern of diffusion from the early adopters through to the laggards.

We know that teachers have used games as tools in their teaching for very many years. They might have been singing games, puzzles, 'decide your destiny' stories, physical games, trust games, card games or board games. Somehow, though, digital games and video games have not evolved in the same way as part of that continuum of game adoption. Their pattern of uptake much more mirrors that of 'disruptive technologies' (Christensen, 1997).

Coming from a marketing perspective, Moore (1983/2014) expanded on Rogers' theory to propose the technology adoption life cycle, and the idea that diffusion was not necessarily a smooth and a complete continuum. He proposed that there was a chasm between the early adopters and the early majority that had to be crossed for a disruptive technology (or product) to become mainstream. Malcolm Gladwell (2000) called this point just before impacting the early majority the 'tipping point'.

Both Rogers and Moore suggest that the needs of early adopters are very different to those of the early majority. Where early adopters are motivated by scarcity, by being individuals in a small leading-edge elite, the early majority are influenced by a level of social proof. They are swayed to take up innovation because others around them and like them are engaging in it.

For educational use of games, this chasm might be perpetuated when we continually share only stories of the most expert of the innovators. Their stories and practices might be too distant from those in the prospective early and late majority. While their stories can inspire and give vision to what is possible, they may not provide the social proof needed by many for a shift in classroom practice.

Where do gameful practices sit in the adoption cycle?

There is a serious dearth of evidence about the uptake of gaming and gameful practices in Australian schools. Recent US studies (Takeuchi & Vaala, 2014) would suggest as much as 55 per cent of teachers allow students to use games at least weekly. However, the type of games and the purpose of their use proved not to be the immersive and transformative game experiences described earlier in this paper. 'Teachers are using dedicated game platforms in particular to motivate and reward students (54%) and for break activities (43%), at about twice the rate they're using these devices to engage students with lesson content' (Takeuchi & Vaala, 2014 p. 56). So while the survey percentages appear to suggest games are now well into early majority use, I would suggest this is not the

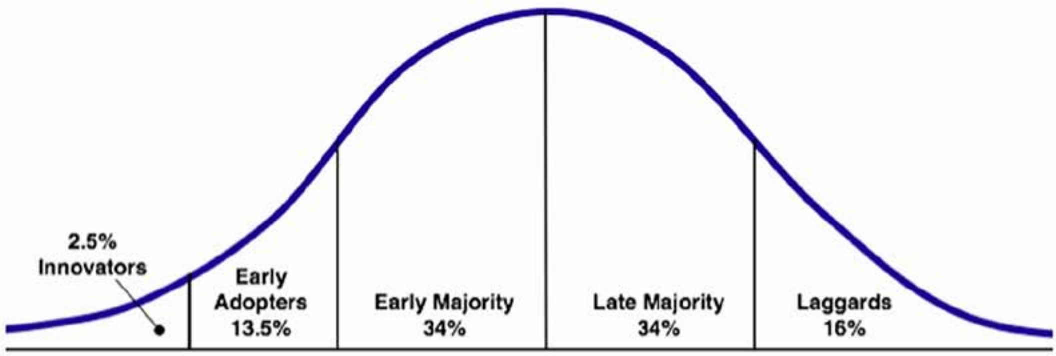

Figure 1 Diffusion of innovation (Rogers, 1962; 1983)

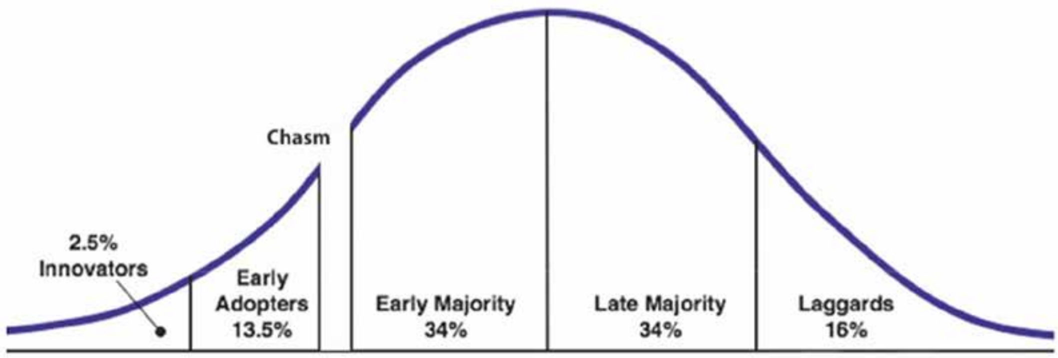

Figure 2 Technology adoption life cycle (Moore, 1983)

case if we consider the affordances of games to be transformational play experiences (Barab et al., 2010a, 2010b) and truly disruptive. We may well be looking at a percentage for adoption much closer to 16 per cent and the tipping point. The tail end of early adopters, those educators having just stepped into new gameful practices for the first time, could hold the key to influencing the early majority mainstream educators.

How are teachers acquiring skill in using games and gameful practices?

'Teachers are learning to teach with digital games via more informal means (i.e., fellow teachers and self teaching) than formal training programs (pre-service and in-service)' (Takeuchi & Vaala, 2014, p. 57).

This informal learning may explain why burgeoning face-to-face practices like Edcamp (http://www.edcamp.org) and TeachMeet (http://www.teachmeet.net) appear anecdotally to be both popular and impactful in uptake of educational innovation. Their participant-driven nature builds relationships and, equally, gives access to a range of practitioner stories – expert and near-novice – and perhaps some level of clear social proof or acceptance of an innovation's benefit.

Conversely, formal educational events continue to host expert stories. We see this at professional conferences, webinars, in media articles and in research case studies. But it is the stories of near novices or 'advanced beginners' (Dreyfus, 2004) that may prove more accessible and influential to true novice practitioners.

What might constitute social proof?

This research project marries constructivist and situated learning, diffusion of innovation, and communities of practice theory to create a social-media-savvy case study approach. We can look to constructivist learning theory to understand why focusing on near novices might be advantageous. If we accept the Vygotsky concept of the zone of proximal development (Vygotsky, 1978, p. 86) as the space where a person is able to perform with guidance and scaffolding, then creating a place for teachers to support each other could work towards jumping the chasm. The research strives to understand if and how telling the stories of near-novice innovators in the tail of the early adopters group might scaffold those true novices following behind them. In this case, the innovation describes all gameful learning practices (bridging game-based learning, game design and game-inspired learning or gamification).

The research motivation and questions

'Those who are successful at creating social epidemics do not just do what they think is right. They deliberately test their intuitions' (Gladwell, 2000, p. 258–9).

This research represents a deliberate testing of intuitions cultivated by the researcher over 20 years of leading teacher professional learning, communities of practice and games in learning research. It is a disciplined and informed intuition that suggests telling the stories of near novices (on the tail edge of early adopters) and building a discourse around those stories will be impactful in influencing those not yet involved in gameful learning practices (on the leading edge of early majority). Essentially, this project is designed to create the zone of proximal development to scaffold novice game-using educators (Vygotsky, 1978, p. 86).

Research questions

- How effective can case stories of near novices be in motivating and scaffolding novices to innovate with gameful learning practices?
- How and in what ways can stories and the intentional community cultivated around them serve to amass the social proof required by early majority adopters?

Methodology

Jumping this chasm will involve collecting and publishing a critical mass of case stories as the core component around which to cultivate professional discourse (and community).

This will involve:

- Case study methodology: Volunteer participants identified through expressions of interest, nominations, events, conferences, and so on
- Stories of near novices as recognisable other: Case stories built from interviews and site visits with volunteer educators
- Blog to dynamically offer and build a critical mass of stories: Cases appear as blog posts with identified educators and a follow-up means of communication
- Facebook group and Twitter handle (#getgamehub): Discourse, networking and community building spaces
- Webinar, Meetup and other community building events and activities: Regular synchronous events to host discussions and meet case educators
- Google Analytics to gather click data: Site data used to understand traffic and usage
- Mailing list to identify users: Identify those engaging with cases for survey feedback
- Survey to determine value to early majority: To question site users and community users about the value of cases and social engagement.

At the time of writing this paper, the tools described are in various stages of development, and the first stories are being amassed. First data should be available in early 2017.

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Promoting girls' and boys' engagement and participation in senior secondary STEM fields and occupational aspirations

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Professor Helen Watt is Professor in the Faculty of Education, Monash University, and Australian Research Council Fellow 2011–2015. Previously she served at the Universities of Michigan, Western Sydney, Sydney, and at Macquarie University. Her interests include STEM motivation and engagement, gendered educational and occupational choices, and quantitative analyses for developmental data. Her work has implications for redressing the gender imbalance in mathematics- and science-related careers, and supporting career development for beginning teachers.

Helen is founder and coordinator of Network Gender & STEM (http://www.genderandstem.com), Associate Editor for AERA Open, and on the editorial boards of the International Journal of Quantitative Research in Education, Contemporary Educational Psychology *and* Australian Journal of Education. *She has attracted awards, media and competitive funding, and co-edited books and journal special issues including* Gender and occupational outcomes *(2008);* Understanding women's choice of mathematics- and science-related careers *(2006);* Teacher motivation *(2014); and* Teaching motivations in different countries *(2012).*

Abstract

Sufficient numbers of people with science and mathematics qualifications are needed for continuing growth in productivity and industry innovation. The Australian Industry Group (2015, p. 5) cautioned, 'the pipeline of STEM skills to the workforce remains perilous' because participation in sciences and advanced mathematics at school and university is in decline, participation is not comparable with other nations, and our students underperform in major international studies. Gender differences in enrolments and career plans continue to fuel the concern of researchers with interest in gender equity. Many have argued girls prematurely restrict their options by discontinuing particular STEM subjects in adolescence, which has ramifications for women's later wellbeing from economic and psychological perspectives. Much research has concentrated on whether and how girls/boys are differently motivated in particular learning domains, towards different career aspirations, and how features of the learning environment can promote or diminish their motivations. In the STEPS Study (http://www.stepsstudy.org), I have been following longitudinal samples of youth over the past two decades using these frames to examine boys'/girls' motivations in particular subjects; how motivations matter differently for girls/boys; in directing them towards particular purposes and aspirations; and as they are influenced by features of their learning environments.

STEM participation is an issue in Australia, as in the US and many countries of the OECD. There have been two main arguments put forward as to why we should care.

Economic drivers

Sufficient numbers of people with science and mathematics qualifications are needed for continuing growth in productivity and industry innovation. The Australian Industry Group (2015, p. 5) cautioned, 'the pipeline of STEM skills to the workforce remains perilous' because participation in sciences and advanced mathematics at school and university is in decline, participation is not comparable with other nations, and our students underperform in major international studies. In May 2012, the Office of the Chief Scientist published 'Mathematics, Engineering & Science in the National Interest' which outlined STEM fields as '... critical engines of innovation and growth'. The previous Labour Government publicised 'New Directions for Maths and Science' (2007) to improve STEM participation:

> For Australia to succeed in a highly competitive global economy, students need to have a strong grasp of basic maths and science and encouragement to pursue careers in this area ... 0.4% of Australian university students graduate with maths and statistics qualifications compared with the OECD average of around 1%. [p. 2]

Personal affordances

Mathematics has been found to act as a 'critical filter', as first proposed by Lucy Sells in 1980, which delimits individual future participation and opportunity to high-status and high-salary fields of education and occupation. It is also a gendered issue. We need to worry about this not only because women are more likely than men to end up as financially responsible for other dependents (Meece, 2006), but because of their own future career opportunities and life satisfaction. The progressive loss of talent from STEM fields is often referred to as the 'STEM pipeline', where the flow slows towards a trickle, and some groups – including girls/ women and those from less advantaged backgrounds – leak out more than others.

An integrative theoretical framework to study influences on the STEM pipeline

An array of factors at the student, institutional, and broader structural levels impact leaks out of the STEM pipeline. These have primarily been studied within the expectancy-value theory (EVT) of Eccles et al. (Eccles et al., 1983; Eccles, 2005). The most proximal predictors of achievement-related choices are self-beliefs and task values (highlighted red in the figure below). Eccles posits that it is not enough to believe that one *can* do something, one also has to *want* to do it, to decide to pursue it. There are four different task values described by EVT. The first is *intrinsic value*, referred to as interest or enjoyment. Second is attainment *value*, which refers to the personal importance of succeeding in a particular

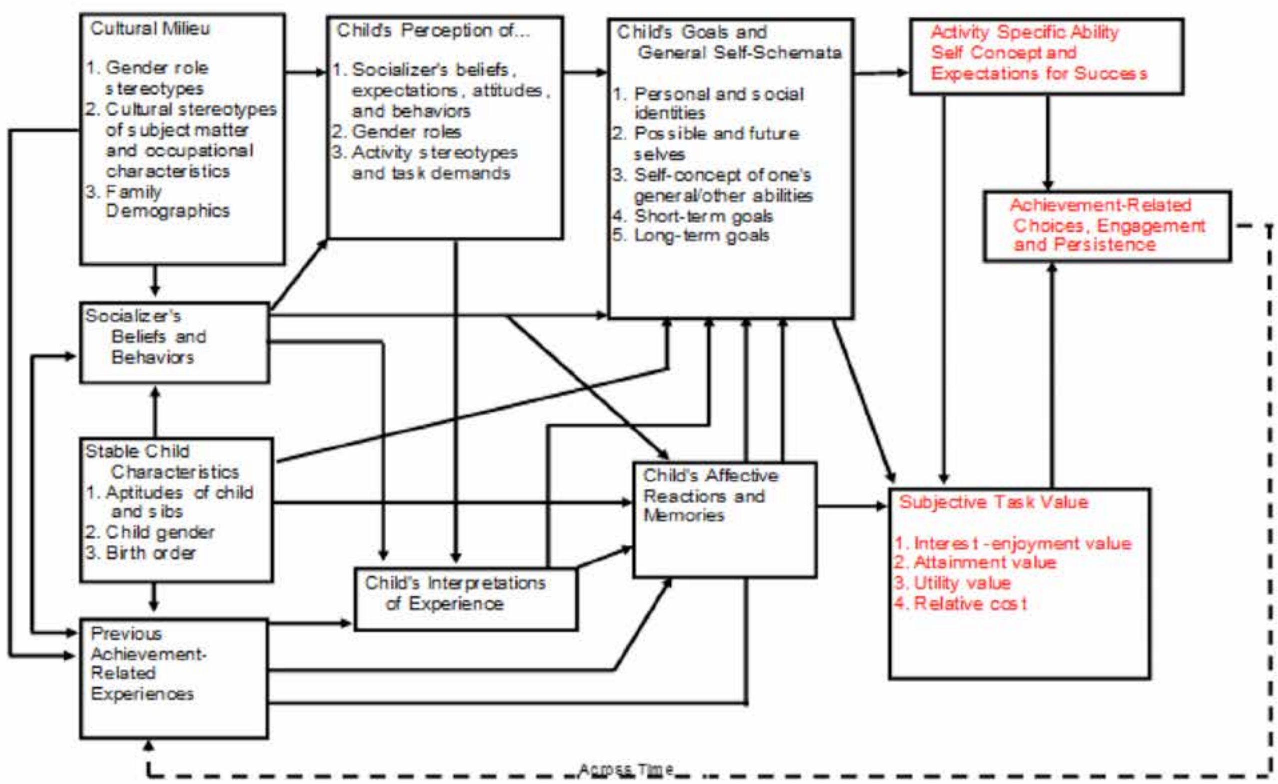

Figure 1 Formulation of the expectancy–value model of achievement choices (Simpkins et al., 2015)

task or domain. *Utility value* is about how useful the task or subject is. Least researched is the negative cost *value*, which would push one away. The first three values should attract a person towards a task or domain. Conversely, different costs should push one away.

What motivates students in mathematics at school, and beyond?

The first longitudinal Australian study of young adults' STEM motivations, participation, aspirations and outcomes, this first (ongoing) of my two longitudinal STEM STEPS studies began in the mid-1990s. It initially involved 1323 adolescents from three coeducational upper-middle-class government schools in metropolitan Sydney, matched for socio-economic status by the Australian Bureau of Statistics. Participants spanned grades 7–11 in a three-cohort sequential design (see Watt, 2004), now being followed up 17 years later. This means I can examine long-term outcomes of how their motivations and perceptions during secondary school mattered for actual career outcomes. My second contemporary longitudinal study focuses on sciences as well as mathematics, described in one of the next sections.

Mathematics participation choices

In the New South Wales mathematics curriculum structure for the Higher School Certificate (HSC) in the 1990s, there were five levels of mathematics: 'Maths in Practice' (MIP), followed by 'Maths in Society' (MIS), '2-unit' (2U), '3-unit' (3U), and the most advanced '4-

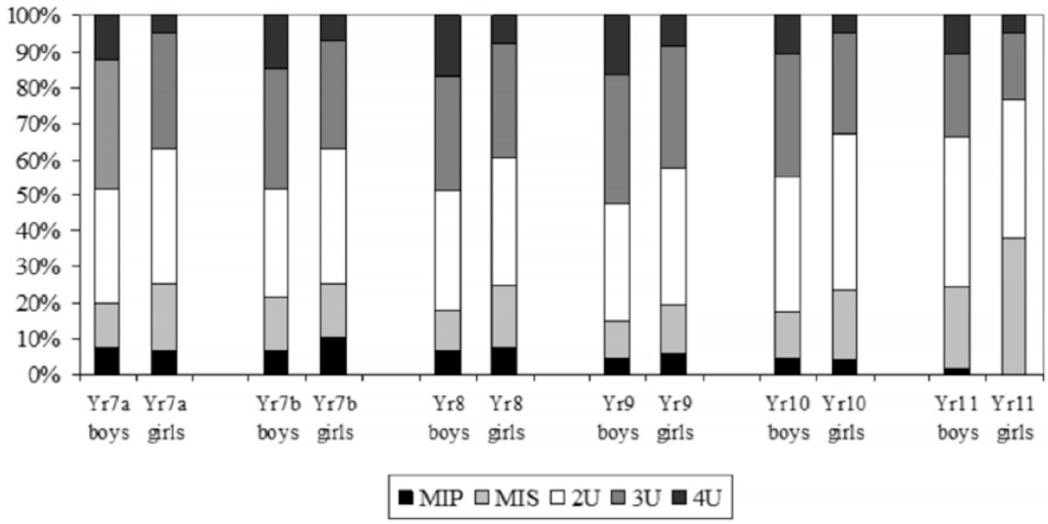

Figure 2 Gendered HSC enrolment choices

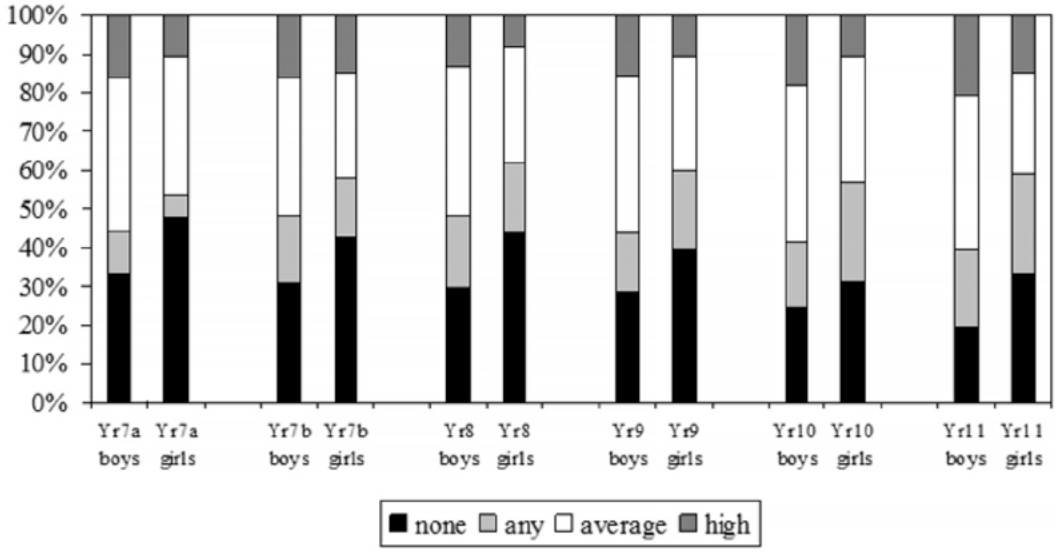

Figure 3 Gendered mathematics-related career plans

unit' (4U) mathematics. Figure 2 left shows proportions of boys and girls aspiring to and, in Year 11, actually undertaking each of those. More boys aspired to and subsequently undertook the most advanced levels of mathematics; vice versa for girls (Cliff's δ: 13—.18, $p < .05$). Students' aspirations appeared rather stable from the start of secondary school, and closely resembled later actual enrolments. Gender differences were robust, and statistically significant. Data reflect those at the national level, and resonate with statistics from other countries. In the US, the gender gap in high school mathematics closed mostly because of levers that mean if students opt out, they cut themselves out of university studies, for example.

Occupational choices

Planned occupations were queried with an open-ended question at each timepoint, coded using the US Department of Labor (1998) Occupational Network Classification system (O*NET™), into how mathematics-related they were, from 'none' to 'high' mathematical knowledge and skills. Figure 3 shows more girls aspired to careers which were not at all mathematics-related, and more boys aspired to highly mathematics-related careers (Cliff's δ: .12—.21, $p < .05$).

Influences on girls', and boys', mathematics choices

Why would girls have lower mathematical aspirations? I examined the extent to which expectancies (or self-concepts) and task values could explain differences over and above achievement. Students responded to survey questions rated from 1 ('not at all') to 7 ('very'). An example self-concept question was, 'Compared with other students in your class, how talented do you consider yourself to be at maths?'; for intrinsic value, 'How much do you like maths, compared with your other subjects at school?'; for utility value, 'How useful do you think mathematical skills are in the workplace?' A path model of estimated influences is depicted in Figure 4. Gender was coded 1=girls, 0=boys; paths from gender convey directional effects for girls (for example, girls considered mathematics to be more difficult than boys). The range of standardised coefficients is 0—1 (or 0—-1 for negative predictions); only statistically significant paths are shown ($p < .05$).

Girls were less interested in mathematics, and thought they were less able, despite equivalent achievement. Higher achievers were more interested, and thought themselves more able. Students who found mathematics more difficult considered it less useful, were less interested, and considered themselves less able. Higher achievers enrolled in more advanced mathematics, as did students who were more interested, considered themselves more able, and aspired to more mathematical careers. It is not entirely obvious which direction this last relationship should go – it is likely students are looking ahead along the pipeline to the kinds of careers involving mathematics and their workplace conditions.

There was no path from utility value to any outcome, but there was an interesting interaction effect. The

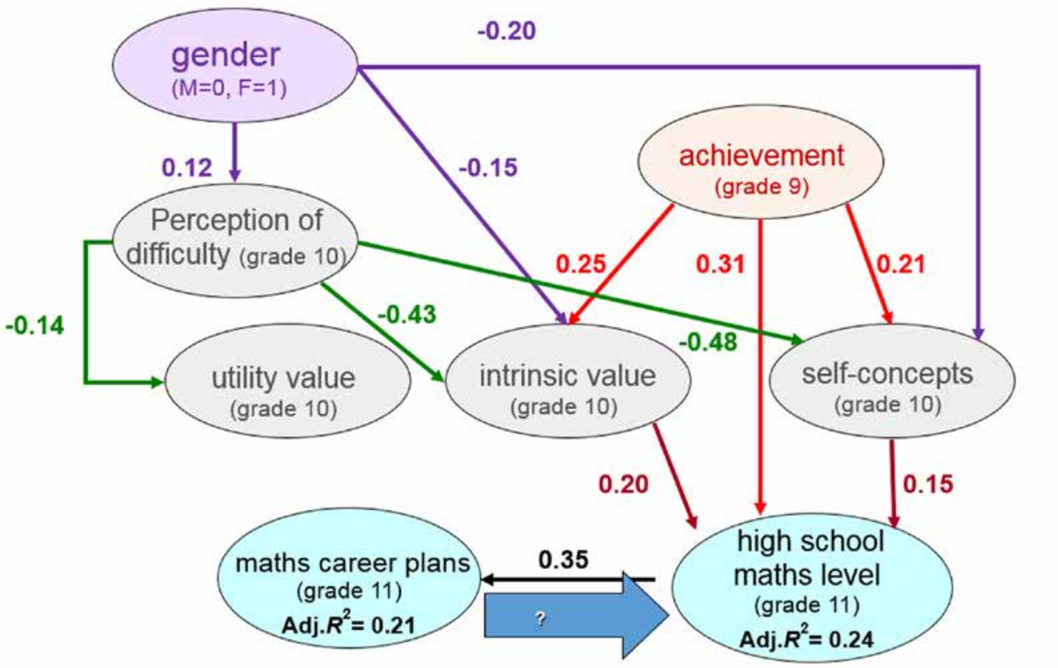

Figure 4 Path model estimating influences on girls' and boys' mathematics choices

circled effect in the figure below highlights that boys who regarded mathematics as moderately useful were as likely as boys who considered mathematics highly useful to aspire to highly mathematical careers (0—3). Whereas, unless girls regarded mathematics as highly useful, they were not likely to aspire to highly mathematics-related careers; girls who thought mathematics was moderately useful were as likely as girls who thought mathematics was low in usefulness to undertake low mathematics-related careers. This suggests many levers to action, such as making connections between different types of mathematical careers and their social uses and values.

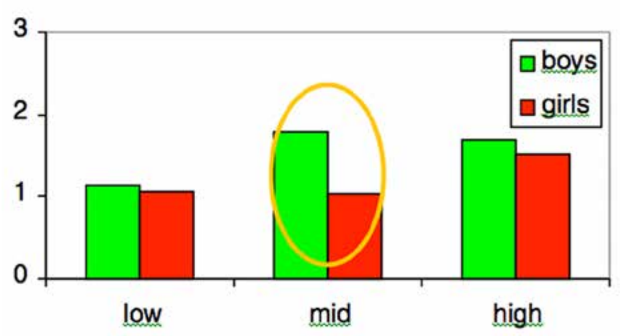

Figure 5 Interaction effect: Gender X utility value on maths occupational decisions

How do motivations translate into occupational outcomes?

Despite the fact that the internet did not exist back in the 1990s, I have so far followed up with 643 of the original 1323 participants. The black arrows in the figure below represent stability paths for same individuals who remained in same categories over time. Red arrows show noticeable 'off-diagonals'; dashed arrows show other atypical pathways. Aspirations (modestly) predicted even long-term outcomes for mathematical careers (p = .20 for boys, p = .21 for girls).

