Practical steps to improve the quality of science and mathematics teaching in Australian Primary schools

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Making STEM a primary priority

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Contents

Foreword

The teaching of STEM (science, technology, engineering, and mathematics) has entered an exciting phase. Right now there is an enhanced attention to STEM and there are now so many suggestions as to how to enhance teaching in ways to entice students to become and remain fascinated with these