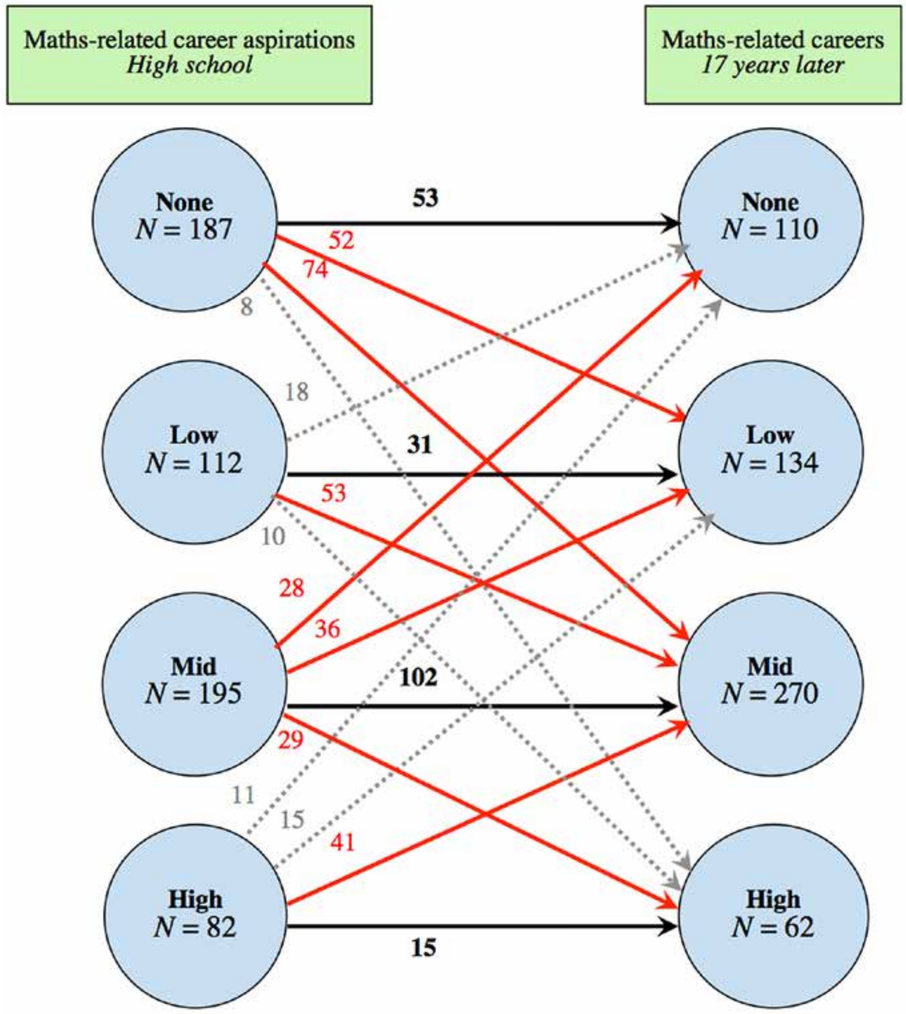

Figure 6 Correlations between aspirations and careers

Motivations matter, even 17 years later!

How difficult students had found mathematics, how interested they were, and their self-concepts of ability predicted subsequent mathematical career plans. Green bars in the figure below show that boys who had been more interested, and thought themselves more able, were those who ended up in more mathematics-related careers. The same was true for girls who had thought they were more able at mathematics; girls also experienced a 'push' factor – if they had found mathematics difficult, they were less likely to end up in mathematical careers.

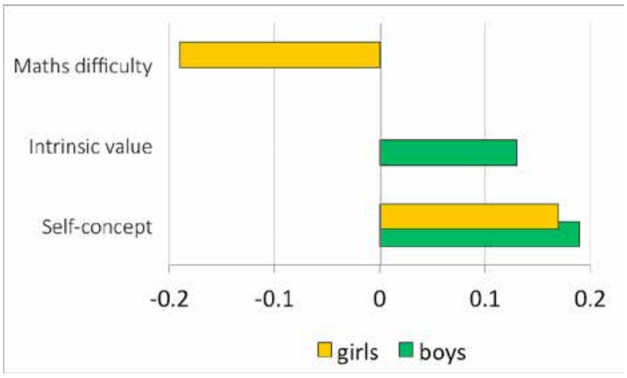

Figure 7 Correlations between motivations and careers

How do self-concepts and values develop?

If self-concepts and values are so important, we should be concerned with their development. This line of work initially focused on the transition to secondary school, and associated disruption and negative impacts on motivations at that time identified by Eccles, Midgley, Wigfield and colleagues who documented differences in the school environment pre- and post-transition that accounted for those changes – such as disruptions to peer networks, increasing normative assessments, multiple teachers throughout the day for different subjects, and greater curricular differentiation. Concerningly, longer-term longitudinal studies show that this is part of a continuing pattern through secondary school, and students do not 'recover' post-transition (see Fredricks & Eccles, 2002, and Jacobs et al., 2002, in the US; Frenzel et al., 2010, and Nagy et al., 2010, in Germany; Watt, 2004, in Australia). Greater realism may explain motivational declines with increased social comparisons and increased normative assessments, but what about the gender differences? Stable magnitudes imply they are in place early on and continue. In the United States, Jacobs et al. (2002) found gender differences in self-concepts as early as grade 2!

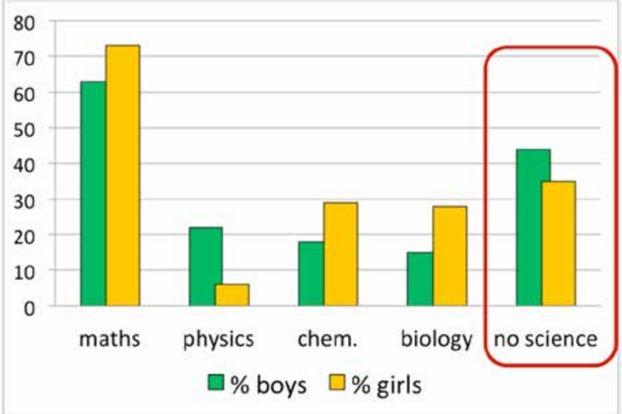

Figure 8 Year 12 STEM participation

A new 'contemporary' longitudinal study: Focus on mathematics and sciences

In a new contemporary longitudinal study, I have been probing sources of mathematics and science motivations among 1172 students from nine Melbourne and Sydney schools, since Year 10 until post-school. I included a mix of government, Catholic and independent schools, coeducational and single-sex, and selective schools. The first striking finding was the high proportion of students undertaking no science in Year 12, or no mathematics (Figure 8). Aspirations towards mathematical or scientific careers were moderate at best (Figures 9 and 10) and declined Years 10–12. There were gender differences for mathematics-related career plans; none for sciences.

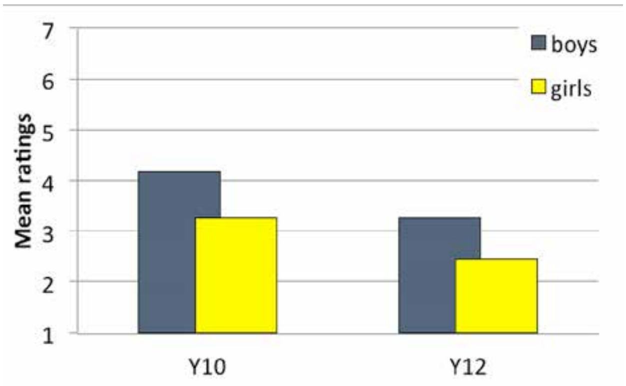

Figure 9 Students' maths career plans

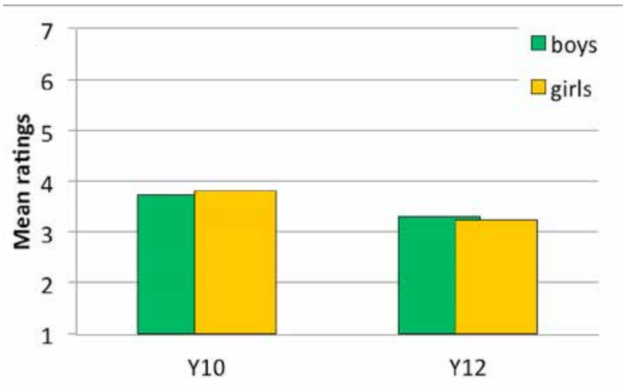

Figure 10 Students' science career plans

What careers do youth today aim to pursue?

In Year 12, the most popular careers for boys were technology, entrepreneurship and health; for girls they were health, creative arts, teaching and entrepreneurship. Careers more significantly attractive to boys were mathematics, technology, entrepreneurship and trades; careers more attractive to girls were creative arts and teaching. Using a new framework and measure, the Motivations for Career Choice (MCC) scale (Watt & Richardson, 2006), developed with colleague Paul Richardson, grounded in EVT, I measured adolescents' career motivations across a set of 16 factors: ability, intrinsic value, make social contribution, enhance social equity, cognitive challenge, content knowledge match, expert career, autonomy, teamwork, secure progression prospects, family-flexibility, portability, salary, social status, social influences, and easy job.

Most important career motivators for girls and boys were interest, ability and salary; least important were wanting an easy job and social influences. There were no gender differences for motivations related to own abilities, cognitive challenge, prior experiences, salary, status, family-flexibility, autonomy, teamwork, portability, or secure progression prospects. This clearly signals girls do not prefer lower salary or lower status careers. Boys were significantly more motivated than girls by social influences, to pursue an expert career, and for an easy job. Girls were more motivated than boys by their interests, to make a social contribution, and enhance social equity. These differences appear consistent with previous findings that girls and women are more interested in 'social' occupations that allow them to socially contribute and help others.

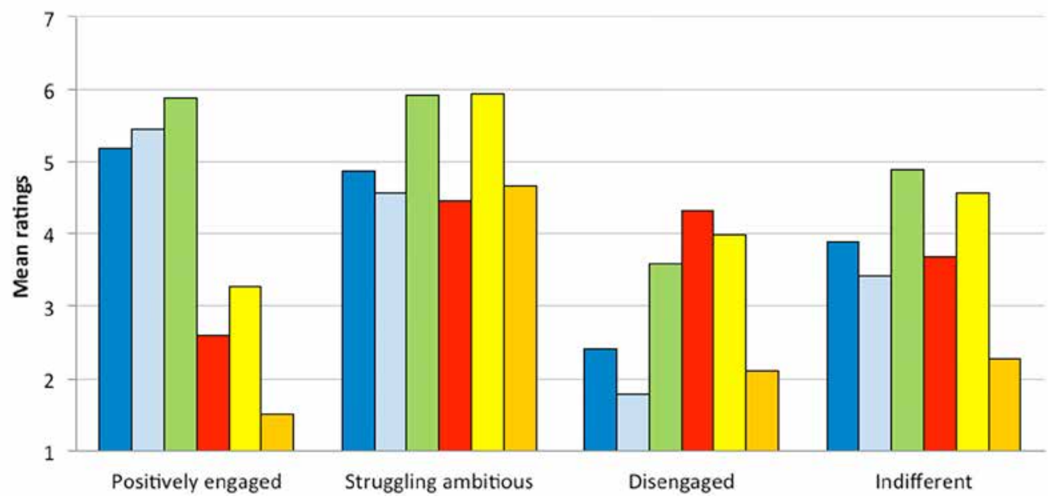

Figure 11 Motivation profile: Maths

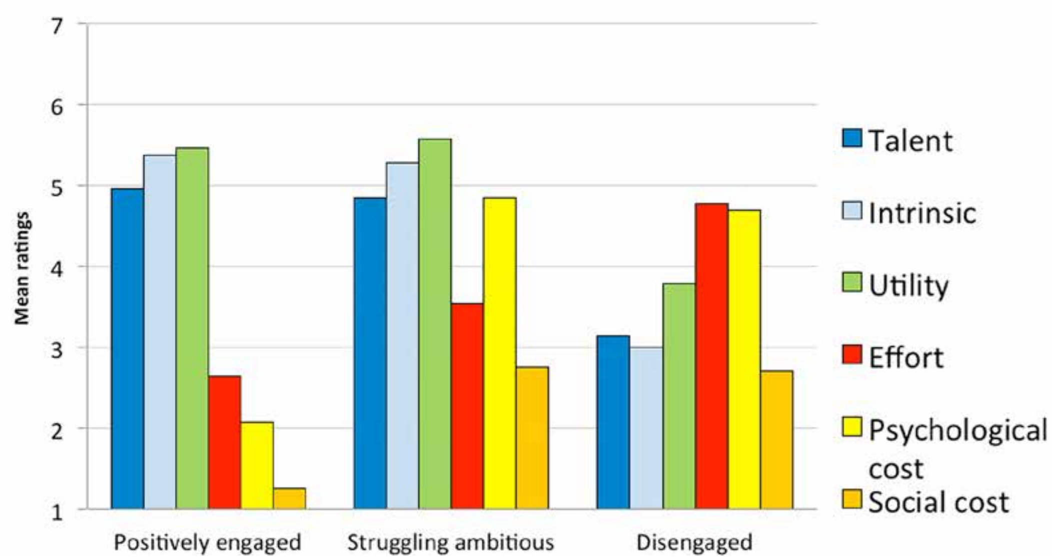

Figure 12 Motivation profile: Science

Contemporary motivations towards mathematics and science: Including costs

Boys had higher self-concepts in mathematics and science, as well as higher intrinsic and importance values in mathematics. Girls experienced higher psychological cost in both mathematics and science (for example, 'I'm concerned that I won't be able to handle the stress that goes along with studying maths/science'), as well as higher social cost in science (for example, 'I'm concerned that working hard in maths/science classes might mean I lose some of my close friends').

It is probably more important to consider profiles of motivations rather than predictions from individual motivations, because we hold a set of individual attitudes simultaneously when making choices. I have been recently investigating costs, alongside expectancies and values within EVT. I have examined effort cost, psychological cost and social cost, to see whether these factors push people away from STEM, and potential consequences for their own personal wellbeing, such as stress and anxiety and depression.

There were three profiles of students in science. The first cluster was high on positive motivations and low on negative costs. The next was high on both, and the third was low on positive and high on negative. The same three clusters were identified in mathematics, as well as a fourth cluster that was rather undifferentiated. I named them (i) *positively engaged*, (ii) *struggling ambitious*, (iii) *disengaged*, and (iv) – only in mathematics – *indifferent*.

The *positively engaged* and *struggling ambitious* profiles had equally high reported history of results, mathematics/science aspired careers, and aimed marks. The only difference was the high costs perceived by *struggling ambitious*, associated with debilitated psychological wellbeing in terms of depression, anxiety and stress. *Disengaged* had similarly good psychological health to the *positively engaged*. What differentiated them was their low mathematics/science career aspirations, aimed marks and history of results. The low expectancies and values held by the *disengaged* associated with lowered achievement/career-striving, but their perceived low costs bolstered wellbeing. The *indifferent* (mathematics only) had moderately depressed wellbeing, aimed marks and history of results, and rather low mathematics career aspirations. It appears that even moderate perceived costs exert negative effects on achievement striving and psychological health. It is not enough to focus on promoting positive self-concepts and values, we need also to protect against costs.

Including negative cost values alongside typically measured positive expectancies/values enabled identification of students who experience particular combinations of motivations and pressures. Similar profiles for mathematics and science, and coherent pattern of antecedents and achievement vs. wellbeing outcomes, suggest the types as rather robust, deserving further investigation across contexts and timepoints. Gender differences in mathematics were consistent with entrenched stereotypes – more girls were *disengaged*, and more boys were *struggling ambitious*, consonant with cultural expectations and social pressures. A significant association ($\mathbf{c}^2$ (6) = 44.01, $p < .001$) indicated a tendency for the same students to be in the same types, thus a possible dispositional base. However, sizeable off-diagonal numbers suggest it is likely we can shift people's motivational profiles, through levers in the curriculum and what happens in the learning environment of classrooms.

Gender and STEM?

Is it a problem if girls and boys develop different interests and ability beliefs, and choose different pursuits? I believe yes. First, because girls' lower self-concepts (or, boys' inflated self-concepts) translate into patterns of gendered participation that advantage boys' achievement prospects, despite no corresponding achievement differences. Second, ability-related beliefs and values in mathematics affect *non*-mathematical outcomes of societal concern, such as aspired level of education and career prestige. Third, mathematics-related careers associate with career prestige, evidencing mathematics-related career fields as a gateway of concern to researchers interested in social gender equity. Finally, girls do not prefer lower salary or status careers; thus, opting out of advanced mathematics harms their own career goals.

Should equal gender participation be our goal, and for all learning domains? I do not think so. But, when girls' mathematics participation is reduced for negative reasons such as anxiety and lower self-concept, and when those participation choices adversely impact their aspired careers, we need to think carefully about why girls come to hold less positive mathematics motivations than boys. Adolescents often have quite inaccurate ideas of which careers require developed mathematical skills. Therefore, detailed information would be likely to promote girls' interest in mathematics when their preferred careers involve it. If this information could be conveyed by women who are passionate about their work and capable of maintaining a balance between family and work, girls would have positive role models as examples.

Because interests and ability-related beliefs exert important influences on the extent of boys' and girls' later mathematical participation, girls' lower intrinsic value and ability self-perceptions should be of particular concern for future studies and intervention efforts. Eccles and her colleagues have demonstrated that girls are engaged by activities they perceive as socially meaningful, and we have seen that mathematics' importance value impacted girls' career choices more than boys'. Making explicit connections between mathematics and its social uses and purposes should heighten girls' interest and the importance they attach to it.

What can educators do?

There is a lot that educators can do. The kinds of learning environments teachers create convey teachers' expectations about what students can achieve and about STEM, which impact students' own self-concepts and values, and consequent career intentions.

A performance structure is one that emphasises competition and results. These teachers will praise high achievement, maybe give awards and prizes, or say who came lowest in the class. Teachers who create a mastery learning environment focus on self-improvement and understanding rather than on how students compare to others. A mastery environment promotes students' self-concepts, STEM values, and related career intentions. Fortunately, mastery climate outweighed performance environments in all eleven cohorts involved in my contemporary study.

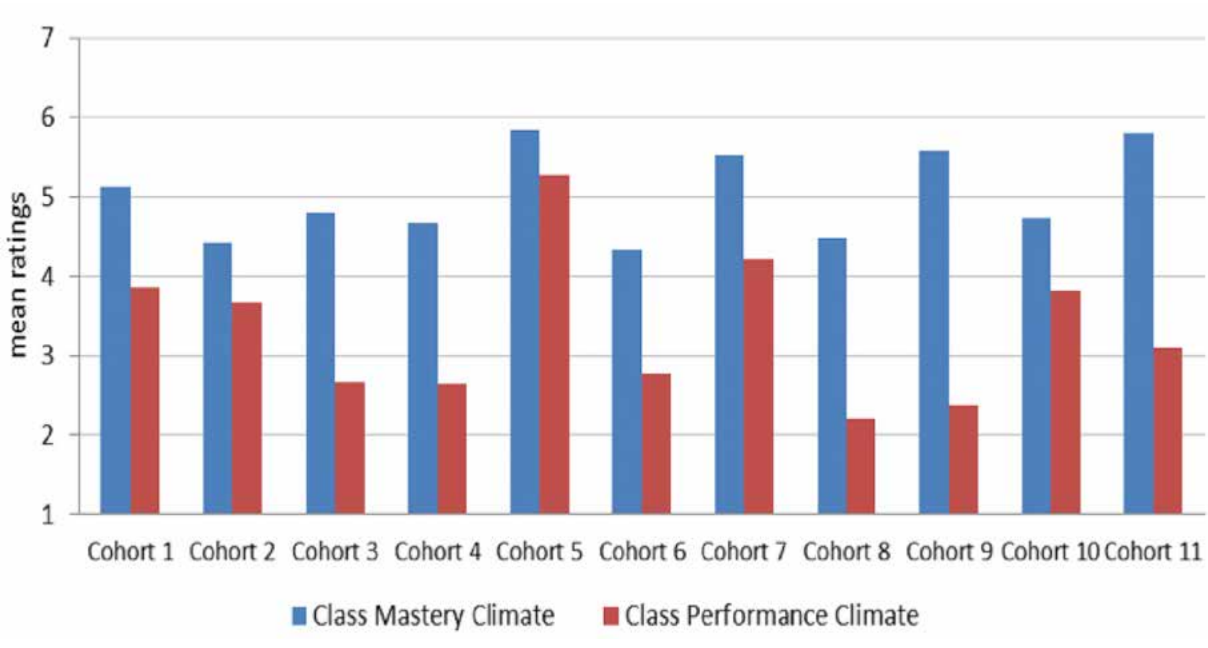

Figure 13 Learning environments for mastery and performance: Maths

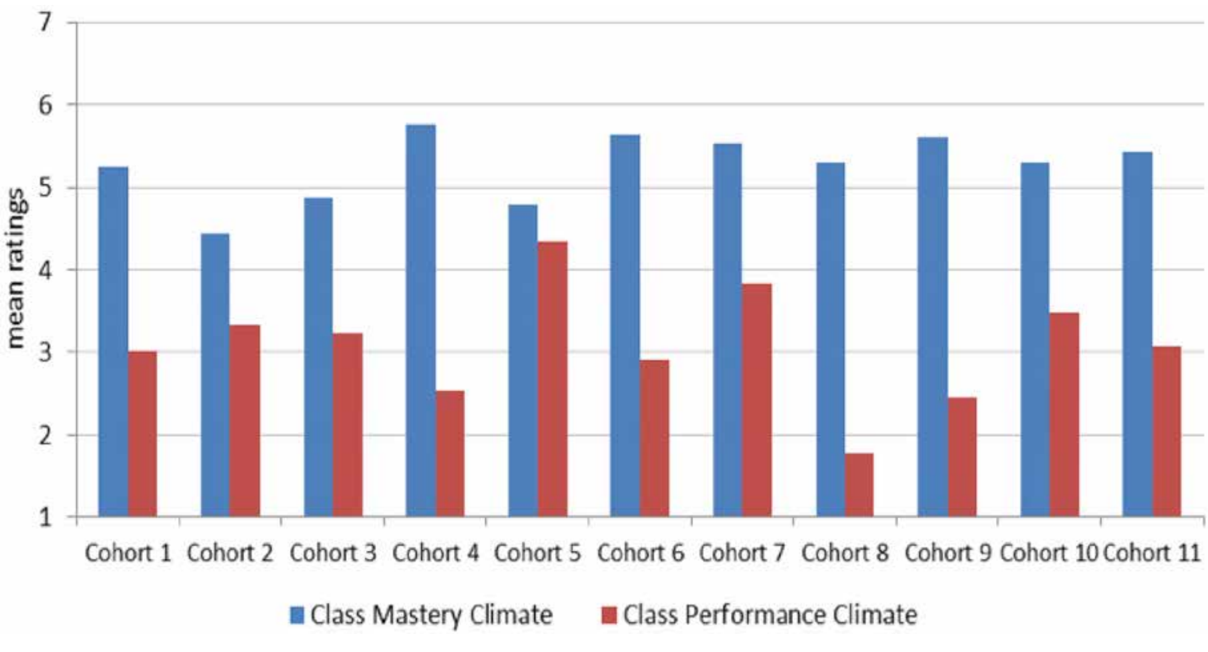

Figure 14 Learning environments for mastery and performance: Science

Summary and outlook

- The STEM shortage is especially in advanced mathematics and physical sciences, and more pronounced in contemporary data.
- Students, especially girls, are opting out of advanced mathematics and sciences when they perceive a real choice to do so.
- Expectancies and values impact STEM studies and career aspirations.
- Importance value matters, especially for girls; we need to be making explicit connections between the social uses and purposes of science and mathematics for a range of careers.
- Self-concepts and values decline throughout secondary schooling, with a robust gender gap; girls perceive lower talents than their achievements warrant.
- Costs impact wellbeing, even for students with high expectancies, values, achievements and aspirations.
- Aspirations modestly predict actual STEM-related careers; we need more long-term longitudinal studies, and to contrast more different settings as 'natural experiments', particularly where there is high participation in STEM and where girls and women participate to a similar degree to men, to be able to learn from those settings.

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Drawing to learn in STEM

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Russell Tytler is Professor of Science Education at Deakin University. He has been involved over many years with system-wide curriculum development and professional development initiatives. He has researched and written extensively on student and teacher learning in science, and science investigations. His recent research interests include the role of representation in reasoning and learning in science, teacher and school change, international perspectives on science and environmental education, and school–community organisation partnerships. He has undertaken a number of influential studies concerning student engagement with science and mathematics, and STEM policy. Russell has held visiting professor positions in Europe and Asia. He has published more than 100 journal articles, books and book chapters. He is a member of the science expert group for the PISA 2015 assessment.

Abstract

Scientists, mathematicians and engineers draw and model to create knowledge. This presentation will describe a guided inquiry approach to teaching and learning science that involves students actively creating visual and other representations to reason and explain as they explore the material world. The approach has been successfully used in a number of major professional learning initiatives in Victoria and NSW. Evidence will be presented of increased student engagement and quality learning flowing from the approach, which aligns classroom processes more authentically with processes of imaginative scientific discovery. Examples of activities and student drawings and model construction will be used to unpack the relationship between representation, reasoning and learning. Video evidence including that generated in the Science of Learning Research Centre (SLRC) classroom at the University of Melbourne, equipped with sophisticated video capture facilities, will be drawn on to explore ways in which drawing, gesture and talk are coordinated to imaginatively respond to material challenges. The presentation will explore the alignment of these sociocultural analyses to recent findings from neuroscience. Evidence will be presented that the creation of representations is central to quality learning across the STEM disciplines and for interdisciplinary STEM challenges.

The problem of engagement

In Australia and internationally we have seen a considerable amount of concern and policy rhetoric around the engagement of students with school science. This takes a number of forms: a) figures that demonstrate declining participation over two decades in STEM subjects in the senior school years, and in higher education (Office of the Chief Scientist, 2012a, b; Marginson, Tytler, Freeman & Roberts, 2013), b) survey data showing declining attitudes to science over the upper primary and secondary years (Tytler, Osborne et al., 2008), c) data that show attitudes to science negatively correlating with countries' development level (Schreiner & Sjøberg, 2007) such that disenchantment with science is seen to be predominantly a Western phenomenon, d) concerns that Australia's performance in international tests in STEM, as in literacy, is dropping, and e) interview data showing disenchantment with science on the basis of a traditionally transmissive pedagogy, that it does not relate sufficiently to the real world, and that it is difficult (Lyons, 2006; Tytler, 2007).

Osborne and Collins (2001) memorably characterise a major problem with school science as being its superficial coverage of large amounts of content such that students are 'frog-marched across the scientific landscape, from one feature to another, with no time to stand and stare, and absorb what it was that they had just learned' (p. 450). Joseph Schwab (1962) argued that school science should increase its focus on what he called the syntactical structure of the discipline rather than its then (and current) preoccupation with the substantive structures of content knowledge; what he famously referred to as a 'rhetoric of conclusions'. In 2006 at the previous ACER conference focusing on science learning, Jonathan Osborne (2006, p. 2) made the point that:

> Four decades after Schwab's (1962) argument that science should be taught as an 'enquiry into enquiry', and almost a century since John Dewey (1916) advocated that classroom learning be a student-centred process of enquiry, we still find ourselves struggling to achieve such practices in the science classroom.

A decade further on, this is still largely the case (Goodrum, Druhan & Abbs, 2012), despite growing evidence of the learning payoff of inquiry (Chi, 2009; Furtak et al., 2012). Increasingly there is a curriculum policy emphasis on the development of the 'soft' skills of collaborative problem solving and creativity, and digital literacy. There is a need felt in advanced economies for the education system to produce flexible and innovative individuals. The advancing Asian economies, which have overtaken Australia in international testing regimes, are increasingly emphasising problem solving and inquiry in their curricula (Freeman, Marginson & Tytler, 2015).

The term 'engagement' is often used in relation to these problems, but is used in a variety of ways. Sometimes 'engagement' is used to denote engagement with activity, perhaps busyness. At other times it is related to science as 'fun' (Appelbaum & Clark, 2001). And at other times it is interpreted in relation to the 'relevance' of content, such as approaches that build physics ideas around skateboards or hobbies. In this paper I will argue that we need to see 'engagement' in terms of commitment to substantive learning, as implied by the critiques of Osborne, and Schwab, above. The deeper meaning of engagement, I argue, must relate to thinking and working scientifically, driven by the same curiosity, interest in and passion for ideas that drives scientific knowledge seeking. I will argue that this is the real meaning of inquiry; that it aligns school science classroom practices with the knowledge-building practices of science itself. I will further argue, given new understandings of the nature of science, and recent understandings from classroom studies of how we learn, and what it is to know, that school science as it is traditionally framed and practiced represents a distortion of scientific practices in very specific ways.

I will propose a new way of looking at inquiry, taking as a principle that if we are to engage students with thinking/reasoning and working scientifically, we need to align classroom practices more authentically with the knowledge building or epistemic practices of science (Duschl, 2008; Tytler, 2007). I will ask the questions: How is knowledge built in science? What does it mean to know, in science?

How is knowledge built in science?

Increasingly we have come to understand that scientific knowledge is built by more complex processes than straightforward rational and logical reasoning involving hypothesis generation and testing. Developing explanations and theories involves an imaginative and often communal process of creation of models and representations such as diagrams, 3D models and mathematical symbols. These are the tools through which we develop new ways of looking at the world. This is as true for wave representations, for food webs, for the arcane symbolism of particle physics, and for molecular models, as it is for heliocentric solar system models. Increasingly, with vastly increased digital power, the representational resources available to scientists have expanded enormously to include 3D graphs, false colour stellar imaging, and sophisticated simulations. Further, recent work has emphasised the embodied nature of much of our developing understandings. The interplay between experimental exploration and creative generation of multi-modal representations that is central to scientific epistemic processes is what we need to capture in school science classrooms.

David Gooding's (2004) analysis of Faraday's detailed notebooks shows the key role of visual images generated by Faraday as he worked on his ideas concerning field lines and the relationship between magnetism and electric current leading to the first electric motor design. Gooding identified a fundamental pattern of dimensional transformation from 2D to 3D to 4D (including time), back to 2D representations in Faraday's and others' discovery work, and argued that complex informal reasoning through a mix of inscriptions and artefacts was a fundamental but unacknowledged characteristic of scientific discovery. Faraday devised 3D models to illustrate his ideas, which served as dual artefacts and representations in mounting complex arguments (Gooding, 2006). Latour was an early commentator on scientific laboratory work, and the collaborative processes by which science teams generated representations to guide and make sense of data generation. In following two scientists studying the encroachment of agricultural land into the Amazon forest, he charted the representational re-descriptions that occurred, from ordered and labelled soil container arrays, to measurements of soil characteristics, to tables and finally graphs that were transported to Paris in preparation for writing a paper (Latour, 1999). He talks of 'circulating representations', in which understanding the nature of the transformations is key to understanding the relationship between theory and evidence in science.

What does it mean to know in science?

Sociocultural perspectives on learning characterise the process of learning in science, as induction into the multi-modal representational tools through which we understand the world scientifically. We become increasingly competent members of the scientific community of practice (Lave & Wenger, 1991). Lemke (1990), in a seminal paper, showed the importance of classroom talk in framing reasoning and learning, and in a later paper (Lemke, 2004) showed the multiple modalities involved in coming to know science through classroom discourse, inevitably involving text, diagrams, images, 3D models, abstracted symbols and formulae, gesture, and artefact. The growth in importance of scientific literacy places a dual burden on our conception of learning in science. First, it is an argument about the purposes of science in school that it should prepare citizens to be able to engage in public discourse about science. Second, it makes the more fundamental demand that we see learning science as involving induction into scientific disciplinary literacy, which involves command of the multi-modal representational forms used to reason about and explain the world, and specialised production genres that reflect the way science creates and interprets evidence through interactions with natural systems.

We see representations as the reasoning/visualising tools through which both scientific discovery, and learning of science, progress. We see the abstracted concepts around which scientific knowledge is often structured and mapped as fundamentally constituted of representational practices. Thus, a sophisticated concept of animal diversity will involve facility with the use of keys, cladistics maps, comparative labelled diagrams, tally tables and graphs, geographic distribution representations, and so on. This is often represented but rarely recognised in textbooks.

In a series of projects, we have worked with teachers to develop an approach to teaching and learning science that brings together these understandings about the material, multi-modal nature of learning and reasoning with the demand that learning in classrooms needs to proceed through inquiry, involving the use of these representational tools to reason about and explain phenomena.

The core principles of this guided inquiry approach are (Tytler et al., 2013):

1. Students inquire into phenomena and develop explanations through actively constructing and evaluating representations.
2. Teachers guide explicit discussion of representations – their adequacy and their partial nature – such that students develop 'meta-representational competence'.
3. Students are challenged and supported to reason through a process of mapping between representations and perceptual experiences/hands-on exploration.
4. Formative and summative assessment is embedded in the process, as students and teachers focus on the adequacy and coordination of representations.

Because science is so often visual and spatial in nature, drawing is a key activity in this representation construction practice, alongside modelling, role-play, and digital simulation. Figures 1–3 show examples of students' drawings in response to representational challenges. Each challenge was part of a learning sequence in which students' representational resources were systematically developed and explicitly acknowledged.

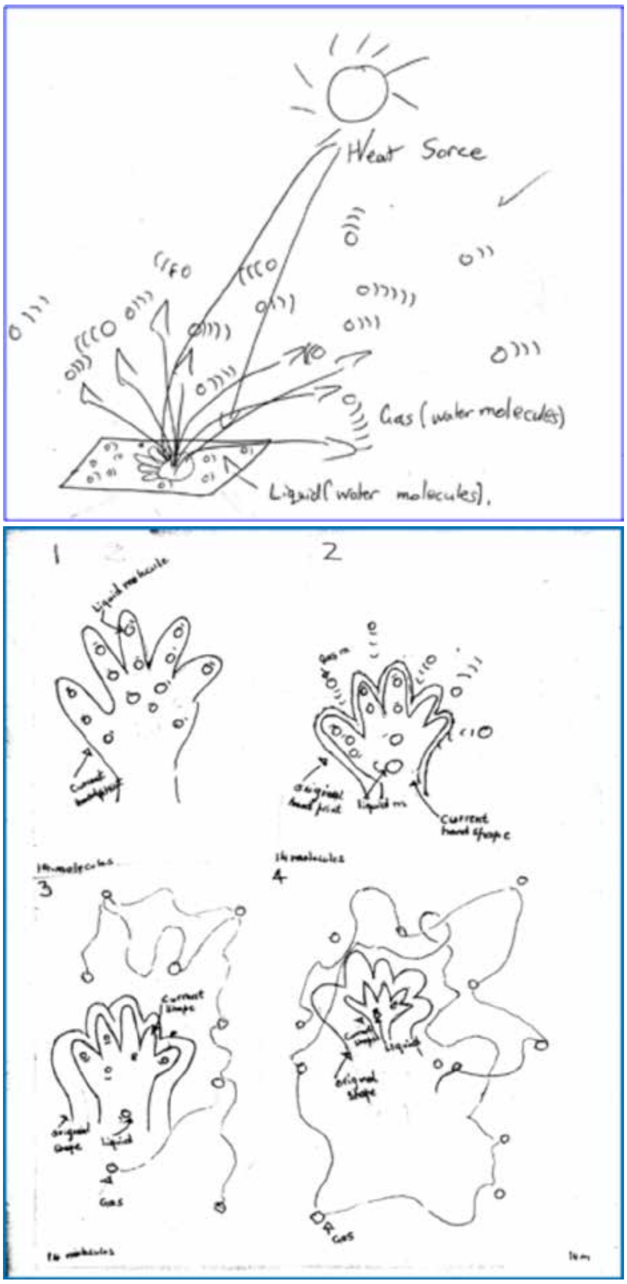

Figure 1 Year 5/6 students' particle representations of a wet handprint on paper evaporating. (Ainsworth, Prain & Tytler, 2011)

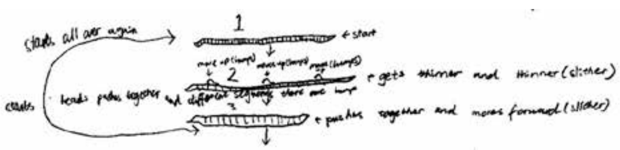

Figure 2 Year 6 students' planning diagram for a model to show how a worm moves (Tytler et al., 2013)

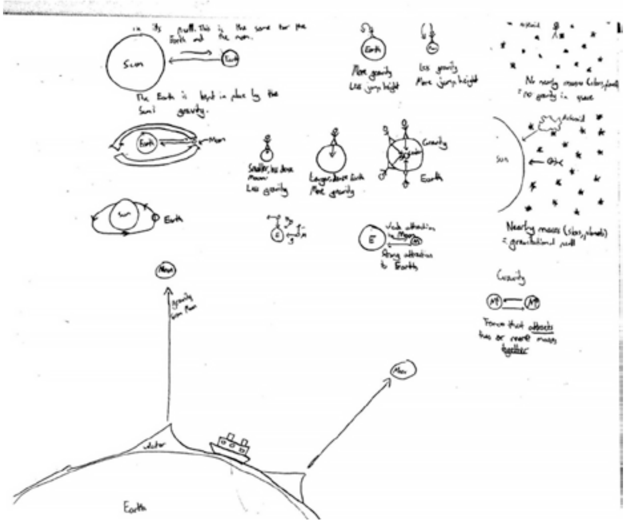

Figure 3 A Year 7 student's exploration of how gravity affects astronomical objects and tides

The effectiveness of drawing and modelling to support rich learning we explain using the notion of affordance as productive constraint. Drawings and models, because of particular visuo-spatial requirements, constrain and guide the learner into seeing phenomena in new ways (Prain & Tytler, 2012). These approaches to representations construction have also been explored in mathematics and in interdisciplinary STEM inquiry, for example in Lehrer's (2009) research with children generating new mathematical forms to investigate growth in plants over time. STEM design tasks are a natural for such representational work.

Studying collaborative reasoning through constructing representations

The Science of Learning Research Centre (SLRC) is a major Australian initiative housed at the University of Queensland, the University of Melbourne, and the Australian Council for Education Research, involving researchers from a variety of universities throughout Australia. A key aim of the Centre is to achieve a productive coordination of understandings about learning from education neuroscience, from psychology, and from in situ classroom studies. A major challenge for the Centre is to translate between sociocultural perspectives on the relation between reasoning, learning, and multi-modal languages and disciplinary practices, described above, and the much more constrained models of learning that have thus far been experimentally investigated in neuroscience.

As part of the SLRC, a Science of Learning (SL) classroom has been set up at the University of Melbourne with state-of-the-art video and audio facilities that can simultaneously capture the talk and work of groups of students engaged in problem-solving tasks. We have thus far captured groups of Year 7 students engaged in representational challenges in the topics of energy and force, levers, plant morphology, and astronomy. For each group of 2, or 4, we have been able to capture their dialogue, their gestures, the artefacts they produce, and to varying degrees a continuous record of their drawing and working with models and digital production. The questions we are investigating include: How do students utilise and coordinate talk, text, artefacts, drawing and embodied modes to collaboratively reason in science? What are the challenges and affordances of transforming and coordinating representations? Under what circumstances is drawing productively engaged with? How do teachers productively support students in inquiry-focused representation construction?

Ethnographic analysis of the video data, supported by StudioCode software, supports the following findings.

- Drawings are a powerful focus for collaborative reasoning and generation of meaning, provided the task is matched to a joint purpose and students are appropriately scaffolded. Drawings often were used to solidify meaning negotiated using talk, gesture, and embodied representation. Students were able to flexibly negotiate drawings, particularly when using a whiteboard that allowed ongoing modifications and joint control.
- The transformation from 3D to 2D representation is challenging, requiring selection of key features and abstraction. For instance, two students achieved sudden insight into why the arctic region can have 24-hour daylight in summer, using a model globe and torch. However, translating this into a 2D drawing proved beyond their resources. Students took a variety of pathways whereby confusion, which is important in inquiry learning, was resolved.
- Conceptual understanding of science concepts involves the capacity to coordinate and re-describe across a variety of representations, which are inherently partial.

Through this and previous research, we argue that to productively engage students in school science, attention needs to focus on the construction and negotiation of representations as disciplinary tools for reasoning and learning, mirroring the way that knowledge is built in science itself.

Implications

In this paper I have argued that inquiry in science classrooms needs to reflect contemporary understandings of the role of representational work in scientific discovery. Traditional versions of inquiry based around hypothesis-method-results-conclusion tend to sidestep the real, and interesting, task of creating explanations in the visuo-spatial forms that provide real insight into phenomena. Experimental results are often taken to speak for themselves without interpretation. Much of traditional investigative designs tend, in the absence of seeking to develop models, to resort to pattern seeking. If we are to develop an engaging invitation for students to take on the challenge of thinking and working scientifically, we need to focus much more strongly on challenging and supporting them to imaginatively construct and explore drawings, models and digital simulations as explanatory resources.

Science curricula, and conceptions of conceptual developmental progression, are traditionally characterised by abstracted concepts expressed in verbal form. However, we would all agree that coming to know involves much more than learning the words denoting concepts. Textbooks reflect this abstracted verbal focus, but concepts are in most cases supported by multiple representations. These, however, are often highly abstracted and simplified, such that the representational practices underpinning them are unacknowledged. Similarly, assessment is often based on the manipulation of high-level abstractions such as formulae or verbal responses, without regard to the visuo-spatial representational practices that are the drivers of reasoning and explanation. We argue that in order to support the agenda described above – where students are challenged to inquire through constructing representations as a core feature of classroom practice – the formal curriculum, resources and assessment need to change to explicitly reflect and acknowledge the primacy of representational work in carrying the burden of reasoning and learning.

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Are Australian mathematical foundations solid enough for the 21st century?

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Australian Council for Educational Research

Ross Turner is a Principal Research Fellow at the Australian Council for Educational Research in the International Surveys research program. As part of Mr Turner's role within ACER's Centre for Global Education Monitoring, he is leading the development of a set of learning metrics in reading and mathematics that may be relevant to the global education community as a tool to support measurement of progress in literacy and numeracy achievements against the Sustainable Development Goals.

As a senior manager in the Programme for International Student Assessment (PISA) for 15 years, Mr Turner managed the test development process across different knowledge domains, with test development teams in several countries. He led the development of mathematics test items, was responsible for developing the methodology used in PISA for reporting student achievement, and contributed to managing other aspects of the project. As well as management skills, his technical expertise in the areas of mathematics curriculum and assessment, statistical analysis of performance data, and educational measurement in general are called on regularly as part of a range of ACER projects.

Before joining ACER in early 2000, Mr Turner worked in a number of roles at the Victorian Board of Studies: he was a member of and then leader of the team that developed the mathematics curriculum and assessment arrangements for the Victorian Certificate of Education; later he managed the Board's research and evaluation function, monitoring and evaluating all aspects of VCE implementation, and was responsible for provision of technical advice and development of statistical procedures. Other interests included comparability of teacher assessments, and provision of student achievement feedback data. Mr Turner was a secondary teacher for 12 years, and worked in pre-service and in-service teacher education programs.

Dave Tout
Australian Council for Educational Research

Dave Tout has worked in schools, TAFEs, ACE providers, universities, AMES and workplaces, and has more than 30 years of experience in the adult education sector. He has had wide experience not only in teaching and training, but also in working at a state, national and international level in research, curriculum, assessment and materials development. Dave has had major responsibility for the numeracy domain of the Australian Core Skills Framework and was also involved in the development of the numeracy components of the CGEA and the VCAL for secondary schools in Victoria. He was a member of the numeracy expert group responsible for the numeracy component of the international Adult Literacy and Life Skills Survey (ALLS) and is now a member of the numeracy expert group for the Programme for the International Assessment of Adult Competencies (PIAAC). Dave joined ACER in 2008, where he is a Senior Research Fellow. His work has included the online Adult Literacy and Numeracy Assessment Tool for the Tertiary Education Commission in New Zealand, and Compass, an online literacy and numeracy assessment tool for disengaged young people and adults. He is also involved in the mathematics test development components of PISA 2012, where mathematical literacy is the major domain.

Background

The OECD's Programme for International Student Assessment (PISA) surveys a random sample of 15-year-old students from a random sample of schools, every 3 years. The domains assessed in every survey administration have been reading, mathematics, and science; and the assessments use what is referred to as a *literacy* orientation. This means PISA focuses primarily on the extent to which students can use their reading, mathematics and science knowledge to resolve challenges that might be encountered at school, home, in the workplace or elsewhere in society. The three assessment domains take turns to be the major focus of the assessment. Mathematics was the major domain in 2012, and it was previously the major domain during the 2003 administration. Up to 2012, PISA assessments have been administered in pen and paper, with an additional computer-based assessment in some surveys. A substantial volume and variety of background data is collected on students and schools.

The OECD's Programme for the International Assessment of Adult Competencies (PIAAC) is an international survey of adult skills that aims to cover literacy, numeracy and problem-solving in technology-rich environments. The Australian Bureau of Statistics conducted this as a household survey in Australia in 2012 (the previous administration occurred in 2006). PIAAC survey instruments are administered to a random sample of 15 to 74 year olds. The survey can be completed using pen and paper **or** computer. Participants answer a significant number of background questions that, together with the survey data, provide the potential for rich analysis.

Abstract

This presentation will look at some key messages from the Australian results of both the Programme for International Student Assessment (PISA) and the Programme for the International Assessment of Adult Competencies (PIAAC). PISA assesses the mathematical literacy of 15-year-old students around Australia, whilst PIAAC assesses the numeracy proficiency of adults aged 15–74. What do the two surveys assess and are they telling a similar story? How solid are Australia's mathematical foundations and what do they say about teaching and learning?

How do Australia's results compare internationally with those leading the field? What are some of the research outcomes and implications for both policy and practice for schools and lifelong learning, including about linking maths and life outside the classroom?

This paper presents a perspective on the mathematical capabilities of Australian students as revealed through data from the two international assessment programs.

Definitions

PISA and PIAAC each have their own definition of the mathematics domain.

PISA: *Mathematical literacy* is an individual's capacity to formulate, employ and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognise the role that mathematics plays in the world and to make the well-founded judgements and decisions needed by constructive, engaged and reflective citizens.

PIAAC: *Numeracy* is the ability to access, use, interpret, and communicate mathematical information and ideas, in order to engage in and manage the mathematical demands of a range of situations in adult life.

These definitions share common features as well as differing in a number of ways. The commonalities include an interest in mathematics in context, not just arithmetic and calculation. The definitions and aims are similar, as are the contexts and mathematics content they address. Some items could be interchangeable between the two assessments. Both surveys employ essentially the same analytic methodology.

The differences between the two include the richer background questionnaire for PIAAC that has a greater emphasis on education, work, wages, and a variety of self-perceptions. PIAAC starts at a lower mathematical level than PISA, and PISA extends to higher levels than PIAAC. PISA is primarily interested in students' ability to *use* formal school-based maths. For a more detailed comparison see Gal and Tout (2014).

Frameworks

The frameworks of the two surveys define their respective assumptions, priorities and the elements that drive the assessments.

Figure 1 shows the main elements of the PISA mathematics framework. The outer box shows the purpose of mathematical activity being dealing with challenges that are met in various real-world contexts. Context categories are specified, and broad strands of mathematical knowledge that may be brought to bear in meeting the challenge are also listed. Within the context of a real-world challenge, mathematical thought and action are activated to meet the challenge. This includes the application of mathematical concepts, knowledge and skills; and the activation of a set of broader 'fundamental capabilities' through which the connection between particular elements of potentially relevant mathematical knowledge are identified and brought to bear on the problem at hand. The third element, represented in the inner part of the graphic, shows an important cycle of action through which mathematical thought and action can occur. The problem in context is transformed into a mathematical problem, mathematical processes are used to produce mathematical results, those results are interpreted and evaluated in relation to the context in which the problem was generated, and, if necessary, refinements to the understanding of the problem and its formulation in mathematical terms may be undertaken, with the steps and processes repeated until a solution that is fit for purpose is obtained.

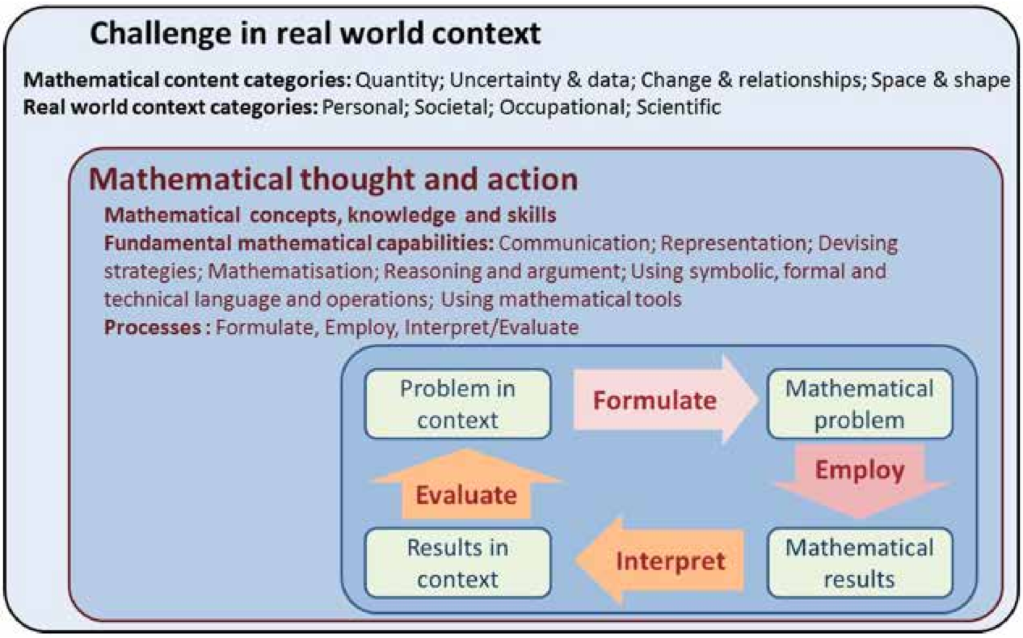


Figure 1 Representation of key elements of the PISA mathematics framework (from OECD, 2013a)

Recent Australian PISA and PIAAC headline results

Figure 2 summarises some of the headline messages coming out of the recent PISA and PIAAC survey administrations.

The headline messages indicate a decline in Australia's PISA results between 2003 and 2012.

This is illustrated further in Figure 3. The graph shows a clear downward trend in Australia's average mathematics score, in PISA units (having a mean of 500 and a standard deviation of 100), from the 2003 survey administration to the 2012 survey administration. Similarly, in the adult survey, the performance in numeracy has declined.

The other message from these headlines is that our relative performance in mathematics is significantly lower than our performance in literacy. Why is this the case? Do we need to look at whether our mathematical foundations are solid enough for the 21st century?

This contrasts with countries such as Germany that have seen an improvement over that period; and also contrasts with a much smaller decline in the average across all OECD countries.

The decline has occurred for both boys and girls, as seen in Figure 4, and while the difference between female and male students has always been evident, it is now statistically significant.

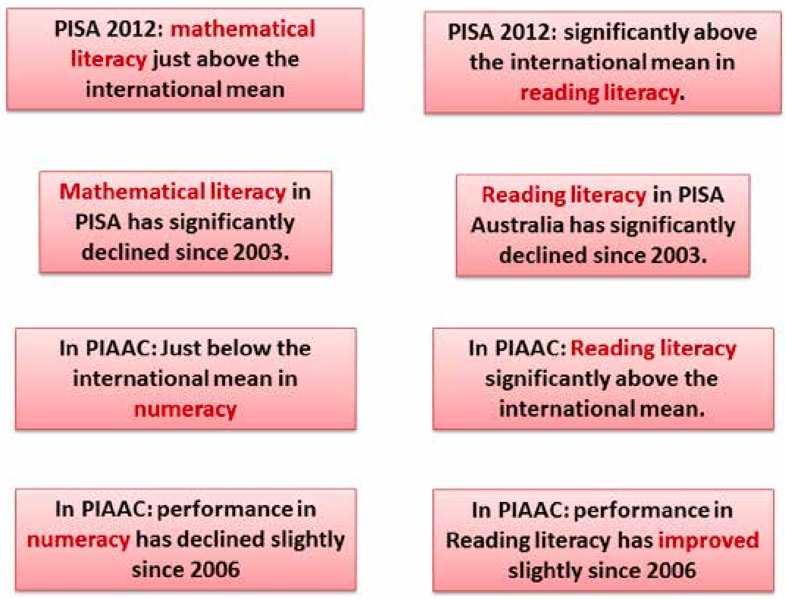


Figure 2 Some recent PISA and PIAAC outcomes

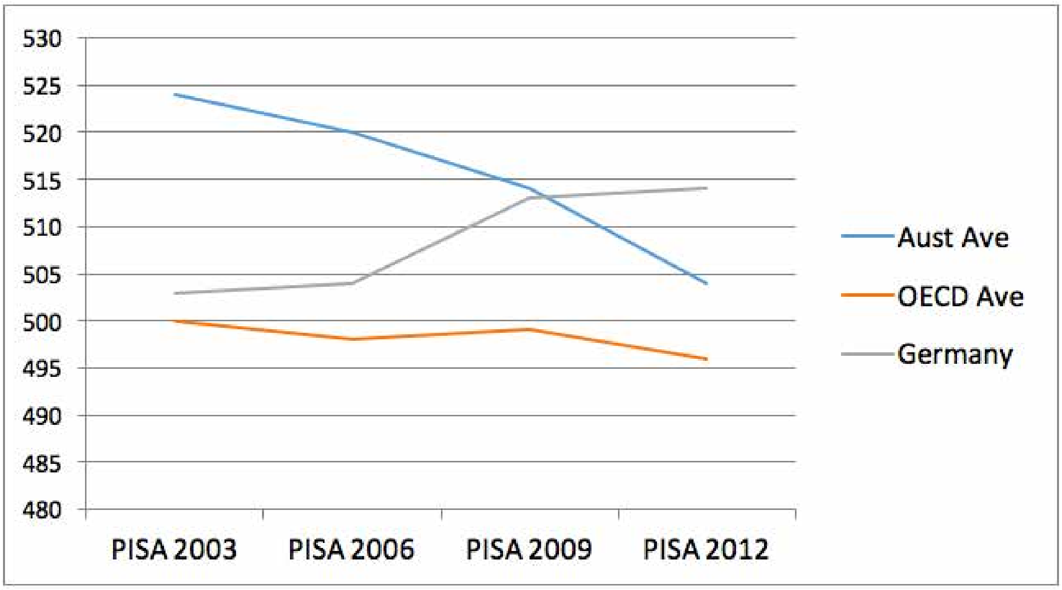


Figure 3 PISA mathematics decline 2003–2012

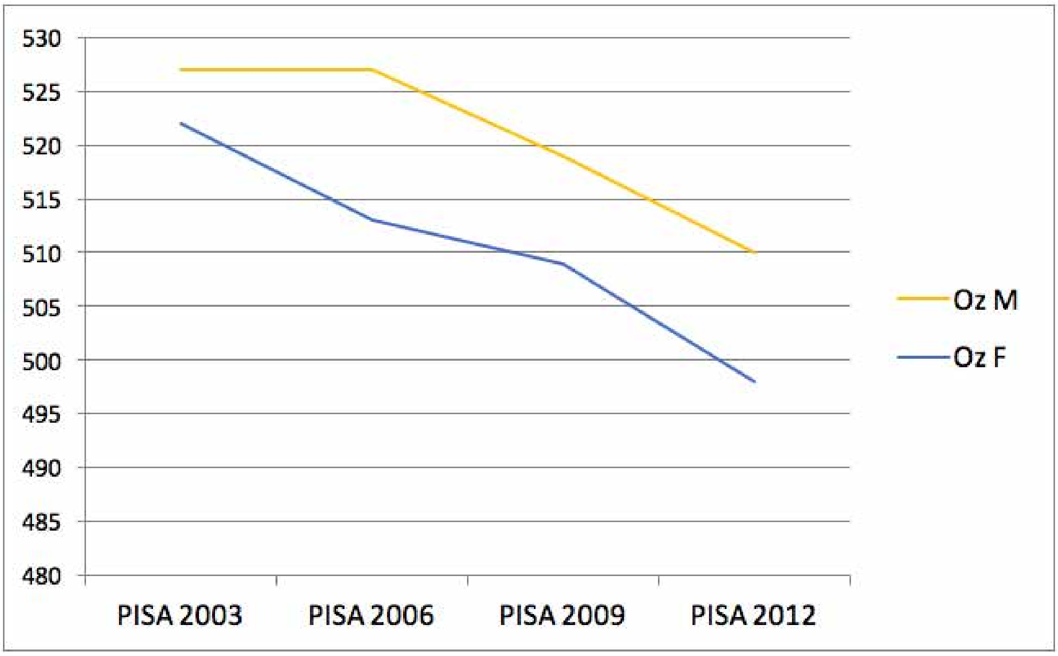


Figure 4 PISA mathematics trend lines for Australian female and male students 2003–2012

For PISA 2012, a key comparative measure frequently used by the OECD is the proportion of students at or above PISA Level 2 (the OECD's minimum level of mathematical literacy).

Twenty per cent of Australian students do not reach the level determined by the OECD as the level of performance at which 'students begin to demonstrate the mathematical literacy competencies that will enable them to actively participate in the 21st century workforce and contribute as productive citizens'.

Forty-four per cent do not meet the baseline identified in the Measurement Framework for Schooling in Australia (ACARA, 2015) as representing a 'challenging but reasonable expectation of student achievement at a year level, with students needing to demonstrate more than the elementary skills expected at this level'. This compares with 36 per cent in reading.

Comparing Australia with top-performing country Singapore, we see that Singapore's mean is 573 points on the PISA scale, compared to Australia's mean of 504. This difference is roughly the equivalent of TWO years of schooling. Forty per cent of Singaporean students achieved at proficiency Level 5 or 6; compared to 15 per cent of Australian students. Four per cent of Singaporean students achieved below proficiency Level 2; compared to 20 per cent of Australian students.

Additionally, mathematical proficiency is markedly lower for particular subsets of Australian students, as shown in Figure 6, Figure 7, and Figure 8. Students in remote areas are much more likely to be achieving at a lower level than students in either provincial or metropolitan areas. More than half of Australia's Indigenous students are not achieving at the OECD minimum proficient standard, compared to 18 per cent of non-Indigenous students. Around one-third of students from low SES backgrounds are not achieving at the OECD minimum proficient standard, compared to eight per cent of those in the highest SES quarter.

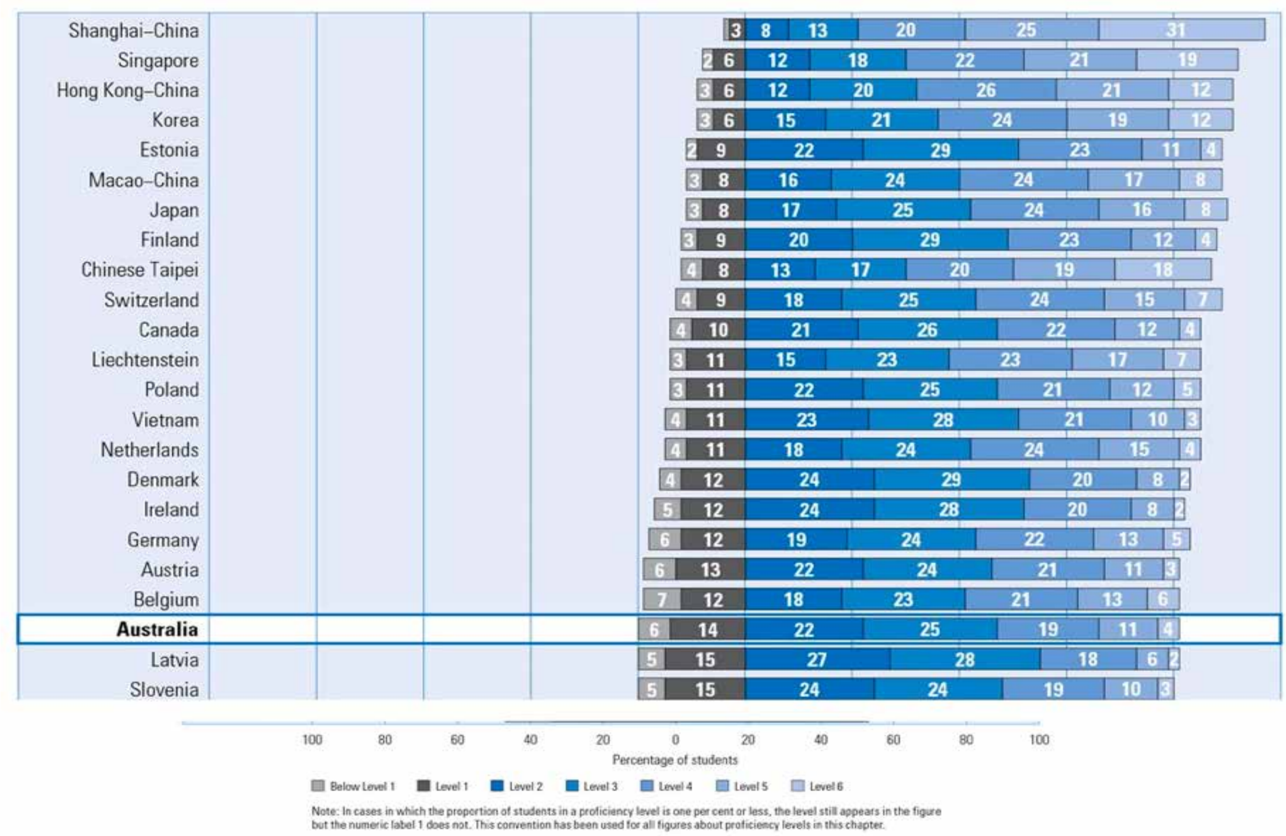


Figure 5 Percentage of PISA mathematics students by level for several countries, highlighting the comparison for percentages reaching Level 2 and above

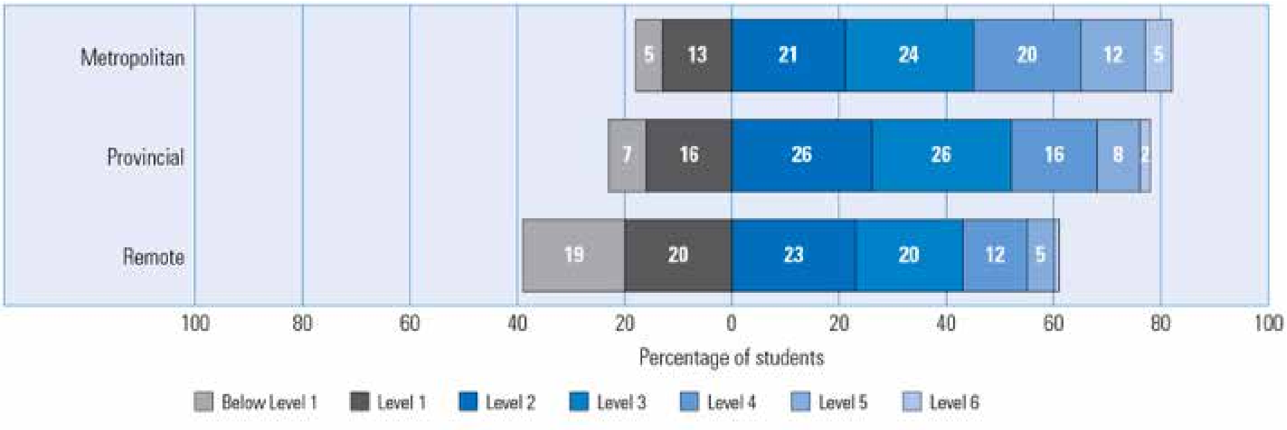


Figure 6 Proficiency profile of Australia's mathematics students by location type

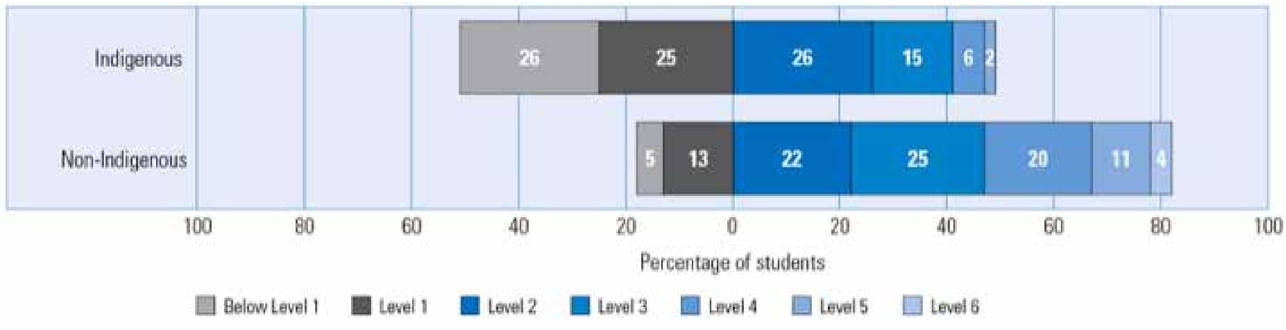


Figure 7 Proficiency profile of Australia's mathematics students by indigeneity

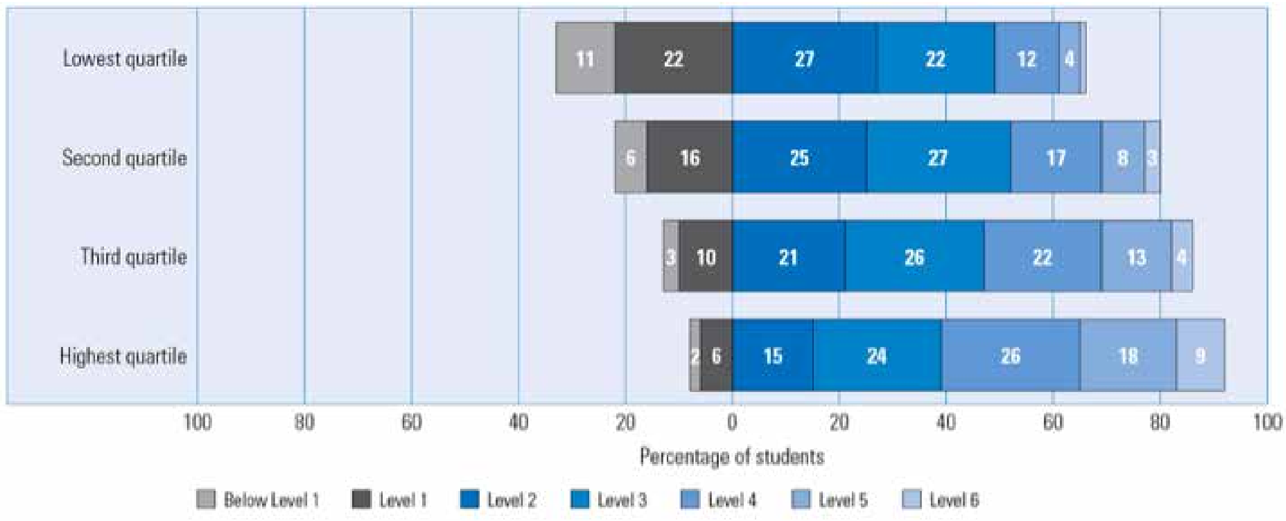


Figure 8 Proficiency profile of Australia's mathematics students by family socio-economic category

How students handle particular PISA tasks

A sample PISA item released to the public domain is the item titled 'Sauce', shown in Figure 9.

> You are making your own dressing for a salad.
>
> Here is a recipe for 100 millilitres (mL) of dressing.
>
> Salad oil: 60 mL
>
> Vinegar: 30 mL
>
> Soy sauce: 10 mL
>
> How many millilitres (mL) of salad oil do you need to make 150 mL of this dressing?
>
> Answer: ………………… mL

Figure 9 The PISA mathematics item 'Sauce'

This item is set in a 'real-world' context; it requires some thinking to formulate as a mathematical problem (recalling the mathematical processes – formulate, employ, and interpret – that underpin the PISA mathematics framework); little guidance given as to what kind of mathematical knowledge is required; the level of mathematics not high – the kind of knowledge useful at work and in daily life.

Fifty-six per cent of Australian students could do this item – substantially below the OECD average per cent correct.

A further PISA example, this time using a workplace context, is titled 'Drip Rate'. 'Drip Rate' is set in a medical (nursing) context, and involves some mathematics used in setting up an infusion. The question gives a formula connecting drip rate (*D* drops per minute) to drop factor (*d* drops per mL), volume of infusion (*v* mL), and infusion time (*n* hours) as follows:

$$D = \frac{dv}{60n}$$

The question states: 'A nurse wants to double the time an infusion runs for. Describe precisely how *D* changes if *n* is doubled but *d* and *v* do not change.'

What is needed to solve this problem? The question demands some reasoning, interpreting and understanding of relationships between variables in a formula; and writing a conclusion.

The Australian per cent correct rate for this item was a little over 20 per cent, compared to the OECD average of 22 per cent.

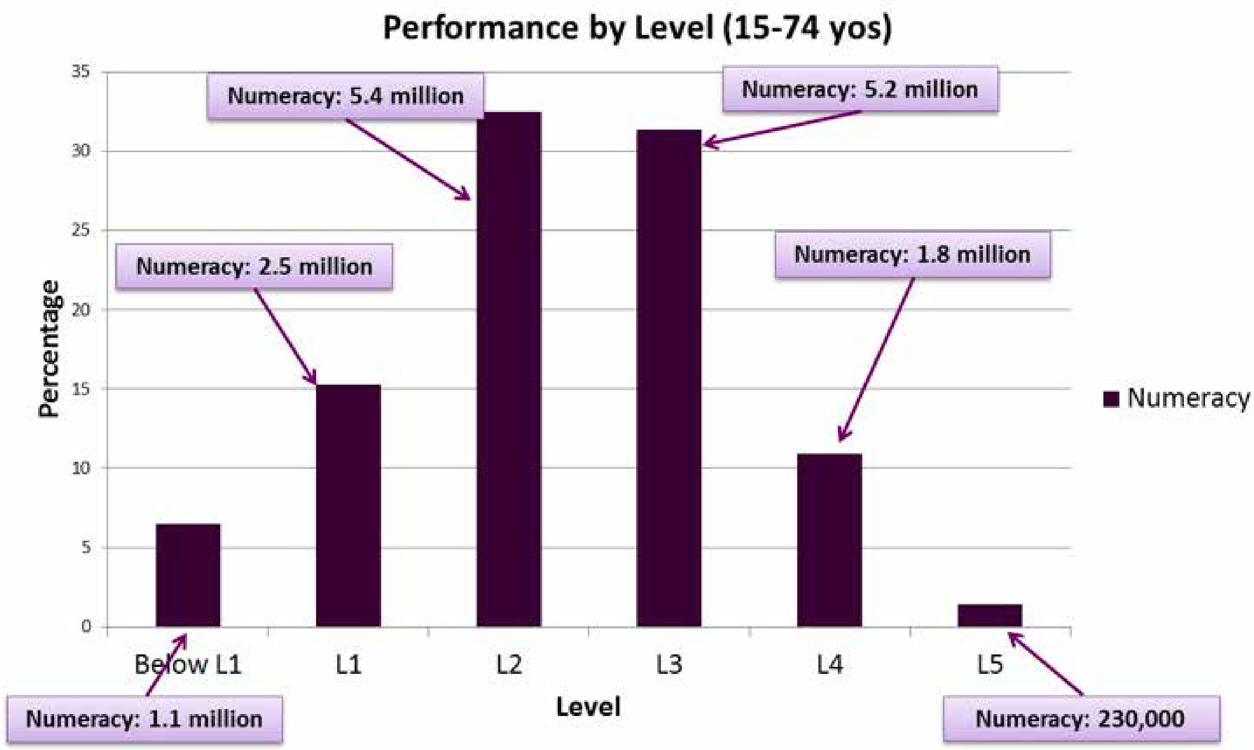


Figure 10 Performance by level in numeracy in PIAAC 2012. Total Australian population aged 15–74 years

Australian performance in PIAAC 2012

Figure 10 shows the distribution of Australia's performance across the different levels defined for PIAAC 2012.

Once again, it is instructive to review particular assessment items, and examine the performance of the assessed Australian population on those items.

In one of the easiest tasks, adults were asked to look at a photograph containing two cartons of cola bottles (changed to water bottles for PIAAC) and give the total number of bottles in the two full cases.

This was a **Pre-Level 1** item:

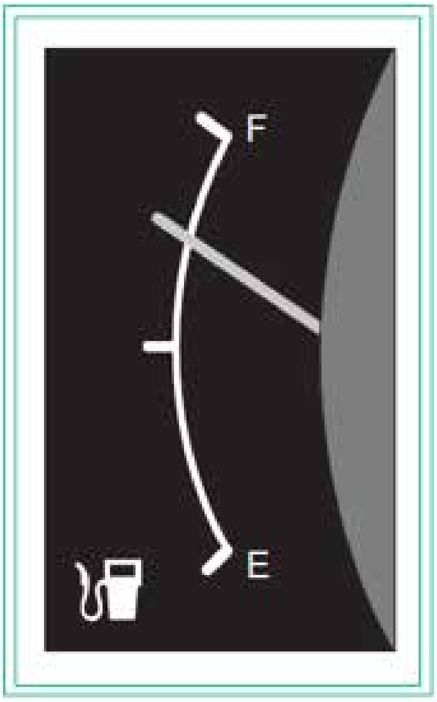
Tasks at this level are set in concrete, familiar contexts where the mathematical content is explicit with little or no text or distractors and that require only simple processes such as counting, sorting, performing basic arithmetic operations with whole numbers or money, or recognizing common spatial representations.

1.1 million Australians aged 15–74 years of age are operating at this level.

When you compare the literacy questions with the numeracy questions at the same level, the literacy tasks appear to be relatively more challenging and not too basic in terms of their literacy demands; whereas the low-level numeracy items, such as the one shown above, require very basic numeracy skills. So, alongside the fact that our performance in numeracy is lower, are our standards and expectations in numeracy also set at a lower level compared with literacy?

In another numeracy task, adults were asked to look at a car petrol gauge image. The task states that the petrol tank holds 48 litres and asks the respondent to determine about how many litres remain in the tank. A range of answers are allowable as correct.

This was a **Level 2** item in PIAAC.



About 3.6 million Australians aged 15–74 years of age could NOT answer this question.

Figure 11 shows the distribution by age group of Australian adults in the three highest PIAAC proficiency levels for literacy (reading) and numeracy (mathematics).

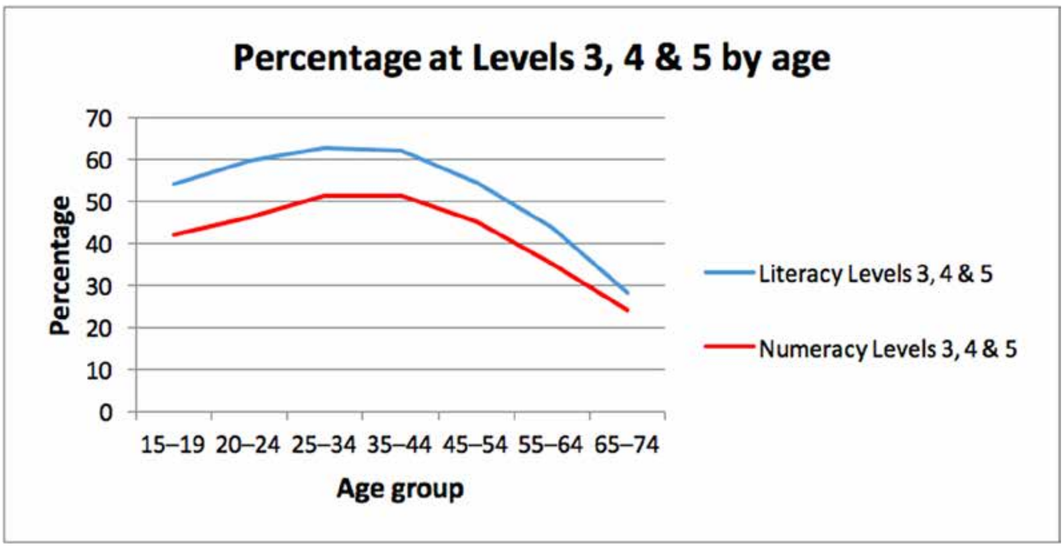


Figure 11 Percentage of Australian PIAAC cohort at the upper proficiency levels, by age

Both assessment domains exhibit increasing performance levels for the 15 or so years after school-leaving age, with a declining performance profile for the older parts of the population, presumably reflecting differing education background for people in older groups and the 'if you don't use it, you lose it' phenomenon. Figure 12 shows the age-group profile for literacy broken down by sex, with the decline in performance starting a little earlier for females, but from a higher performance level than for males in the younger age groups; and Figure 13 shows a similar pattern for numeracy, but with a more consistent male-female difference. Indeed, 49 per cent of males are at Level 2 or below, with 59 per cent of females at Level 2 or below, a difference of almost 10 percentage points.

Based on three cycles of international assessments of **adult** literacy and numeracy skills (IALS, ALLS and PIAAC), research indicates, amongst a number of other findings, that people with higher literacy and numeracy skills are significantly **more** likely to be employed, to participate in their community, to experience better health, to engage in further training, and to earn more on average.

As well, the research demonstrates that each extra year of education improves literacy and numeracy skills.

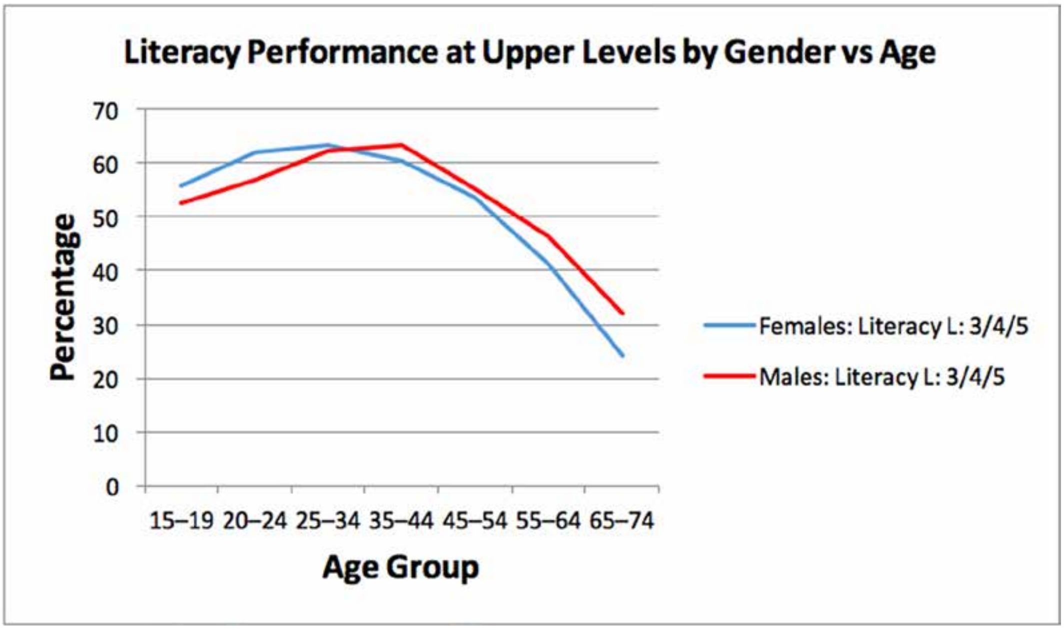


Figure 12 Age-group profile for PIAAC literacy for females and males

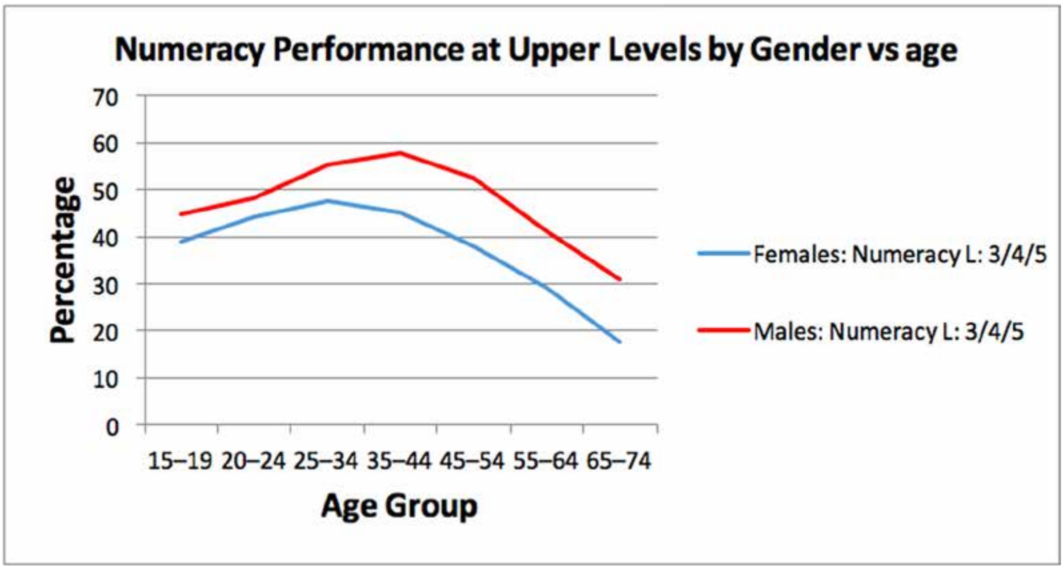


Figure 13 Age-group profile for PIAAC numeracy for females and males

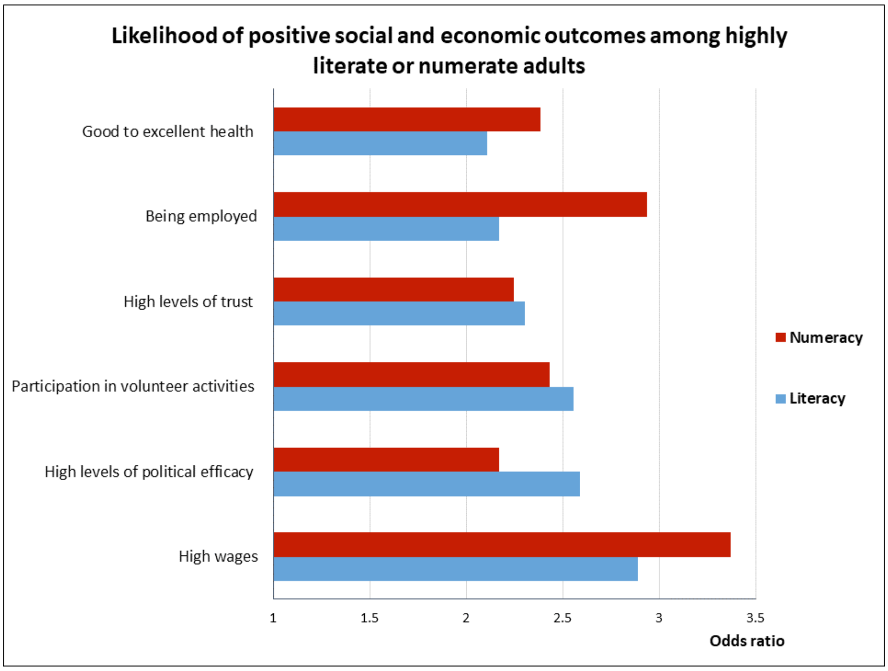


Figure 14 Likelihood of positive social and economic outcomes among highly literate or numerate adults (OECD, 2013b)

As an example of the analytic potential of PIAAC, this graph shows OECD data demonstrating that adults with high proficiencies in literacy and in numeracy are much more likely, compared to those with lower skills, to report good health, to be employed, to have higher earnings, and to have positive social dispositions and take part in community life; and that **numeracy** appears to be a more potent predictor of positive social and economic outcomes such as **health**, **employment**, and **high salary**, compared with literacy. In other words, numeracy can play a more important role than literacy in both human and social capital terms.

Research from the UK also indicates that for women, low numeracy has a greater negative effect even than low literacy. Poor numeracy skills make it difficult to function effectively in all areas of modern life, particularly for women (Bynner & Parsons, 2005, p. 7).

Other research argues that owing to globalisation and the introduction of technology, workplace numeracy demands are growing rapidly, and more workers are now engaged in mathematics-related tasks of increasing sophistication (for example, Hoyles et al., 2002).

A recent Australian project, The Quantitative Skills in 21st Century Workplaces project, undertook research to identify and analyse the gaps between young peoples' quantitative skills and the expectations of 21st century workplaces. One of the more interesting conclusions of this project by the practicing maths teachers involved was that the relationship between workplace mathematical skills and school mathematics could be described as 'distant' at best, and that although the skills observed appear to be fundamental, it is their use and application in work contexts that is not straightforward (see: http://www.aamt.edu.au/Activities-and-projects/Workplace-maths-skills).

The key lessons

Our interpretation of the research includes the following lessons.

- Investing in the mathematical literacy/numeracy skills of young people and adults has significant benefits – for the individual, for society and for the economy.
- Numeracy counts at least as much as literacy.
- As part of battling negative attitudes towards mathematics in the community (families, workplaces, training organisations and so on), schools should have high expectations for all students.
- We should not lower our standards or expectations, rather we should do all in our power to counter the community and cultural attitude that it's OK to not be good at mathematics. Mathematics counts, socially and economically.
- The low levels of foundational skills of many Australians speaks to disempowerment, and to reduced ability to make considered mathematically based decisions, whether they be actions or decisions at a workplace, when out shopping,

following instructions about a medical matter, making decisions about financial matters, or understanding the implications of gambling.

If students are unable or unwilling to see their world through mathematical lenses, if they have little experience grappling with real-world situations and problems, and if they can apply mathematical procedures only when problems are packaged in very familiar ways, then why would we expect our adult workforce to do any better?

Schools have a critical role in encouraging our students to see their world through mathematical lenses, and ensuring that students learn to use their mathematical knowledge to deal with work and other life challenges. Our mathematics classes must provide students opportunities to grapple with real-world situations and problems, and find ways to connect their mathematical knowledge with those problems, including unusual problems, problems that require the problem solver to transform messy, real-world situations into a form amenable to mathematical treatment.

Schools generally do NOT prepare students particularly well for mathematics in the real world; nevertheless, it is clear that students will need numeracy and mathematical literacy. Numeracy and mathematical literacy need to be taught – leaving it to providence will not guarantee success. We need to use problems in context. We need a conscious focus on mathematical processes: communication, modelling, devising strategies, representation, and reasoning. We need a conscious focus on all stages of mathematical modelling (formulating, employing, interpreting/evaluating).

And gender is still a crucial issue that needs continuous focus.

Instead of using traditional word problems of the kind shown in Figure 15, we encourage greater use of mathematics tasks more like PISA and PIAAC problems such as the one in Figure 16.

More PISA items are available from: http://www.oecd.org/pisa/pisaproducts/pisa2012-2006-rel-items-maths-ENG.pdf

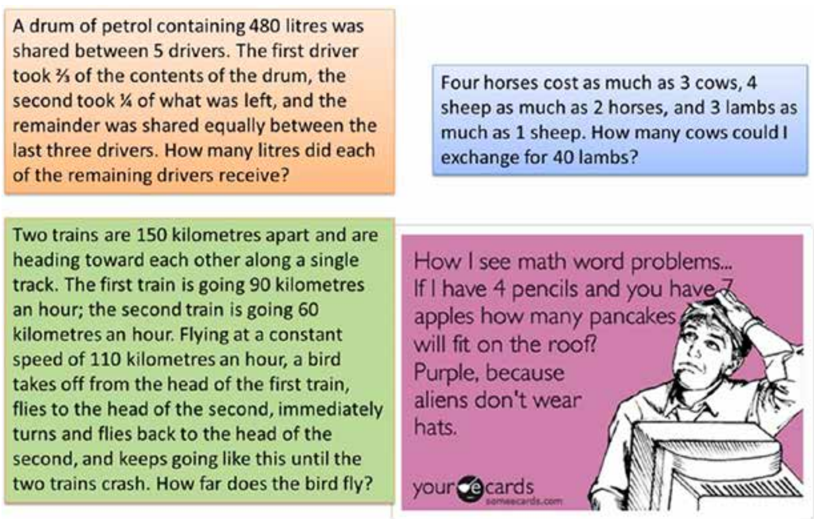


Figure 15 The wrong approach

Mount Fuji

The Gotemba walking trail up Mount Fuji is about 9 kilometres (km) long.

Walkers need to return from the 18 km walk by 8 pm.

Toshi estimates that he can walk up the mountain at 1.5 kilometres per hour on average, and down at twice that speed. These speeds take into account meal breaks and rest times.

Using Toshi's estimated speeds, what is the latest time he can begin his walk so that he can return by 8 pm?

Figure 16 A better way – PISA item 'Mount Fuji'

Problems likely to promote the kind of mathematical thinking that will build the STEM skills required by students as they move further into the 21st century have characteristics shown in Figure 17. We propose more of that.

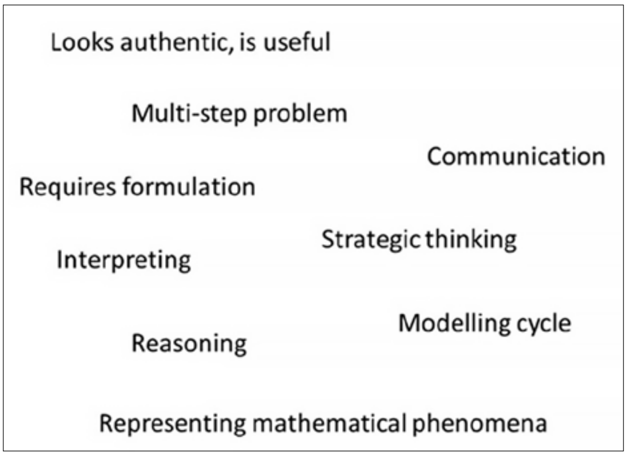


Figure 17 Desirable characteristics of good mathematics tasks

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STEM and Indigenous students

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Elizabeth McKinley is currently Professor Indigenous Education in the Melbourne Graduate School of Education at the University of Melbourne. Her role is to establish, build and provide leadership to the school's Indigenous Education Research Centre. Professor McKinley brings extensive experience in leading research, and research and development (R&D), projects with Indigenous students, and collaborating with – and drawing on the expertise of – other R&D teams. During her time in Auckland, she was a Professor in Māori (Indigenous) Education at the University of Auckland, and the director for The Starpath Project for Tertiary Participation and Success, which is a Partnership for Excellence between the University of Auckland and the government of New Zealand. This 10-year externally funded project has focused on students from schools that serve our low socio-economic communities, particularly Māori (indigenous) and Pacific Island students. Professor McKinley also co-led a major R&D project to increase the achievement of Māori students in English-medium schools. She brings extensive experience in research relating to school-wide change for Māori and Pacific students, and in higher education. She has also had extensive experience at research higher degree supervision and postgraduate teaching.

Abstract

Achievement disparities between Indigenous students and their non-Indigenous peers in education continue to be documented across the globe. Over the past three decades, there has been a significant amount of writing on Indigenous methodologies, epistemology and, to a lesser extent, pedagogies. All are crucial in the lifelong process of teaching and learning – the nature of knowledge, how it is gained, and the transmission of it. However, much of this work is contested or seen as inappropriate or irrelevant in STEM education. Indigenous students do not perceive STEM subjects as being welcoming. As STEM educators, we need to take a broader perspective that encompasses the complex interaction of family, social, cultural, educational, economic and political contexts, and to take into account the nature of knowledge and the importance of cultural identity to Indigenous communities. PISA data shows that Indigenous students have an interest in science that is equal to that of their non-Indigenous peers. So the questions we need to ask are: Why have STEM educators and schools not been able to capitalise on this interest? What makes for effective STEM teaching for Indigenous students? What makes for quality STEM teaching for Indigenous students? What makes for successful learning for Indigenous students in STEM subjects? This presentation will debate current approaches and ask what more needs to be done

Introduction

Recent educational policies in Australia explicitly aim to provide high-quality education and learning opportunities for *all* students, while at the same time promoting high performance outcomes and the development of specialist, knowledge-based skills (MCEECDYA, n.d.). Increasing the numbers of students pursuing science, technology, engineering and mathematics (STEM) education has been identified as the means to achieve this outcome (see Freeman et al., 2015). Australia consistently performs well on international assessments like the Programme for International Student Assessment (PISA) (Knighton, Brochu & Gluszynski, 2010), yet Indigenous peoples continue to have significant disparities in educational attainment relative to non-Indigenous peoples (Woods-McConney & McConney, 2014). Other research shows the achievement gap between Australian Indigenous and non-Indigenous students is far larger than that found in New Zealand (Song et al., 2014). These disparities are well documented. This paper will briefly review what we know about the achievement of Indigenous education in STEM, and discuss how we might move forward.

Research literature

Research in the Indigenous STEM field has examined the engagement and achievement of students in science and mathematics, and focused on issues of teaching and learning, foregrounding Indigenous languages, ontologies, and epistemologies. This work includes Indigenous knowledge in the curriculum, place-based curriculum, pedagogical theories on cultural border crossing, culturally responsive pedagogy, and language of instruction (see McKinley & Gan, 2014; McKinley & Stewart, 2009; Meaney, Trinick & Fairhall, 2011). There have been fierce debates, particularly concerning the nature of science and whether Indigenous knowledge of the landscape can be and should be considered as knowledge to be included in school science. But such debates, while important, leave the teachers and the practice of STEM education with little guidance. Such debates, in a variety of settings, provide a broader context for all teachers of Indigenous students.

Achievement

One of the latest PISA reports on Australian Indigenous students (Dreise & Thomson, 2014) states (emphasis mine):

> The latest international assessment of students' mathematical, scientific and reading literacy – the Programme for International Student Assessment (PISA) – shows that the gap between Indigenous and non-Indigenous students *has remained the same for the last decade*. In short, Indigenous 15 year olds remain approximately two-and-a-half years behind their non-Indigenous peers in schooling.

While such results are dire, it would be wrong to think that by giving Indigenous students more of the same, and by saying it with more emphasis, their STEM achievement will be raised.

A recent Australian report suggests the reason Australian Indigenous students don't participate and achieve in STEM is because of their low proficiency levels in STEM literacy; there is a suggestion that there is a need to look to other countries (for example, Canada, NZ, the US) for 'solutions' (Marginson et al., 2013). These 'solutions' include different approaches to curriculum and pedagogy to engage Indigenous students in STEM; programs and activities to facilitate Indigenous student engagement; and professional development for teachers in cultural literacy (for example, respect, recognition, culturally responsive pedagogy). Using these approaches, researchers – in conjunction with STEM teachers – have attempted to resolve the questions on Indigenous students' engagement and achievement in science and mathematics education through specific contexts, with consideration given to the local sociocultural and sociopolitical backgrounds. But while important, possibly too much emphasis has been placed on cultural difference and low literacy as explanations.

It has been suggested that more attention should be given to the potential of large international datasets, such as PISA, beyond the country reports. Work carried out by McConney et al. (2011) has demonstrated that Indigenous students' interest in science (PISA works with literacy in science and maths) is greater than that of non-Indigenous students. In a subsequent analysis, Woods-McConney et al. (2013) demonstrated that engagement in science was most strongly associated with the extent to which students participated in science-related activities outside of school. These indicators provide some thought as to how interest might be constructed with Indigenous students in science, and how science educators may be able to engage Indigenous students more.

Culturally responsive pedagogy

Recent research has been carried out in Australia on effective teaching practices for Indigenous students, as reported by Aboriginal parents, students, and teachers in a group of schools in Queensland (Lewthwaite, Lloyd & Boon, 2015). Of note in this work is the difference in views between teachers and parents in relation to knowledge of Indigenous histories, and how this manifests itself in schools, and especially teacher–parent and teacher–student interactions. Parents, teachers and students recognised the need for assistance on 'code-switching', but teachers tended to take a narrower view, in that they recognised that assistance was required linguistically, but were not necessarily able to respond to the incommensurability and discontinuity between home culture and school culture and academic success. Another factor identified by the participants was the need for positive relationships in the classroom, where individuals are respected and seen as important, and priority is placed on 'caring'. Students and parents thought there was a limited awareness shown by teachers of the linguistic, social and behavioural capital that is necessary for success in classrooms; and limited awareness of the assistance students identified as necessary for negotiating the demands of the classroom. The researchers reported that teachers also showed a limited awareness of the importance students and parents place on cultural inclusion and affirmation, especially in regards to promoting an educational experience that validates cultural identity. Rozek et al. (2015) argue that there have been very few projects looking at the influence on parents to motivate their children in STEM classes. In their study, they found that mothers have an effect on their high-achieving daughters' STEM achievement behaviours, but no further general conclusions could be drawn.

Boon and Lewthwaite (2015) have extended their work into developing measures of culturally responsive pedagogy. A tool is being tested with teachers; early piloting and analyses indicate that there is considerable variability found among the measures related to whether teachers were teaching in primary or secondary contexts. Analyses of variance showed significant difference between primary and secondary teachers in their overall scores in culturally responsive pedagogy, in their Indigenous cultural value, behaviour support, literacy teaching, and pedagogical expertise. Secondary school teachers:

- found communication with parents and community difficult
- found incorporating literacy teaching into subjects difficult
- scored lower on developing self-regulated behaviours in students for learning.

However, they reported confidence at incorporating Aboriginal and Torres Strait Islander perspectives into their subject areas.

While this work is still being developed and tested, it shows promise. At the moment, it is able to provide practicing teachers with an overall picture of their teaching against the characteristics that Indigenous parents and teachers believe are the most supportive of learning for Indigenous students. Potentially it gives the opportunity to a teacher to reflect on areas that could be moderated to accommodate the needs of Indigenous students or to focus on an area that could improve. The instrument could be modified to be used by students to appraise their teachers, and for principals to identify and arrange for professional development for staff. The behaviours measured are about quality teaching and effective teaching for Indigenous learners.

These findings are consistent with research with other Indigenous groups in Western countries (see Bishop et al., 2012; Webber et al., 2016). The Te Kotahitanga project carried out in New Zealand has shown a sustained increase in achievement scores of Māori students in the participating schools (see Bishop et al., 2012). Focusing on the nature of the interpersonal relationships between Māori students and their teachers, Bishop created an effective teaching profile and implemented a professional development program. The success of this program indicates that a pedagogy that improves Māori student experiences at school can affect achievement outcomes regardless of students' literacy levels.

Conceptions of culture in science education research

While most researchers recognise that culture plays an important role in the teaching and learning of the sciences in schools (Aikenhead, 1996; Gutierrez & Rogoff, 2003), there is less consensus on the conceptualisation of 'culture' in school sciences instruction and how it is understood and applied by educators in classroom practices. One line of research that draws on developmental psychology and anthropology conceptualises a cultural view of teaching and learning as a dichotomy of two idealised developmental pathways: *individualistic* – focusing on individual identity, independence, self-fulfilment, and standing out; and *collectivistic* or *socio-centric* – focusing on group identity, interdependence, social responsibility, and fitting in (Greenfield et al., 2003). The two cultural pathways are often viewed as in conflict when there is a mismatch between what is valued in the classroom and what is valued at home or in the community where the student comes from. Greenfield et al. (2000) argue that the two divergent cultural priorities placed upon the student mean that teachers need to understand and mediate the learning process, not only in relation to cognitive demands, but cultural demands as well. Bridging between home and school culture thus provides an underlying cultural approach for teachers to support learners who come from different cultural backgrounds.

Attempts to engage non-Western students into the subculture of STEM are challenging for STEM teachers. Students who are capable of negotiating the transitions between their everyday worlds and the subculture of STEM without having to assimilate or acculturate STEM's cultural baggage are seen as more successful learners, particularly by some Indigenous communities. Those who struggle to negotiate the cultural borders will require explicit instructional support in order to traverse from the subcultures of their peers and family into the subcultures of STEM and school STEM. This is aptly captured by the metaphor 'border-crossing' (Giroux, 1992), which suggests that there are domains of knowledge specific to various cultural contexts and that excursions from one way of knowing to another can occur in science learning. Aikenhead (2006) proposed that teachers make border crossings explicit for students; facilitate these border crossings; promote discourse so that students, not just the teacher, are talking science; substantiate and build on the legitimacy of students' personally and culturally constructed ways of knowing; and teach the knowledge, skills, and values of Western science in the context of its societal roles (for example, social, political, economic, and so on).

Some tentative concluding thoughts

This short paper has shown there has been a surge in research on culturally responsive STEM pedagogies. The increase in interest in culturally responsive pedagogy implies that there are a number of research avenues to investigate. First, research is needed to identify ways to support teachers and students to better leverage on the funds of knowledge that each bring to the STEM classroom. An important area of research involves how teachers and students from diverse backgrounds make use of their linguistic and cultural experiences as intellectual resources in learning STEM subjects, and how they attempt to overcome the tensions and challenges that may arise when these resources are found to be discontinuous with the way STEM subjects are defined and taught in the classroom. Recent research from the US suggests teachers who position themselves as learners with – and build strong relationships with – their Indigenous students are more likely to have stronger culturally responsive practices in their classrooms (Nam et al., 2013).

A number of questions that could be pursued in future work include: Does culturally relevant pedagogy support Indigenous students to learn STEM subjects? If so, how? And what can be done to help teachers become more skilled in practicing culturally relevant STEM teaching? Little work exists on finding out what students bring to STEM classrooms.

Secondly, developing teachers' culturally responsive pedagogies must arise from the actions of an entire school system rather than from classroom teachers alone. The school system should actively support teachers to build a cultural perspective on teaching STEM and involving the community in helping to create a collaborative learning environment, which will not only enrich the school content but promote a cultural shift of school STEM that facilitate more responsive science teaching (Bang et al., 2010).

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Enhancing students' mathematical aspirations and mathematical literacy as the foundation for improving STEM learning

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Professor Merrilyn Goos is Head of the School of Education at The University of Queensland. She is an internationally recognised mathematics educator whose research is well known for its strong focus on classroom practice. She has led projects that investigated students' mathematical thinking, the impact of digital technologies on mathematics learning and teaching, the professional learning of mathematics teachers, and numeracy across the curriculum. She won a national award for excellence in university teaching for her work as a mathematics teacher educator. She is also the lead author of Teaching Secondary School Mathematics*, a widely used teacher education reference book.*

Research on raising students' mathematical aspirations

Secondary school students are increasingly opting out of mathematics subjects that provide the knowledge base for tertiary degrees, thus closing down opportunities for employment and further study. Between 1994 and 2012, participation rates for intermediate level mathematics subjects dropped from 38 per cent to 27 per cent of the Year 12 cohort, and from 16 per cent to 9 per cent for advanced mathematics (Kennedy, Lyons & Quinn, 2014).

Research conducted in Australia and the UK has aimed to understand the challenges of building aspirations for studying higher-level mathematics at school (for example, McPhan et al., 2008; Noyes, Wake & Drake, 2011). However, this research has tended to use *retrospective* designs that ask students or teachers to look back in time to recall factors influencing subject choices. An alternative approach involves using a *prospective* design to explore students' aspirations for

Abstract

Mathematics is the foundational enabling discipline that underpins STEM and its other constituent disciplines of science, technology and engineering. Central to Australia's mathematical vitality is universal access to high-quality mathematics education. Without this, young people are at risk of early school leaving, low participation in post-school education and training, poor employment outcomes, and social isolation (COAG, 2008; Parsons & Bynner, 2005). But Australia faces significant problems in ensuring that all young people are successfully engaged in learning mathematics at school, and in providing them with teachers who can inspire their learning.

This paper explores approaches to addressing two problems that continue to challenge researchers, practitioners, and policy makers: (1) raising students' mathematical aspirations and (2) enhancing mathematical literacy across the school curriculum. It draws on the findings from two current research projects. The first project is developing case studies of schools that have increased student participation in higher-level mathematics in the senior secondary school years. The second project builds on a long-term research program for embedding numeracy across the curriculum by creating a suite of online videos illustrating what numeracy looks like in real classrooms in different school subjects.

studying mathematics while these aspirations are formed in 'real time'. This is the approach my colleagues and I are using to investigate effective schooling practices that promote sustained student interest and engagement in secondary school mathematics (Ng, Goos & Bahr, 2014). This paper offers a snapshot of initial findings from one case study school that has recorded substantial increases in enrolment in intermediate and advanced mathematics subjects over the past six years. We observed mathematics classrooms and interviewed the mathematics Head of Department, other mathematics teachers, groups of Year 10 and Year 11 students, and one of the school's career guidance counsellors to gain insights into factors influencing students' emerging aspirations for studying mathematics.

Effective practices: Promoting aspirations for studying mathematics

Our case study school is a co-educational government high school located in an outer metropolitan area in south-east Queensland. In 2013, the year before our study began, the school had an enrolment of 814 students, with 145 in Years 11/12, and a school ICSEA value of 975. In the previous year, around one-third of Year 12 graduates went to university, while the remaining destinations were evenly divided between TAFE/vocational study and employment. Between 2008 and 2013, enrolments in Mathematics B, the senior secondary intermediate mathematics subject, increased from 28 to 56 without any increase in the total Year 11/12 cohort, while at the same time enrolments in Mathematics C, the advanced subject, increased from 7 to 12. This school had recorded one of the highest percentage increases in enrolments in intermediate mathematics of any government school in south-east Queensland, and it also had one of the highest percentages of its senior secondary cohort taking this subject.

Our preliminary analysis of interviews with teachers, students, and a guidance counsellor suggests that there are both whole-school factors and mathematics classroom factors influencing students' decisions to persist with higher-level mathematics beyond Year 10.

Whole-school factors that seem to matter are: (1) pastoral care and subject selection guidance with a strong focus on building awareness of personal strengths, connecting mathematics to post-school goals, and encouraging aspirational subject choices; and (2) early identification of mathematical capability and flexible placement of students in class groups that extend their capabilities. The school used Year 7 NAPLAN results[1] initially to place students in different Year 8 mathematics classes, including an 'extension' class, and modified these class groupings in subsequent years based on school assessment and Year 9 NAPLAN results. The mathematics Head of Department expected that students in the extension classes would proceed to enrol in intermediate and perhaps advanced mathematics in Year 11. However, there was some evidence that student behaviour, rather than mathematics capability, was a determining factor in class allocation. One student who was enrolled in Year 11 intermediate mathematics recounted how he had been placed in 'the lowest maths class' in Years 8–10, even though he obtained the highest possible NAPLAN result in Year 7. According to this student, 'I was so far ahead of everyone else, that it was just – I had nothing else to do, so I would play games and muck around with my mates.' Despite earning grades of A for mathematics achievement, his D grades for effort ensured that he remained in the regular mathematics classes instead of the extension class, until the Head of Department intervened: 'It took four years to realise that I was actually pretty good at maths, until they finally moved me up. I don't know what happened there', the student says.

Classroom factors also matter, with students in junior mathematics extension classes commenting on their preference for open-ended investigation tasks that challenged their thinking, and a 'loose/active' lesson structure that allows them to 'roam around the room and get help from other people or work together on things'. Their teacher encourages both independence and communal accountability by asking students to 'use all the lifelines' – their own thinking, their partner, their group – before asking her for help.

The mathematics Head of Department reported that in all classes, the emphasis is on success, enjoyment, challenge and awareness of the value of mathematics in enhancing post-school choices. Vocational education has a high profile in this school, but the great majority of students on this pathway take one of the pre-tertiary mathematics subjects instead of pre-vocational mathematics, because they have enjoyed the experience of mathematical challenge and success. Thus the approach taken by this school seems to build mathematical aspirations in all students, not only those who intend to go to university.

Research on enhancing mathematical literacy

Australian students' performance in the Programme for International Student Assessment (PISA) of mathematical literacy has declined since 2003, and there are persistent equity gaps in the performance of students from disadvantaged groups (Thomson, De Bortoli & Buckley, 2013). In Australia it is more common to refer to mathematical literacy as *numeracy*,

1 Year 7 was the final year of primary school in Queensland at the time of this study.

and numeracy is identified as a general capability that must be developed across all subjects in the Australian Curriculum. Being numerate involves more than mastering basic mathematics, because numeracy connects the mathematics learned at school with out-of-school situations that additionally require problem solving, critical judgement, and making sense of the non-mathematical context.

Numeracy can be addressed across the curriculum by attending to numeracy demands and opportunities as they emerge when teaching subjects other than mathematics. This does not mean that teachers in other subjects should be required to be expert teachers of mathematics. It does mean that teachers need to be familiar with the inherent numeracy demands of their subject, be able to recognise a numeracy opportunity when it arises, and have the disposition and pedagogical skill to take advantage of such opportunities. These have been the goals of a long-term research program that has enhanced numeracy teaching across a range of school subjects, including mathematics, history, science, English, health and physical education, and studies of society and environment (Cooper et al., 2012; Gibbs et al., 2012; Goos, Geiger & Dole, 2014; Peters et al., 2012; Willis et al., 2012). This program was based on a multi-faceted model of numeracy that represents a synthesis of research related to effective numeracy practice. The model incorporates the dimensions of *mathematical knowledge*, *contexts, dispositions* and *tools*, embedded in a *critical orientation* to using mathematics (see Table 1).

Effective practices: Promoting numeracy across the curriculum

The numeracy model has been used to identify the numeracy demands of non-mathematics subjects in the Australian Curriculum, investigate teachers' understanding of numeracy, and analyse teachers' capacity to recognise and take advantage of numeracy opportunities in the subjects they teach. This work has culminated in development of a set of online resources for teachers comprising six videos: four illustrating how teachers are embedding numeracy in the subjects they teach, one showing teachers discussing how they established a numeracy committee within their school, and one in the form of a PowerPoint presentation with voiceover that explains the numeracy model. Each video is accompanied by discussion questions that are designed to engage the viewer with the numeracy model (for example) as the underlying design for a lesson.

The video resources were developed for the Queensland College of Teachers and are available on the QCT ClassMovies website (http://www.classmoviestv.com/qctuq).

Mathematical knowledge	Mathematical concepts and skills; problem-solving strategies; estimation capacities
Contexts	Capacity to use mathematical knowledge in a range of contexts, both within schools and beyond school settings
Dispositions	Confidence and willingness to use mathematical approaches to engage with life-related tasks; preparedness to make flexible and adaptive use of mathematical knowledge
Tools	Use of material (models, measuring instruments), representational (symbol systems, graphs, maps, diagrams, drawings, tables) and digital (computers, software, calculators, internet) tools to mediate and shape thinking
Critical orientation	Use of mathematical information to: make decisions and judgements; add support to arguments; challenge an argument or position

Table 1 Elements of the numeracy model

Improving Australia's mathematical vitality: What will it take?

This brief research summary has focused on only two of the many issues that need to be addressed in order to improve Australia's mathematical vitality. The first, raising students' aspirations for studying higher-level mathematics at secondary school, recognises the significance of the mathematical sciences for the nation's future economic growth (Commonwealth of Australia, 2015). The second, enhancing the mathematical literacy of all students, acknowledges the social burden of poor numeracy in limiting young people's life chances (Parsons & Bynner, 2005). While mathematics teachers have an important role to play in encouraging aspirational mathematics subject choices, teachers of all subjects are responsible for developing their students' subject-specific numeracies. The evidence from the snapshots of practice presented here suggests that at least part of 'what it takes' to improve young people's mathematical futures is a whole-school approach to understanding and operationalising the ways in which mathematics enhances learning in other disciplines as well as post-school study and career options.

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Conference papers

Tuesday 9 August

Addressing the STEM challenge through targeted teaching: What's the evidence?

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Dianne Siemon is a Professor of Education in the School of Education at RMIT University (Bundoora). Di is actively involved in the professional development of practicing teachers, particularly in relation to the development of the 'big ideas' in numbers, the teaching and learning of mathematics in the middle years, and the use of rich assessment tasks to inform teaching. She has worked extensively with state and territory Departments of Education to support numeracy coaching initiatives and develop commissioned materials such as the Assessment for Common Misunderstandings. Di has directed a number of large-scale research projects and is currently directing the Reframing Mathematical Futures project that involves 32 secondary schools nationally. Di was a member of the Expert Numeracy Panel for the Australian Mathematics Curriculum and is a member of the Victorian Expert Numeracy Panel. She is a past President of the Australian Association of Mathematics Teachers and a life member of the Mathematical Association of Victoria

Abstract

Numerous public reports are pointing to the critical importance of STEM (science, technology, engineering and mathematics) to Australia's future, but the number of students studying STEM subjects in senior years is declining, and many students in the primary and middle years of schooling do not have access to the ways of thinking and learning needed to succeed in school mathematics. Research over the past 10 years has established the critical role of multiplicative thinking in building student knowledge and confidence at this level of schooling, but there is a need for an expanded, evidence-based learning and teaching framework to support the development of mathematical reasoning more generally, if students are to have a realistic chance of actively participating in a STEM future.

This session will report on the findings and experience of an Australian Maths and Science Partnerships Programme (AMSPP) Priority Project in 2013 that explored the efficacy of formative assessment and targeted teaching in relation to multiplicative thinking in a number of secondary schools around Australia. It will also introduce the work of the Reframing Mathematical Futures II AMSPP project, which is aimed at building sustainable, evidence-based, integrated learning and teaching resources to support the development of mathematical reasoning in Years 7 to 10 in relation to algebra, geometry, statistics and probability.

Understanding the challenge: The role of multiplicative thinking

There are many reasons why Australian students choose not to pursue STEM-related studies in the senior secondary years, but a major contributing factor is the seven- to eight-year range in students' access to multiplicative thinking in the middle years of schooling, which is needed to solve more difficult problems involving rational numbers and proportional reasoning (Siemon, Breed, Dole, Izard & Virgona, 2006; Siemon, 2013a).

Multiplicative thinking involves recognising and working with relationships between quantities. Although some aspects of multiplicative thinking are available to young children, multiplicative thinking is substantially more complex than additive thinking and may take many years to achieve (Vergnaud, 1988; Lamon, 2007). This is because multiplicative thinking is concerned with processes such as replicating, shrinking, enlarging, and exponentiating, which are fundamentally more complex than the more obvious processes of aggregation and disaggregation associated with additive thinking and the use of whole numbers.

For the purposes of the Scaffolding Numeracy in the Middle Years Linkage Project (SNMY, 2003–2006), multiplicative thinking was viewed in terms of:

- a capacity to work flexibly and efficiently with an extended range of numbers (for example, larger whole numbers, decimals, common fractions, ratio, and per cent)
- an ability to recognise and solve a range of problems involving multiplication or division, including direct and indirect proportion
- the means to represent and communicate this effectively in a variety of ways (for example, words, diagrams, symbolic expressions, and written algorithms).

In short, multiplicative thinking is indicated by a capacity to work flexibly with the concepts, strategies and representations of multiplication (and division) as they occur in a wide range of contexts (Siemon, Breed & Virgona, 2005).

Project outcomes[1] included an evidence-based Learning and Assessment Framework for Multiplicative Thinking (LAF), two formative assessment options, and teaching advice specific to the eight developmental zones identified in the LAF. Medium to large effect sizes (in the range of 0.45 to 0.75 or more), as described by Cohen (1969), were found in research schools, compared to small to medium effect sizes (in the range of 0.2 to 0.5) found in the reference schools, suggesting that teaching that is targeted to identified student learning needs was effective in improving students' multiplicative thinking. Breed's (2011) 18-week intervention, conducted as part of the SNMY project, involved nine Year 6 students identified in Zone 1 of the LAF. When re-assessed three months after the intervention, all nine students shifted at least 4 zones, with the majority shifting five zones to be age- and grade-appropriate.

1 See: 'Scaffolding numeracy in the middle years', http://www.education.vic.gov.au/school/teachers/teachingresources/discipline/maths/assessment/Pages/scaffoldnum.aspx

Targeted teaching

Conceptualised originally as assessment-guided instruction, this came to be referred to as *targeted teaching* in the latter part of the SNMY project (Siemon, Breed, Dole, Izard & Virgona, 2006). The value of using assessment data to inform and improve teaching, generally referred to as formative assessment, is widely recognised (for example, Ball, 1993; Black & Wiliam, 1998; Callingham & Griffin, 2000; Clark, 2001). However, it was felt that a different term was needed to distinguish the long-term, multi-faceted nature of the interventions needed to scaffold students' multiplicative thinking from the equally valid but short-term or spontaneous teaching decisions that might be informed by a pre-test on subtraction or an informal observation of student thinking in the course of a classroom discussion. Targeted teaching is characterised by an unrelenting focus on big ideas, where a 'big idea' for this purpose is an idea, strategy, or way of thinking about some key aspect of mathematics, without which students' progress in mathematics will be seriously impacted, that encompasses and connects many other ideas and strategies, and provides an organising structure or a frame of reference that supports further learning and generalisations. A big idea may not be clearly defined, but it can be observed in activity (Siemon, 2006).

Targeted teaching requires:

- assessment tools/techniques that expose students' thinking and provide valid and reliable information about where students are 'at' in relation to an important big idea
- a grounded knowledge of underlying learning progressions, key steps in the development and application of big ideas and how to scaffold these
- an interpretation of what different student responses might mean, and some practical ideas to address and progress student learning
- an expanded repertoire of teaching approaches that accommodate and nurture discourse, help uncover and explore students' ideas in constructive ways, and ensure all students can participate in and contribute to the enterprise

- sufficient time with students to develop trust and supportive relationships
- flexibility to spend time with the students who need it most.

Importantly, targeted teaching is not a prescribed process; schools and teachers need to appropriate it to their circumstances and capabilities. Our experience to-date has shown this to be a very organic process that is not in any way equivalent to systematic streaming/ tracking. It is best used where it has evolved over time with the support of key individuals and the leadership group. An example of this, Blue Sky College, is included in the recent Grattan report on targeted teaching (Goss, Hunter, Romanes & Parsonage, 2015).

Since 2006, the SNMY assessment options and teaching advice have been used in a range of coaching and professional learning activities in Victoria, South Australia, Tasmania and Queensland. However, while their use to support a targeted teaching approach has been generally successful in the upper years of primary school, their use in secondary schools has not been as widespread. Funding was obtained from the Australian Maths and Science Partnerships Programme (AMSPP) Priority Project round to explore the efficacy of and the issues involved in implementing a targeted teaching approach in secondary schools using the SNMY materials. Twenty-eight schools located in lower-socio-economic settings in the Northern Territory, Queensland, South Australia, Tasmania and Victoria participated in the 10-month study. Nominated 'specialists' in each school were provided with professional learning, and supported to work with at least two other teachers at their school to implement a targeted teaching approach to multiplicative thinking. The SNMY assessments were conducted in August and November of 2013. Matched data sets were obtained from 1732 students from Years 7 to 10, with the majority (59 per cent) from Year 8. Although the results varied considerably between schools, the overall achievement of students across the 28 schools grew above an adjusted effect size of 0.6, indicating a medium influence beyond what might be expected (Hattie, 2012). This can be seen in the shift in the relative proportions in each zone of the LAF from August to November, shown in Figure 1.

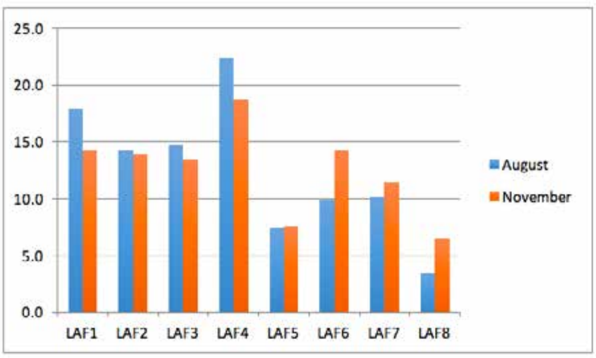

Figure 1 Proportion of students by LAF Zone in August and November 2013 (n=1732)

Mathematical reasoning

Mathematical reasoning – spatial reasoning in particular – is known to be associated with those engaging in STEM studies and STEM careers (Wai, Lubinski & Benbow, 2009). Described generally in the Australian Curriculum: Mathematics as a 'capacity for logical thought and actions', mathematical reasoning has a lot in common with mathematical problem-solving, but it also relates to students' capacity to see beyond the particular to generalise and represent structural relationships, which are key aspects of further study in mathematics and, thereby, STEM options.

Choosing and/or developing targeted interventions is difficult for teachers at all levels, but it is particularly challenging for those teaching out-of-field in the middle years who are faced with a seven- to eight-year range in student mathematics achievement. An integrated, research-based learning and teaching framework for mathematical reasoning is needed to inform a deeper, more connected approach to teaching all aspects of mathematics in Years 7 to 10. The framework needs to extend and add value to the LAF, recognise and build on what learners already know, and equip teachers with the knowledge, confidence and disposition to go beyond narrow, lock-step, skill-based, topic-focused approaches to teaching mathematics in the middle years.

Reframing Mathematical Futures (RMFII) is a three-and-a-half-year AMSPP Competitive Grant project that extends the Priority Project partnerships to include the Departments of Education in New South Wales and Western Australia and the Australian Association of Mathematics Teachers (AAMT). The aim of the project is to develop, trial and evaluate a learning and teaching resource to support algebraic, statistical and spatial reasoning in Years 7 to 10 that will enable teachers to identify and respond to student learning needs using a targeted teaching approach aimed at improving students' mathematical reasoning. For this purpose, mathematical reasoning is seen to encompass:

- core knowledge needed to recognise, interpret, represent and analyse algebraic, spatial, statistical and probabilistic situations and the relationships/ connections between them
- an ability to apply that knowledge in unfamiliar situations to solve problems, generate and test conjectures, make and defend generalisations
- a capacity to communicate reasoning and solution strategies in multiple ways (that is, diagrammatically, symbolically, orally and in writing) (Siemon, 2013a, 2013b).

This is a non-trivial exercise that might be described as a Learning Assessment System (Masters, 2013). It requires the identification of Draft Learning Progressions (DLPs) for algebraic, spatial and statistical reasoning from existing research, the development and validation of rich tasks to assess and refine the DLPs using item response theory (for example, Bond & Fox, 2007), the preparation of targeted teaching advice, and the development and trial of a series of online professional learning modules. While there are elements to build on – for example, the LAF and Callingham and Watson's (2003, 2005) statistical literacy scales – this is a genuinely innovative endeavour that is reflected in the expertise of the research team, which, in addition to Rosemary Callingham and Jane Watson, includes Lorraine Day, Marj Horne, Rebecca Seah, Max Stephens, Bruce White and Tasos Barkatsas. Will Morony and Kate Manuel from AAMT are also members of the team. They are working with us and four other AMSPP projects to develop project materials for inclusion on a web-based professional learning portal.

The results of the SNMY project, the AMSPP Pilot Project and the preliminary analysis of the first phase of the RMFII project provides convincing evidence that targeted teaching works to improve student learning and engagement and teacher knowledge and confidence. We look forward to being able to report on progress in future forums.

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Coding in the curriculum: Fad or foundational?

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Introduction

There has been an explosion in mobile devices over the past decade, with the associated issue of developing the skilled workforce needed to write the apps that run on the devices. This has been a significant factor in highlighting what is taught in schools – STEM education in particular. For schools, technology – the 'T' in STEM – is primarily digital technology.

This paper concerns what should be taught in digital technology, and specifically the role of computer coding. We take it for granted that computers are now essential in schools, and students need basic computer literacy skills. Pleasingly, basic computer literacy is a separate curriculum item from digital technology, and is not the subject of this paper. Note that naming the discipline underlying digital technology has been challenging. Computer science, informatics and computational thinking have all been suggested and used, with advocates and detractors for each name.

Computer scientists prefer the term computational thinking, a position advocated 10 years ago by Jeanette Wing (2006), with wide adoption. According to Wing, 'computational thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science.' Much material has been developed to teach computational thinking, with Computer Science Unplugged (Bell et al., 2015) an influential and representative resource.

Abstract

There has been an unprecedented push to revitalise interest in STEM education. Much of the discussion of the 'T' in STEM education has centred around whether coding should be a central element of school education. This paper investigates arguments for and against 'coding in the curriculum'. No sensible person thinks that teaching coding in the classroom will produce master programmers, any more than teaching music in the school curriculum will produce master musicians. However, the teaching of music can encourage some students to become musicians, and the same would be true for coding. The issue is more what concepts are addressed in teaching coding, and how essential they are for engendering an understanding of the digital world around us, and improving productivity and innovation, for which ICT skills and capability are essential.

Grover and Pea (2013) provide a systematic review of progress in implementing computational thinking in the curriculum for the six years immediately following Wing's influential position paper; they note the Committee for the Workshops on Computational Thinking run by the National Research Council (NRC) in the United States of America, with associated reports (NRC, 2011). Grover and Pea take an educational research perspective and are largely positive.

Where should computational thinking be placed in the curriculum, and what topics, if any, should it displace? My personal belief is that computer science is the new applied mathematics. Just as mathematics applied itself to the physical world, explaining mechanics and electro-magnetism, we are currently applying mathematics to understanding data, information and knowledge. Thus, computational thinking has a role in mathematics curriculum, and also in a science curriculum where insights provided by data add to our scientific knowledge. Indeed, software is essential to many physical devices like telescopes and microscopes, and should be explained as such to students. If students work in advanced scientific fields, they will be interpreting the results of programs and they need to understand how computers operate. Admittedly, there is a lack of agreement on whether computational thinking should ultimately be incorporated into education as a general subject, a discipline-specific topic, or a multidisciplinary topic (NRC, 2011).

Teaching computer programming in schools

Rather than focus on computational thinking in this paper, however, I want to discuss the more contentious issue of teaching computer programming in schools. As discussed in Webb et al. (2016):

> The distinction between computational thinking and programming is subtle; in principle computational thinking does not require programming at all, although in practice, representing a solution to a problem as a program provides a perfect way to evaluate the solution, as the computer will execute the instructions to the letter, forcing the student to refine their solution so that it is very precise.

The phrase 'coding in the curriculum' seems to be the current preferred option to programming, presumably partly because it is catchy. Note that much of the discussion seems to be happening in social media and blogs rather than the academic literature.

A case for students learning coding is well-made by Professor Mitchel Resnick from MIT's Media Lab in his 2012 TED talk (Resnick, 2012). Resnick is the designer of Scratch (Resnick et al., 2009), the leading language for teaching coding to primary students, which is also used for teaching secondary students. Scratch is a fun and engaging collaborative environment that has been popular and successful. Resnick's argument centres on the positive design skills that students gain from undertaking a project with Scratch.

What are the benefits of teaching children to code from an early age? In my opinion, what is important is twofold: the thinking engendered by coding, and an appreciation of what computers can and cannot do, laying the groundwork for what they may do in the future. A typical argument in social media is contained in a blog post (Tufts, 2016) that lists seven benefits. The benefits fall loosely into three groups: teaching children general problem-solving and design skills – essentially the arguments for computational thinking; introducing the students to the environments they will be using in the future; and encouraging more students to take up careers in coding, with benefit to society and the workforce.

There is merit in students having positive experiences with environments they are likely to meet later in life. Scratch and other environments have communities within them that encourage and enable code sharing, cooperating and mentoring. Many children have tablets and other technology, and experience with coding brings the home and the classroom closer together. However, experience with the tablet environment is essentially an argument for digital literacy.

The argument on teaching coding because society needs more professional coders is a stretch. We teach music and sport in schools because of the inherent value in music and sport rather than because we need more professional musicians and sportspeople. Incidentally, programmers are often the sharpest critics of teaching coding, as they think it detracts from the coding profession. One coding class at school does not make a professional programmer. However, it can identify talent and interest.

Pedagogy and positive outcomes

I would like to address several potential objections to placing coding in the curriculum. The first argument is that teaching coding does not come from an adequate pedagogical basis. In my opinion, the pedagogy is under control. There is consensus that Scratch works well. Concepts underlying Scratch are drawn from a tradition of research dating back to Seymour Papert in the 1960s, 1970s and 1980s. The key features of using a block-based programming language, avoiding children having to worry about minor syntax issues, being able to rapidly see the results of executing programs, and being able to draw on a rich library of multimedia are all significant.

And Scratch is not the only option. In recent years, there has been an increase in the number of programming environments that are freely available for use by novice programmers, particularly children and young people (Good, 2011). There is much training material of high quality, including Codecademy (https://www.codecademy.com); Code Club in the UK and Australia (https://www.codeclub.org.uk and http://www.codeclubau.org) and elsewhere; Code.org (http://code.org); and commercial providers such as Tynker(https://www.tynker.com), to name a few. To some extent, market forces have ensured suitable pedagogy.

The second argument is that there is no evidence base establishing that coding is beneficial. That is not correct, but the evidence is primarily anecdotal, rather than from random experimental trials. A typical effort to introduce programming to primary schoolchildren, using Scratch, is described in Wilson and Moffat (2010). From the abstract:

> [W]e used Scratch to teach some elementary programming to young children (eight years old) in their ICT class, for eight lessons in all. Data were recorded to measure any cognitive progress of the pupils, and any affective impact that the lessons had on them. The children were soon able to write elementary programs, and moreover evidently had a lot of fun doing so. An interview with their teacher showed that some of the pupils did surprisingly well, beyond all expectations.

As Wilson and Moffat comment:

> While the cognitive progress is moderate, the main advantage to Scratch in this study seems to be that its enjoyability makes learning how to program a positive experience, contrary to the frustration and anxiety that so often seems to characterise the usual learning experience.

While a rigorous trial is preferable to anecdotal evidence, the difficulties of running a rigorous experiment should be acknowledged. It is difficult to justify running control groups where some students gain the benefit of learning coding and others do not. It is hard to have comparable teaching. The passion and skills of the teacher are currently influential on how successful classes are in teaching coding. As languages are rapidly evolving, it is not clear what standards should be used for evaluating trials of technology. There should be active discussions about what the evidence should be. There are active discussions about assessment, as noted by Grover and Pea (2013) and others.

The next potential objection is that the push for coding is primarily about vested interests. Indeed, vested interests influenced the push for computers in the classroom. Negative experiences in introducing computers in the classroom might deter some people from trying to teach coding. Large multinational companies like to lock schools into their particular products. However, advocating for teaching coding in the curriculum is different to advocating for computers in the classroom. The drivers for coding are public interest groups as well as vendors, and there are quality resources that are free and open-source. Nonetheless, there is considerable scope for research on distinguishing between claims of competing products and environments for teaching coding.

It is significant that there is much collaboration happening between academic interests and industry. For example, two initiatives aimed at introducing computing into schools, CS4HS (http://www.cs4hs.com) and the Code.org Advocacy Coalition, represent collaboration between academia, national bodies, and industry leaders such as Microsoft and Google. The Computer Science Teachers Association's Model Curriculum for K–12 Computer Science, supported by the Association for Computing Machinery (the largest computing professional association) provides suggestions to help engage and motivate students (https://csta.acm.org/Curriculum/sub/CurrResources.html). Google's Exploring Computational Thinking website (http://www.google.com/edu/computational-thinking) has a wealth of links to web resources.

Another complaint is that current popular Scratch-like environments for students are too limited to learn the important concepts in programming. That concern is being addressed. Snap! (http://snap.berkeley.edu) is a well-designed extension which is used in Algorithmics, the Victorian VCE subject. Other environments facilitate transition from a block-based language to the text-based syntax used in industry. For example, Code.org facilitates transition from a Scratch-like block-based language to the JavaScript language.

Coding in the curriculum

Let us reconsider the place of coding in the curriculum. Is there a compelling rationale for all children, including those who allege no interest in pursuing STEM careers, to learn coding in school? Space can be made in the curriculum by connecting coding to mathematics and science lessons. Computing examples and well-designed exercises can highlight the relevance of maths and science. Recognising faces, translation between languages, and searching in large collections can all be explained in terms of data, and provide practical and interesting experiences for using coding and scientific methods. Computing projects can easily be structured to give students experience with important generic skills such as persistence, collaboration and communication. Overall, I believe that coding is foundational.

What about year level? The Australian curriculum for digital technology sets objectives for each year level from

K–10. The approach is ambitious, but well structured. Coding should be a key component of meeting the digital technology curriculum objectives.

There has been some discussion that learning a computer language is like learning a foreign language. Indeed, earlier this year, a bill was approved in the Florida senate allowing high school students to take computer coding classes in place of foreign language requirements. That is not a position I support. Supporting science and mathematics is a better place for coding in the school curriculum than replacing the teaching of second languages. Using language is about communicating with people and recognising the culture from which the language emanates. Communication between people is fundamentally different from communicating between human and computer.

Worldwide there is momentum behind teaching coding. Many countries are experimenting with including coding in the school curriculum. Last year, the Australian Labor Party issued a platform entitled 'Coding in Every Australian School'. Webb et al. (2016) discuss vignettes from five countries: the United Kingdom, New Zealand, Australia, Israel, and Poland, where programming is in the curriculum. Much can be learned from these experiences.

One concern is that teachers may not have the skills to teach computer coding correctly. Resources are being prepared. In May, the Australian Department of Education awarded a project after a tender for National Computing Challenges for Year 5 & 7 and Cracking the Code, which are helping with teacher and student resources.

Competitions are growing. The ACER Australian STEM Video Game Challenge (https://www.stemgames.org.au) introduced in 2014 has had excellent uptake. Learning to code games is fun and exciting, and can spark interest in digital technology.

Summary

In summary, what have we learned so far about teaching coding in the curriculum? Plenty of experimentation is happening. Projects introducing coding through Scratch or similar positive environments are largely successful. Teaching computing can be made to be engaging, though perhaps not to everybody. Being able to see the results of executing the code immediately is essential. Curriculum material is being developed. The lack of resources for teachers is being addressed, though there is a challenge to produce resources in time. Note that the block-based languages are more accessible to teachers, just as they are for students, such that many more teachers are able to create or modify resources.

My personal opinion is that coding should be taught in all schools. While it is not necessary nor realistic that all students become coders, it is important that they appreciate what computers do and how they do it. The best way I know of conveying the understanding is by having students code. Some students struggle to learn to code. However, without attempting to code, something essential is missing.

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Targeting all of STEM in the primary school: Engineering design as a foundational process

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Abstract

With the increased national and international focus on advancing STEM education, it is important to ensure all of its disciplines are represented in the curriculum. To-date, the STEM acronym has been used largely in reference to science, with less emphasis on the remaining disciplines – especially engineering. Yet engineering design, a core component of engineering education, is now seen internationally as a foundational process linking the STEM disciplines, not just confined to engineering. Engineering concepts, design processes, representing, modelling, and innovative design-based problem-solving are all featured within the new Design and Technologies Curriculum. This paper will explore the nature and roles of these engineering components and discuss ways in which they might be integrated within primary school students' STEM learning. The paper will include findings from STEM-based problem-solving research with a focus on engineering learning.

Introduction

Promoting STEM education across the school years is a core goal of many nations (for example, Lucas, Claxton & Hanson, 2014; National Research Council, 2014; Office of the Chief Scientist, 2014; Office of the US President, 2013). 'Inspiring STEM literacy' is one of the pillars of Australia's recently released National Innovation and Science Agenda (7 Dec., 2015: http://www.innovation.gov.au/page/inspiring-nation-scientists), yet despite this increased focus on STEM education, not all of the disciplines are receiving equitable recognition.

One aspect that remains in need of greater attention is the relative lack of inclusion of engineering experiences in STEM curricula, especially in the primary grades, despite the contributions of engineering having been well documented. For example, the literature has indicated how engineering-based experiences can develop young students' appreciation and understanding of the roles of engineering in shaping our world, and how engineering can contextualise mathematics and science principles to improve achievement, motivation, and problem-solving (for example, English, 2016; Stohlmann, Moore & Roehrig, 2012). In particular, engineering design and thinking are not being capitalised on in school curricula, especially at the primary level, yet they are recognised as major components of engineering education across the school years, as well as being foundational processes for all citizens (for example, Next Generation Science Standards, 2014).

Engineering design and thinking

Engineering design is commonly described as comprising iterative processes involving (a) defining problems by specifying criteria and constraints for acceptable solutions, (b) generating a number of possible solutions and evaluating these to determine which ones best meet the given problem criteria and constraints, and (c) optimising the solution by systematically testing and refining, including overriding less significant features for the more important. Underpinning this design is engineering thinking or 'habits of mind', which includes systems thinking, innovative problem finding and solving, visualising, and collaborating and communicating (English & Gainsburg, 2016; Lucas et al., 2014).

Although traditional views have generally considered engineering design and thinking to be too complex to teach and learn, particularly for younger learners, recent research has revealed learners' capacity to undertake basic design work such as imagining, planning, constructing, and evaluating (for example, Dorie, Cardella & Svarovsky, 2014; Lachapelle & Cunningham, 2014). Young students' propensity for applying multiple ideas and approaches to innovative and creative problem-solving provides a rich foundation for fostering early design-based problem-solving (Lachapelle & Cunningham, 2014).

Integrating engineering design within the Australian Curriculum

Opportunities for integrating engineering design and thinking across STEM content areas appear in the new Australian Curriculum: Design and Technologies (version 8.1), beginning with the earliest grades, where it is recommended that young students 'experience designing and producing products' (p. 58). Given our increasingly technological and complex world, the Curriculum highlights the importance of students developing the knowledge and confidence to critically analyse and creatively respond to design challenges.

The integrative potential of engineering is evident in its definition in the Curriculum, namely '[t]he practical application of scientific and mathematical understanding and principles as part of the process of developing and maintaining solutions for an identified need or opportunity' (p. 22). Although much has been written on STEM integration (for example, English, 2016; Moore & Smith, 2014), the nature of such learning experiences and how these might be integrated within the curriculum remain open to debate. In the remainder of this paper, I address one example from a recent longitudinal study in which my colleagues and I implemented design-based engineering problems across grades 4–6 in multiple schools, including state and non-state. This study, as well as a prior three-year study in the middle/early secondary years, was supported by Linkage grants from the Australian Research Council. Strong support has also been received from the Queensland Department of Transport and Main Roads.

Underpinning each of the problems implemented throughout the study was students' appreciation and independent application of engineering design processes. Drawing on their learning in mathematics, science and technology, students were encouraged to apply their own ideas and approaches to designing and creating solutions. One of our goals was for the students to appreciate how their learning in these disciplines applies to solving problems in the outside world. We planned the learning experiences in consultation with the teachers, building on their existing curriculum programs. The teachers implemented each of the problem activities, and participated in regular briefing and debriefing meetings before and after each implementation.

Earthquake engineering problem

Multiple sixth-grade classes participated in the Earthquake Engineering problem, which was the seventh of eight comprehensive, multi-session problem activities implemented across the three years. Applying their preliminary learning about earthquakes, students designed and constructed a building that could withstand earthquake damage. Students applied engineering design processes and thinking to build their structures (using toothpicks and plasticine), which they subsequently tested using a shaker table to simulate an earthquake (the table comprised a platform and tab that when pulled simulated an earthquake measuring 4 or 8 on the Richter scale). The problem was presented within an AusAid context and included the problem description together with the materials to be used and their costs, as well as constraints to be met in designing their building (namely, at least two toothpicks high; must contain at least one triangle and one square; must contain cross-bracing to reinforce the structure; materials may be cut to size; and budget not to exceed $40).

The first part of the activity included earthquake video clips, together with hands-on activities where students explored techniques that make buildings earthquake-proof, including cross-bracing, tapered geometry, and base isolation. Understanding the properties of shapes and how combining shapes yields new properties (for example, increased strength) and relationships was also an important learning goal. In completing the second part, the students designed and built their first structure, and then discussed possible changes to their initial design to more effectively earthquake-proof their structures.

Students worked the problem in small groups, completing their responses in individual workbooks where they drew their initial designs and redesigns, and also answered a number of questions (for example, 'How will you make it [the building] strong?' 'What can you change to improve your design?' 'How will these changes make your structure better?') Data analysis drew upon the students' workbook responses, their initial and improved designs and constructions, and transcripts of student group and whole-class discussions.

Applying design processes

In analysing the group transcripts, the use of design processes became evident as students identified the problem goal and constraints, debated ideas on their designs and subsequent constructions, sketched and interpreted their designs, transformed their designs into their constructions, tested their first structure, and redesigned and tested their second. The application of STEM concepts was also evident in, and essential to, their solutions.

As an example, I briefly report on Catherine's group (Catherine is a pseudonym). Catherine's group engaged in substantial debate throughout their design, while keeping in mind the problem goal and constraints, in particular their budget limit. In designing their first structure, the group noted that the placement of cross-bracing 'will be important' and decided to cross-brace all sides, bottom and top. They then considered base isolation, commenting that it 'will be the bottom because we will have the square pyramid. And then at the bottom [of the structure] will be the cross-bracing.' Considerable time was spent deciding where the cross-bracing would go, how much material would be used, and the costs involved. Figure 1 presents Catherine's first design sketch, where she labelled the materials and their costs, and indicated where cross-bracing was to be placed.

On testing the group's structure on the shaker table at Richter scale 4, then 8, Catherine recorded in her workbook, '[e]ven though our design was very rigid, the force of the earthquake allowed it to topple over onto its side because it had no base isolation.' The group welcomed a second design opportunity, with Catherine explaining, '[t]he good thing about doing two designs is that you can actually see where the flaws are and you can actually make it better ... because the first time you don't know what the flaws are; you haven't tested it. We do know now ... it needs supporters (pointing to base of structure), but it's very rigid, which is good.' Catherine's enhanced second design appears in Figure 2.

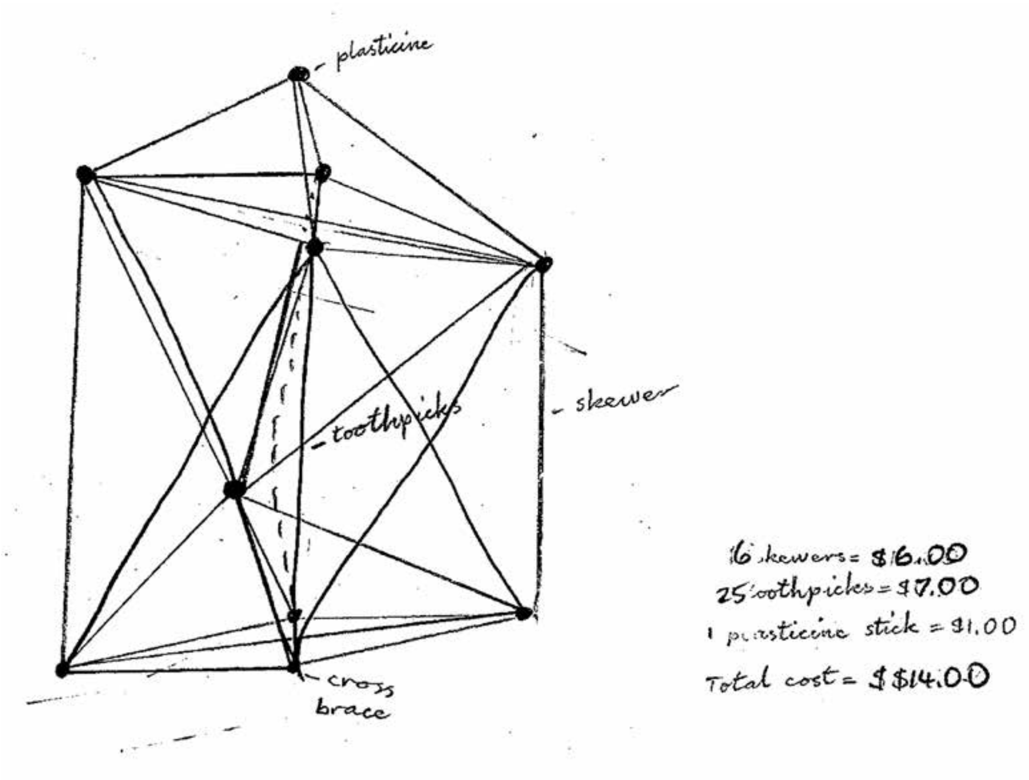

Figure 1 Catherine's first design

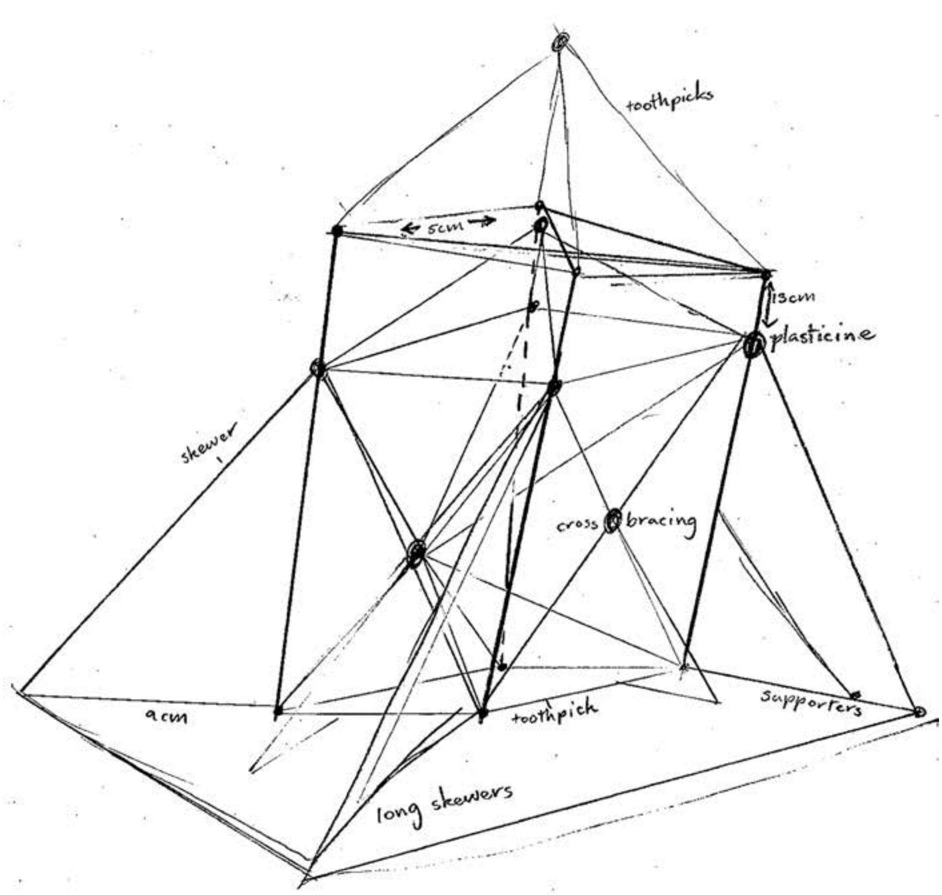

Figure 2 Catherine's second design

Concluding points

Engineering is an ideal field for developing design-based problems that draw not only upon the STEM disciplines, but also other areas, including literacy. Our programs have been enriched through Andrew King's engineering-based story books (2013; 2014; in press). By their very nature, these problems are complex and often ambiguous, and require students to apply both STEM content knowledge as well as engineering design processes and thinking. Furthermore, these engineering experiences incorporate 21st century skills called for by employers (Partnership for 21st Century Skills, 2011).

The engineering education programs we have implemented across several grade levels have revealed young learners' potential for engaging in design-based problem-solving, applying their STEM content knowledge in doing so (for example, English & King, 2015). Although these problem experiences are intended for student groups to solve independently, our research has shown that an appropriate balance is often needed between teacher input of new concepts and students' application of their learning in ways they choose.

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Why is a STEAM curriculum perspective crucial to the 21st century?

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Abstract

Well-recognised as a powerful driver of national economic growth, STEM lies at the heart of calls worldwide for educational reform. In Australia, Chief Scientists are calling for STEM education to better engage students on STEM-related career pathways. In the US, STEM educators are being urged to produce graduates with creative and innovative abilities required of an increasingly high-tech workforce. However, an equally important challenge for STEM education is to prepare young people with general capabilities for active participation in community and professional forums for addressing ethical issues associated with the global impact of science and technology. Education for sustainable development remains a pressing priority. Thus, STEM educators are being challenged to design curricula and pedagogies to develop students' disciplinary knowledge and skills, as well as their abilities as critical consumers, creative and ethically astute citizens, innovative designers, good communicators and collaborative decision-makers. There is an international wellspring of educators endeavouring to meet this challenge by combining STEM and the arts to produce a multi-literate citizenry and workforce for the 21st century. In this presentation I will outline how two secondary schools in Western Australia are developing interdisciplinary STEAM curricula.

In this paper I outline reasons why integrating the arts with science, technology, engineering and mathematics is not just another curriculum fad but an important response to the pressing need to prepare young people with higher-order abilities to deal positively and productively with 21st century global challenges (crises) that are impacting the economy, the natural environment and our diverse cultural heritage.

Australian Curriculum: Science

My starting point is close to home for teachers of science. The Australian Science Curriculum provides an exciting futures perspective on preparing young people with not just disciplinary knowledge and skills, but also essential higher-order abilities for working and living in a rapidly globalising world that is experiencing unprecedented development and disruption.

The Australian Science Curriculum is impressively multi-dimensional. As expected, it directs teachers to engage students in developing a range of important scientific concepts and inquiry skills. It then adds the dimension of *science as a human endeavour*, which opens the door to understanding the nature and limitations of science and to considering the cost to the planet and to humanity of unintended side-effects of science and technology. Although this is a significant advance, it is the next two dimensions of the broader Australian Curriculum that fully open the door to a radically expanded scope for science education to address pressing global issues.

The Australian Curriculum has been designed with a higher purpose in mind. Two overarching dimensions – *general capabilities* and *cross-curriculum priorities* – spur teachers to develop their students as global citizens capable of not only adapting to a rapidly changing world, but also to participating actively in shaping it for the better. Importantly, this includes consideration of the many competing (values-laden) perspectives on what 'better' might mean and how to work towards unity in diversity.

The general capabilities focus on developing a suite of higher-order abilities – *critical and creative thinking*, *personal and social capabilities*, *ethical understanding* and *intercultural understanding* – aimed at preparing future citizens 'to contribute to the creation of a more productive, sustainable and just society' (ACARA, 2016). The cross-curriculum priorities – *sustainability*, *Aboriginal and Torres Strait Islander histories and cultures*, *Asia and Australia's engagement in Asia* – provide compelling contexts for students to understand the worldviews of culturally different others and develop a moral conscience about the impact of their planetary footprint. It is intended that teachers of all learning areas, including science, will build these new curriculum dimensions into their teaching programs.

But the prospect of designing teaching and learning activities to develop students' higher-order abilities can be daunting for science teachers. Understandably, many are likely to focus primarily on teaching the 'tried and true' dimensions of science knowledge and inquiry, perhaps with a modicum of science as a human endeavour added to improve student engagement. This standpoint is reinforced by assessment systems that privilege the science understandings and inquiry skills dimensions of the curriculum, especially for Years 11 and 12.

To these teachers I want to emphasise the importance of embracing the new curriculum dimensions. The importance of doing so arises from two significant drivers: economic and sustainability imperatives.

The technology workforce of the future

Given the rapid emergence of digital technologies, artificial intelligence, DNA mapping, robotics, nanotechnology, 3D printing, biotechnology and the 'internet of things', business and industry leaders are calling for graduates with *liquid skills* that enable them to adapt to a fluid working landscape throughout their lives; to prepare for jobs that currently do not exist, but that will be essential to the nation's economic wellbeing.

Liquid skills include the ability to work with others, verbal communication, creative and critical thinking, active listening and active learning, and a disposition towards lifelong learning. These capabilities are deemed to be more important than high academic achievement for IT workers in the 'fourth industrial revolution' (Infosys, 2016).

Recent national reports on future-proofing Australia's high-tech, digital workforce call for STEM graduates with creative and innovative abilities (Australian Government, 2015; PricewaterhouseCoopers, 2015). Australia's Chief Scientist has called for educational reforms to better engage students in STEM-related career pathways (Office of the Chief Scientist, 2013).

Education for sustainable development

We are now experiencing an unparalleled period in the history of the Earth, an epoch in which we have wrested control over Nature: the *Anthropocene* (Crutzen & Stoermer, 2000). This era has its genesis in the industrial revolution and is characterised by our use of fossil fuels and development of powerful technologies. Alarmingly, our technological superpowers are dangerously altering the natural systems of the planet, including the climate, oceans and soils, resulting in fundamental changes to biological and geological systems. The impact of the Western modern human footprint has become so profound that, for the first time in history, natural ecosystems are at the mercy of human systems.

In the public mind, the clearest evidence of our detrimental impact on the planet is climate change (National Research Council, 2011; IPCC, 2014). Another major impact, one that is not so well embedded in public consciousness (unless one is a regular watcher of NITV), is loss of linguistic, cultural and biological diversity, which together are framed as *biocultural* *diversity*. The importance of the intimate interrelationship between language, culture and the environment has been documented by UNESCO, the World Wide Fund for Nature and Terralingua (Skutnabb-Kanga, Maffi & Harmon, 2003):

> In the language of ecology, the strongest ecosystems are those that are the most diverse. That is, diversity is directly related to stability; variety is important for long-term survival. Our success on this planet has been due to an ability to adapt to different kinds of environment over thousands of years (atmospheric as well as cultural). Such ability is born out of diversity. Thus language and cultural diversity maximises chances of human success and adaptability. [p. 10]

Because we have failed to resolve human-induced global crises during the *United Nations Decade of Education for Sustainable Development 2005–2014*, the UN has established the *2030 Agenda for Sustainable Development* (2015), with 17 Sustainable Development Goals. Goal 4 is Education, which is to promote the wellbeing of self, family, community, nation, and humanity at large, as well as the planet's living systems and other life forms. In setting out the following principles of education for sustainable development, UNESCO (2006) recognises that sustainable development is an ethical challenge as well as a scientific concept. Education for sustainable development (ESD):

- is based on the principles and values that underlie sustainable development
- deals with the wellbeing of all four dimensions of sustainability – environment, society, culture and economy
- uses a variety of pedagogical techniques that promote participatory learning and higher-order thinking skills
- promotes lifelong learning
- is locally relevant and culturally appropriate
- is based on local needs, perceptions and conditions, but acknowledges that fulfilling local needs often has international effects and consequences
- engages formal, non-formal and informal education
- accommodates the evolving nature of the concept of sustainability
- addresses content, taking into account context, global issues and local priorities
- builds civil capacity for community-based decision-making, social tolerance, environmental stewardship, an adaptable workforce, and a good quality of life
- is interdisciplinary. No single discipline can claim ESD for itself; all disciplines can contribute to ESD.

In responding to these principles, a 21st century science education for sustainable development (of the economy, the environment and the social-cultural world) would incorporate values education, citizenship education and global issues, and embrace interdisciplinarity. It is clear that, in addition to developing students' science knowledge and inquiry skills, a socially responsible science education needs to contribute to preparing students as future citizens by developing their higher-order abilities, as required by the Australian Curriculum's general capabilities and cross-curriculum priorities.

STEAM curricula

STEM education has become a nationwide focus of innovation and entrepreneurial funding, as witnessed by industry-sponsored initiatives such as the 21st Century Minds (21CM) Accelerator Program, which aims to prepare children with '21st century skills' for the jobs of the future, including the ability 'to think smart and creatively, solve problems, persist and take risks, have strong digital skills and know how to collaborate effectively' (PricewaterhouseCoopers, 2016).

On the other hand, in the nation's schools, especially at the secondary level, the STEM learning areas are relatively bereft of curriculum resources for teachers to foster students' innovative and creative abilities, despite the requirement to address the Australian Curriculum's general capabilities.

Deloitte's (2015) report on the IT worker of the future argues that creativity is a key priority and that STEM educators need to embrace the arts in order to foster students' creative design and performance, using various media:

> IT leaders should add an 'A' for fine arts to the science, technology, engineering, and math charter – STEAM, not STEM. Designing engaging solutions requires creative talent; creativity is also critical in ideation – helping to create a vision of reimagined work, or to develop disruptive technologies deployed via storyboards, user journeys, wire frames, or persona maps. Some organisations have gone so far as to hire science fiction writers to help imagine and explain moonshot thinking [p. 126].

Elliot Eisner (2008) explains that the arts are concerned with expressiveness, evoking emotion, generating empathic understanding, stimulating imagination that disrupts habits of mind and creates open-mindedness, and eliciting emotional awareness. In sum, the arts enable us to discover our humanity. Such an altruistic goal sits well with education for sustainability.

A succinct account of what the arts have to offer was discussed by arts educators Bucheli, Goldberg and Philips (1991):

> The arts can be, for both students and teachers, forms of expression, communication, creativity, imagination, observation, perception, and thought. They are integral to the development of cognitive skills such as listening,

thinking, problem-solving, matching form to function, and decision making. They inspire discipline and dedication. The arts can also open pathways toward understanding the richness of peoples and cultures that inhabit our world, particularly during this period of global change. The arts can nurture a sense of belonging, or community; they can foster a sense of being apart, or of being an individual. By acknowledging the role of the arts in our lives and in education, we acknowledge what makes individuals whole.

In the 1950s, Snow (1998) argued for a rapprochement of the cultures of science and the arts. Today, there is a wellspring of opinion that combining science and the arts in the form of STEAM education is essential for producing a creative, scientifically literate, and ethically astute citizenry and workforce for the 21st century (Boy, 2013; Edwards, 2010; Feldman, 2015; Piro, 2010). Already, the US, Korea and China have begun producing STEAM curricula for their respective nations (White, 2010). Recognising their limitations in developing students' higher-order abilities, visionary science educators are teaming up with their colleagues in the arts learning areas to design innovative interdisciplinary STEAM curricula and teaching approaches (Root-Bernstein, 2008; Sousa & Pilecki, 2013).

Early research studies on ground-breaking STEAM curricula in the US have demonstrated that learning activities integrating science, technology and the arts successfully engage minority and disadvantaged students, resulting in improved literacy and numeracy competencies (Clark, 2014; Stoelinga, Silk, Reddy & Rahman, 2015). In WA, a science/mathematics teacher in a Big Picture school integrated stories about everyday ethical dilemmas into her Earth Science lessons and demonstrated that at-risk students engaged in ethical decision-making while developing scientific knowledge and inquiry skills (Taylor, Taylor & Chow, 2013).

So, to sum up:

- STEAM education is not in opposition to STEM education; it enriches and expands the scope of STEM education.
- STEAM education is a curriculum philosophy that empowers science teachers to engage in school-based curriculum development.
- STEAM education involves teachers in developing a humanistic vision of 21st century education and their role as professionals.
- STEAM education provides a creative design space for teachers in different learning areas to collaborate in developing integrated curricula.
- STEAM education on a modest scale can be designed and implemented by an individual innovative teacher.
- STEAM educators can draw inspiration from project-based learning programs (for example, Holm, 2011).
- STEAM education engages students in *transformative learning*, which is based on five interconnected ways of knowing: cultural self-knowing, relational knowing, critical knowing, visionary and ethical knowing, knowing in action (for details see Taylor, 2015).

Current STEAM projects

St Lukes Secondary College, Karratha. For the past 3 years, Rebecca Loftus, Head of Science, led an interdisciplinary team of teachers to develop a 7–10 STEAM curriculum. Learning areas represented are: science, drama, religious education, humanities and social sciences (HASS) and English. Rebecca is now enrolled in a PhD at Murdoch University and is investigating the impact of STEAM teaching on student engagement.

Cecil Andrews Senior High School. The State Government of WA awarded Cecil Andrews $4.8 million to build new STEM labs for the school. Under the visionary leadership of the principal, the school has embarked on a 7–10 STEAM curriculum development project. The Fogarty Foundation has awarded Professor Peter Taylor and Associate Professor Peter Wright (Murdoch University) a 3-year grant to support Cecil Andrews' STEAM curriculum project.

Christian Outreach College, Toowoomba. John McMath, Head of Science, is building on his doctoral research into socially responsible science, which investigated ethical dilemma pedagogy (Settelmaier, 2009) for engaging science students in higher-order thinking, and is working with colleagues in other learning areas to plan a STEAM curriculum for the school.

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Activating teachers' creativity and moral purpose in science education

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After completing his degree and PhD at Cambridge University, Martin moved to Oxford University as a Research Fellow in Biological and Medical Sciences at Lincoln College. He left academia to pursue other interests and then returned to Oxford in 2005 as the Deputy Director of the Institute for the Future of the Mind, where he ran the research program on the influence of modern lifestyles and technologies on the minds of the young and the old. Now Martin works with schools and systems across Australia, with DEEWR, to provide some of the evidence base for the National Career Development Strategy, and with UNESCO looking at the future of education in the Asia-Pacific region.

Martin and his family moved to Adelaide in September 2007. His wife Val is a mathematics educator and they have two boys who attend public schools.

Sonia Cooke

Morphett Vale East School R–7, South Australia

Sonia Cooke is Deputy Principal at Morphett Vale East School R–7, a southern Adelaide primary school. Her strong passion for science teaching developed as a result of her observations of increased student engagement in learning during science lessons. Science was a way to 'hook' students into learning and develop them as questioners and observers.

Sonia's work in the area of primary science has seen her in the role of Science Coordinator, Science Facilitator, Project Officer: Primary Maths and Science Strategy, and then as a Primary Australian Curriculum Implementation Officer, working with leaders and teachers on the implementation of the Australian Curriculum. As part of this role, Sonia was responsible for the development of primary science across the state, which included working with Professor Martin Westwell on the development and implementation of the statewide Scientist in Residence program. Sonia has presented at both SASTA and CONASTA annual conferences.

Abstract

Over the past three years, the Scientist in Residence program (a collaboration between the South Australian Department for Education and Child Development, and Flinders University) investigated a model of professional learning in science education that capitalised upon teachers' moral purpose, and drove their creativity. Teachers changed their practice and, in turn, there was a change in the engagement and achievement of the children. The approach described and the resources produced serve to illustrate some of the principles of practice that the teachers drew upon. In particular, starting with the Science as a Human Endeavour strand of the curriculum and using the content of Science Understanding as the vehicle for the development of the scientific thinking were a crucial part of the teachers' success. A shift in teachers' perceptions and practice speaks to the characteristics of the professional learning – making time and space for teachers to achieve a closer match between their classroom practice and their professional identity.

ACARA (n.d.) tells us that the Australian Curriculum 'sets the expectations for what all young Australians should be taught, regardless of where they live in Australia or their background', but it is surprisingly quiet about the purpose of that teaching. Why do we teach the various learning areas and what will be our measures of success? From the platform provided by the Melbourne Declaration (MCEETYA, 2008), in the overview for parents, we are told that:

> The Australian Curriculum is designed to teach students what it takes to be confident and creative individuals and become active and informed citizens ... In the early years, priority is given to literacy and numeracy development as the foundations for further learning. As students make their way through the primary years, they focus more on the knowledge, understanding and skills of all eight learning areas.

Of course, these phrases are vague enough to allow for a range of interpretations, but at one level, the focus on knowledge, understanding and skills seem to be the very definition of an industrial model of education. At a time when, for example, the OECD is supporting education systems to help young people deal with complex, unfamiliar and non-routine situations (Mevarech & Kramarski, 2014), their knowledge, understanding and skills remain necessary but are no longer sufficient.

Challengingly, Laszlo Bock, Senior Vice President of People Operations at Google, highlighted the likely demands of future work in a Google Hangout in which he recently participated (Google Students, 2014):

> The first and most important is what we call general cognitive ability ... intellectual ability, how well people learn, how well they acquire new skills. The second is emergent leadership, characterised not by formal authority but by somebody recognising there's a vacuum or a void and stepping in to fill that leadership vacuum and just as importantly stepping back out of it. The third thing we look for is cultural fit. The idea there is not that we want a monoculture. We don't want everybody to be the same. What we do want is everybody to have a shared sense of curiosity, of conscientiousness, a little bit of humility when it comes to learning and being open to new ideas and that they might be wrong, and that they want to have an impact on the world.

In the context of a world that has these demands of young people, as expressed to some extent in the Melbourne Declaration, it seems there is a widening gap between a curriculum that spells out 'what all young Australians should be taught' and the learning and developmental needs of our children.

The South Australian Department for Education and Child Development (DECD) initiated the Scientist in Residence program to support primary school teachers to reconnect their own professional and moral purpose with the Australian Curriculum: Science. The program ran for several years, and each year's new cohort of teachers was asked to articulate their views on why we teach science at all, the reasons why society invests in science education, and their personal motivations for teaching and, specifically, for teaching science. Without exception, each cohort would have the development of science content knowledge and practical skills as non-negotiable purposes of science education. However, these components were always of relatively low priority. Closer to teachers' moral purpose was the empowerment of young people through, for example, the development of evidence-informed decision-making, future-thinking, creative problem-solving, strategic competence, testing of ideas (from themselves and others), and forming their identity within a changing world, in particular with respect to their use and a potential career that might involve science, technology, engineering and mathematics.

In collaboration with the authors (a scientist and a lead educator from DECD), teachers reinterpreted the Australian Curriculum: Science to find synergies between the documentation and their own moral purpose. As the analyses unfolded, teachers found that the Science Understanding strand of the curriculum contained few connections. However, the Science as a Human Endeavour (SHE) strand either explicitly described some of their reasons for teaching science or was now seen by the teachers as creating an opportunity to express their moral purpose through their teaching. With this viewpoint, the Science Understanding became both content to be understood and a vehicle for the development of the children's development as science learners. That is, in reinterpreting the curriculum in this way, they identified that science education could deliver the intent of the Melbourne Declaration, the empowerment to deal with complex, unfamiliar and non-routine situations as demanded by the OECD, and at the same time be more professionally satisfying. The Science Inquiry Skills had a number of connections to the teachers' moral purpose and, for many, provided the 'glue' that would help bring together the other two strands.

The paradoxical situation in which the teachers universally highly valued the ideas expressed in the SHE strand of the curriculum and yet gave them the least emphasis in their teaching was not lost on them. Some reasons why this may be the case were discussed, including the paucity of quality resources, the influence of earlier curricula and their own science education. The challenge for the rest of the program was to collaborate with other teachers, scientists, and the children themselves to be creative and develop ways to combine authentically all three strands of the Australian Curriculum: Science.

The scientist in residence was used throughout the program in a role that promoted collaboration and disruption, and there was no formal delivery of scientific knowledge to the participants. The group was supported to discuss scientific concepts when a lack of understanding or misunderstanding was identified, and the scientist was able to bring an external academic perspective and knowledge base to these conversations. In addition, the scientist initiated conversations about scientific thinking. For example, the idea of 'misconceptions' was challenged, in that while there are common scientific misunderstandings that clearly exist within the population, they are often appropriate, given the experiences that people have had. Many people still believe that they have five senses because they were told this in primary school, rather than by being asked how many senses they think they might have. Transforming a 'telling' of information to an 'asking' for a suggestion not only promotes more scientific thinking, it is an approach much more in line with learning in a constructivist and conceptual manner. As such discussions progressed, appropriate researchers and others were brought in to add an evidence base to the developing understanding. For example, a science education researcher, Chris Dawson from Adelaide University, was able to help participants draw on recent developments in neuroscience research to see how newly learned scientific concepts do not replace so-called misconceptions but exist at the same time. A key skill for the student, and their scientific thinking, becomes choosing when to use the scientific concept and when to use the everyday concept.

To promote teachers to be creative in their lesson planning and to support them to deal with the challenges created by considering the curriculum in a non-linear way, the team attempted to 'combat entrained thinking' and 'use experiments and games to force people to think outside the familiar' – a recommended response to a 'complicated' situation (Snowden & Boone, 2007). As a thought experiment, participants were presented with a random content descriptor from the Science Understanding strand of the curriculum appropriate for the year level of children they were teaching. For example, a Year 5 descriptor may have been, 'Solids, liquids and gases have different observable properties and behave in different ways.' A group of teachers would discuss how they would normally teach this, perhaps with existing pen and paper resources and/or through a practical investigation. Next, they would be presented with a randomly chosen SHE descriptor, say 'Scientific understandings, discoveries and inventions are used to solve problems that directly affect peoples' lives.' In the thought experiment, teachers were asked to develop children's understanding as described by the SHE descriptor using the Science Understanding descriptor as the vehicle for this development. The silence that followed indicated that 'entrained thinking' was indeed being challenged. In this case, after a short pause for thought, teachers' divergent thinking produced a range of possibilities including (i) undertaking a structured discussion in the form of a Community of Inquiry (see below) to find out to what extent the children knew how the properties of a state of matter might be utilised, (ii) identifying technologies in which the behaviour of a state of matter plays a role, and (iii) presenting students with everyday problems where understanding the properties of the states of matter helps solve such problems. For example, why is this area of my garden always flooding during rainstorms? What difference does the air pressure in my tyres make when I am riding my bike? This exercise was not intended as a planning process but as a way to support participants to interpret the curriculum in more creative ways.

This process is formalised in an online tool, The Randomiser, produced by DECD (n.d.-a) to stimulate similar thinking in the first six learning areas of the Australian Curriculum (English, Mathematics, Science, Arts, History and Geography – the latter now subsumed into Humanities and Social Sciences). A second part of the same resource, the Bringing it to Life Tool (DECD, n.d.-b) was also utilised to prompt thinking about the types of questions that teachers might ask of their students, and how the questions might develop from Foundation to Year 10.

This way of thinking about the curriculum was also helpful for teachers when planning for composite and multi-age classes. By starting with SHE, teachers were able to better connect the Science Understanding from the different year levels and create a unit of learning that met the requirements of all years of schooling within the one class group.

Each teacher in the program was supported to take the creative thinking simulated by such processes and turn it to their own practice and lesson planning. The principles to which the group identified and held onto throughout the program were expressed differently from year to year, but there was a great deal of commonality. They included:

- start with the Science as a Human Endeavour Strand
- be vigilant about who is doing the thinking (teacher or student; for example, shift from 'tell' to 'ask')
- promote, recognise and reward creativity
- promote, recognise and reward students asking questions
- promote, recognise and reward students making judgements (for example, through 'non-Googleable' questions) rather than collecting information (through 'Googleable questions')
- use metacognitive strategies – get students to think about their thinking and recognise the need to do 'slow thinking' (for example, Kahneman, 2011), especially to challenge their existing conceptions.

These principles (strategies) were put into action in a number of different ways (tactics) by each participant. Some drew heavily on the Community of Inquiry approach, an idea about the nature of scientific inquiry introduced by philosopher Charles Sanders Peirce at the end of the 19th century (published 1992), broadened into education settings by John Dewey (1902), modernised by Matthew Lipman (2003) as Philosophy for Children (P4C), and taken as the subject of an independently evaluated large-scale randomised control trial in the UK (Gorard, Siddiqui & See, 2015). Through this project, the program group closed the loop and modified the P4C approach to reconnect with Pierce's original conception of Community of Inquiry as a scientific process. Participants in the program used the structured conversation at the heart of the Community of Inquiry to drive student–student interaction in response to a specific stimulus or at the introduction of a scientific idea (to explore their pre-existing thinking). These discussions explored scientific concepts and some of the related issues and opportunities created by the science. They also shaped the questions that would subsequently be investigated and the ways in which they would be investigated by the children.

Other participants focused on 'noticing', and supported their students to slow down their thinking when engaging with the world. For example, a teacher of a Year 1–2 class in the coastal town of Port Lincoln placed hermit crabs upside down on the floor and asked the children not to rescue them or touch them (a challenge to their impulse inhibition). She provided a scaffold for the children to note down what they noticed about the crabs, what questions they had about the crabs and what they liked about hermit crabs. By scaffolding the children's thinking in this way and turning passive observation into active directing of attention and noticing, the teacher helped the children to develop the skills that underpin scientific thinking. She also found that they would write at a higher standard and produce more writing when asked to produce a persuasive text on 'why hermit crabs make good class pets.'

Other teachers asked students to make suggestions where they might otherwise start with sharing content and information. For example, a number of teachers used the *Flanimals* series of books by comedian Ricky Gervais (Gervais, 2006; Gervais & Steen, 2005). These books of nonsense animals created opportunities for children to create their own animals, develop their thinking about the evidence and reasoning that their animal had certain features, and think about the relationships between the features and the animal behaviour. The children still explored the scientific principles of structure-function relationships, classification, growth, change and heredity, but in a way that started with a low floor so that all students could engage with the process and take some ownership of the thinking. This created a platform from which the teachers transferred the learning to more real-world examples. Almost all of the Biology Science Understanding content descriptors from Reception to Year 7 could be introduced through fictional animals. Again, teachers commented on increased levels of engagement from the children, and the amount and quality of their writing.

School leaders noted changes in the participants' pedagogy and language, including more of a focus on asking questions and a higher expectation that children would be playing a more active role within the lessons. As one school principal described:

> There is a changing language that teachers are now using with kids, and there's a change in the language that they're expecting children to use. I've noticed that the teachers' planning is riddled with questions right through that they are wanting to ask or that they want kids to ask. I've observed in classrooms that kids are asking more questions and those questions are actually being documented and put up on word walls or actually highlighted in big labels. Children are finding answers to those from their friends' questions and talking about it. What I've seen in our school is the teachers are valuing, and therefore children are valuing, what other people are saying about their learning. But they're also being

able to express themselves in writing at a far higher level because they've actually thought through the processes of learning. They've actually thought about it and talked about it before they actually come to write it. They're not being asked to document stuff from the onset. They're being asked to wonder and think and question and predict. And that enables them therefore to articulate it more both orally and in writing.

In a post-program interview, one of the participating teachers summed up the value of the program:

It was a transformation of what I thought science teaching was about. I went into the program thinking that science as a human endeavour was a bit of vague fluffy stuff that didn't fit, wasn't useful and couldn't be quantified. I was attempting to stick it on through activities like a comprehension or the things that were in textbooks. I was finding it clunky and disengaging for kids. So I went in as a skeptic. After having my world turned upside down [through the program, I could see] that not only could I teach this stuff but it was going to make my teaching better. The research was useful and I think I had forgotten that teaching should be based on research. Collaborating with other teachers to get a big pool of ideas [was also useful]. I think that it was just that it was deep thinking and being brave enough to say what I am doing is not good enough and here is a way of making it better. The combination of having a real hard look at why we teach science and at my truth of teaching science compared to what I actually do and what I could do [was useful]. We were on a journey that we then wanted to replicate with our own students.

It clarifies your thinking to collaborate with other people. Having to justify my purpose to myself and to others and argue the merits of [my approach] was excellent. There was a lot of discussion and enthusiasm and that dialogue, the time and space, and the triggers to start those conversations were invaluable. I am now a Science as a Human Endeavour evangelist. I can't highlight enough the potential that the Science as a Human Endeavour strand presents for opportunities to teach science in a more engaging way.

Through this program, South Australian teachers were given time to become clear about their own moral purpose as a science educator. In doing so they reinterpreted the Australian Curriculum: Science in a strategic way so that they and their students could be more creative and engaged in their teaching and learning in science. The collaboration with a scientist and lead teacher created some disruption, but also helped the teachers to not lose sight of the principles that they themselves set and the scientific concepts within the Science Understanding strand of the curriculum as they put their learning into classroom practice. The children have become more engaged, active participants in their science education and are achieving more highly against the Achievement Standards in both the quality of work they are producing and the quantity of evidence that they are providing against the standards. The reinterpretation of the curriculum by their teachers is helping them to develop as effective learners and thinkers in science, as envisaged by the OECD and Google, rather than recipients of 'what should be taught'.

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Poster presentations

Coding drones in primary education

Beth Claydon and Daniel Martinez
St Hilda's Junior School, Gold Coast, Qld

Coding is an area of digital education that is gaining traction throughout the world. Critical thinking and systems-based problem-solving are two of the many important skills that can be developed through learning about computer coding.

Daniel Martinez and Beth Claydon have designed an iTunes U course where Year 6 students and their teachers are able to gain the basic skills necessary for controlling a Parrot MiniDrone device by creating their own coded programs. Students have the opportunity to explore the principles of programming while strengthening their understanding of maths and science. The course comprises nine lessons and an assessment that is in line with the Australian Curriculum: Technologies .

Both Daniel Martinez and Beth Claydon are Apple Distinguished Educators.

Science of Learning Research Centre – Improving learning outcomes

Victoria Anderson
Science of Learning Research Centre

The Science of Learning Research Centre (SLRC), established in 2013, is a Special Research Initiative of the Australian Research Council, administered by The University of Queensland.

At the heart of the Centre is a drive to improve learning outcomes, at pre-school, primary, secondary, tertiary and vocational levels.

The SLRC brings together 25 of Australia's leading researchers in neuroscience, education and cognitive psychology from across the country, collaborating in programs to better understand learning, using innovative experimental techniques. The SLRC collaboration includes eight Australian universities and the Australian Council for Educational Research, along with three state government education departments, Questacon and international partner investigators.

Knowledge gained from SLRC research feeds into a suite of research translation activities aligned with the Centre's overarching goal of developing evidence-based strategies and tools to assess and evaluate learning outcomes, evaluating existing strategies and dispelling learning myths. Through the translation program, research findings are shared with educators and policy makers to enhance educational practice and, as a result, enhance teaching and learning outcomes.

Research is being conducted in the molecular research laboratory; in brain imagining facilities; in real-world classrooms; and in two specially constructed research classrooms. The Learning Interaction Classroom at the University of Melbourne is designed to study learning interactions, and the Educational Neuroscience Classroom at The University of Queensland is equipped to monitor neurological and physiological activity during learning events. SLRC translation activities have already seen more than 1000 teachers in three states attend professional development programs informed by SLRC research.

Research Conference 2016

Improving STEM Learning
What will it take?

7–9 August 2016

Brisbane Convention and Exhibition Centre

Conference program

Sunday 7 August

2.00–4.30*

Pre-conference event

STEM digital projects at The Cube

An exploration of The Cube: A digital and interactive STEM learning environment

Jacina Leong, Public Programs Curator of The Cube

Jacina Leong will guide participants through an interactive and hands-on exploration of The Cube, one of the world's largest digital and interactive learning environments.

The Cube, at the Queensland University of Technology Science and Engineering Centre, is dedicated to providing an inspiring, explorative and participatory experience of STEM. It is designed for a diverse community of users, with a strong focus on engagement with school students in Grades 5 to 12. It does this through separate interactive applications, or digital projects that have been designed to enable novel interactions and experiences with curriculum-aligned STEM content.

For more information about The Cube, visit www.thecube.qut.edu.au/about

- *(This event is now fully booked).*

5.30–7.00

Networking drinks (Lego Robotics Challenge display)

Plaza Terrace Room, ***Brisbane Convention and Exhibition Centre***

Peter Kellett, Director of Information Services at Grace Lutheran College and Director of FIRST® LEGO® League Brisbane Bayside

Monday 8 August

8.00–9.00	**Registration**
9.00–9.30	**Welcome to Country** **Conference opening** Great Hall 2 Prof Geoff Masters AO, CEO, ACER
9.30–10.45	**Keynote 1** Great Hall 2 ***Must try harder: An evaluation of the UK government's policy directions in STEM education*** Pauline Hoyle, STEM Learning, York, UK
10.45–11.15	**Morning tea, exhibitor expo, poster presentations**
11.15–12.30	**Concurrent session Block 1**

SESSION A GH 2 Door 8	SESSION B Mezzanine M1	SESSION C Mezzanine M2	SESSION D Mezzanine M3	SESSION E GH Door 6
The STEM Teacher Enrichment Academy	Lifting Australian performance in mathematics	Sharing the stories of near novices to impact mainstream change	Promoting girls' and boys' engagement and participation in senior secondary STEM	Drawing to learn in STEM
Assoc Prof Judy Anderson, The University of Sydney	Dr Sue Thomson, ACER	Dr Bron Stuckey, independent consultant	Prof Helen Watt, Monash University	Prof Russell Tytler, Deakin University

12.30–1.30	**Lunch session**, Plaza 1 (Bring your lunch). Flexible, online postgraduate study with ACER. Designed to develop high-level assessment skills and understandings, ACER's Graduate Certificate of Education program is intended for classroom teachers, school leaders and those with leadership roles in assessment, come along to find out more.
1.30–2.45	**Keynote 2** Great Hall 2 ***What's all the fuss about coding?*** Prof Tim Bell, University of Canterbury at Christchurch, NZ
2.45–4.00	**Concurrent session Block 2**

SESSION F GH 2 Door 8	SESSION G Mezzanine M1	SESSION H Mezzanine M2	SESSION J GH Door 6
Are Australian mathematical foundations solid enough for the 21st century?	STEM and Indigenous learners	Conversation with a keynote	Enhancing students' mathematical aspirations and mathematical literacy as the foundation for improving STEM learning
Ross Turner and Dave Tout, ACER	Prof Liz McKinley, The University of Melbourne	Pauline Hoyle, STEM Learning, York, UK (limited numbers)	Prof Merrilyn Goos, The University of Queensland

6.30 for 7.00	**Conference dinner** Graduation Ceremony for the ACER Graduate Certificate of Education (Assessment of Student Learning) Dinner speaker: Prof Tim Bell, University of Canterbury at Christchurch, NZ ***Rydges South Bank, Level 12 Rooftop, 9 Glenelg Street, Brisbane*** Delegates need to register prior to conference.

Tuesday 9 August

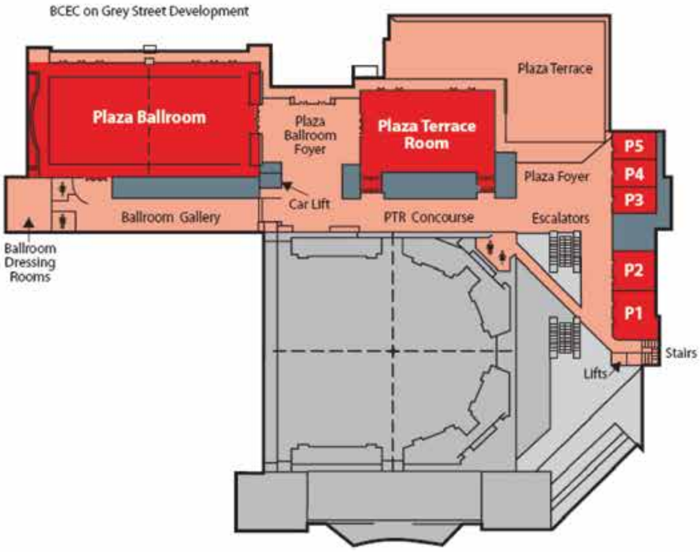
9.15–10.00	**Keynote 3** Great Hall 2 ***Innovation, snakes and ladders, and the greatest equation*** Dr Geoff Garrett, Queensland Chief Scientist
10.00–10.45	**Morning tea, exhibitor expo, poster presentations**
10.45–12.00	**Concurrent session Block 3**

SESSION K GH 2 Door 8	SESSION L Mezzanine M1	SESSION M Mezzanine M2	SESSION N Mezzanine M3	SESSION O GH Door 6
Addressing the STEM challenge through targeted teaching: What's the evidence?	Coding in the curriculum: Fad or foundational?	Targeting all of STEM in the primary school: Engineering design as a foundational process	Why is a STEAM curriculum perspective crucial to the 21st century?	Activating teachers' creativity and moral purpose in science education
Prof Dianne Siemon, RMIT University	Emeritus Prof Leon Sterling, Swinburne University of Technology	Prof Lyn English, Queensland University of Technology	Prof Peter Taylor, Murdoch University	Prof Martin Westwell, Flinders University; Sonia Cooke, Morphett Vale East School R–7

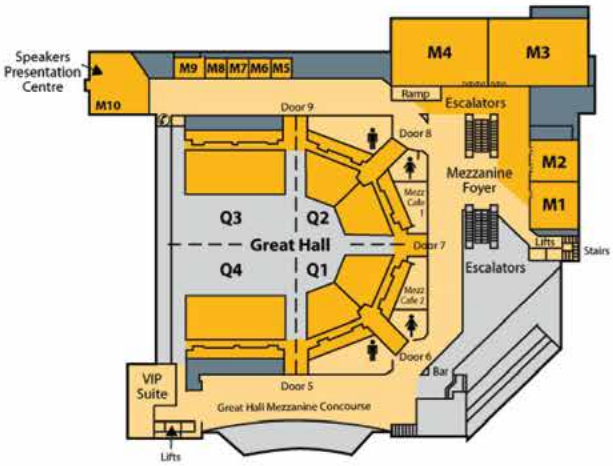
12.00–1.00	**Lunch session**, Plaza 1 (Bring your lunch). STEM Hackathon, Ormiston College, QLD. This STEM experience will provide you with take-home skills and cutting-edge ideas to implement in your curriculum. Come and learn from Ormiston College students as they facilitate short interactive workshops. Hands-on activities include: creating an interactive story using simple coding; learning how to send an Ozobot on a hunt by coding a maze with coloured pens; constructing simple circuits to create a dancing sign with littleBits; and programming a 3D robotic hand using Arduino kits.
1.00–2.30	**Debate** Great Hall 2 ***That research shows the what and the how of improved STEM learning*** The format of the debate will be a slightly altered form of an Oxford debate. There will be two opposing teams comprising of three panel members each side. The audience will be asked to cast a pre-debate vote on the motion. At the close, the audience will again be asked to cast a deciding vote on the winner.
2.30–3.00	**Conference close** Great Hall 2 Prof Geoff Masters AO, CEO, ACER

Venue floor plan

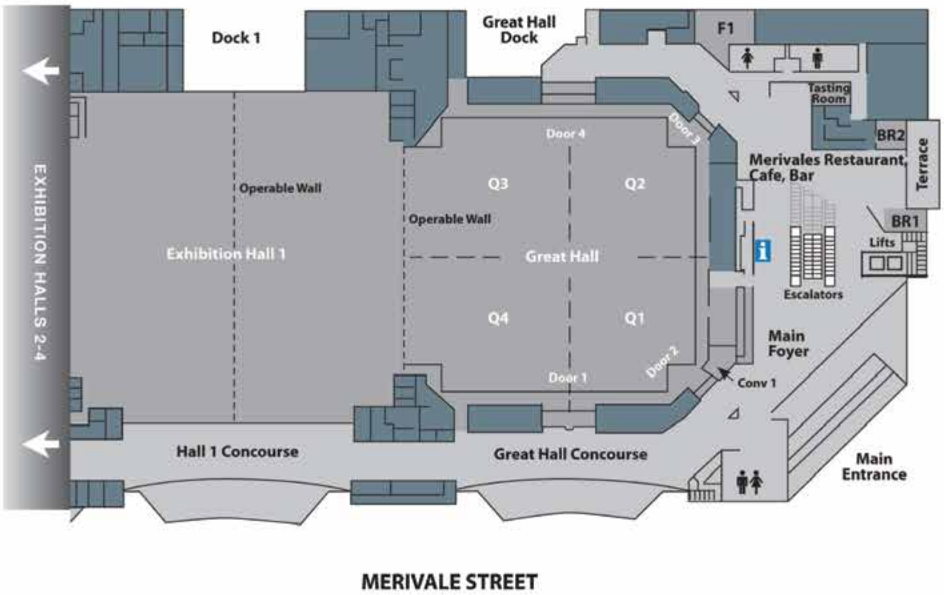
Plaza Level



Mezzanine Level



Foyer Level



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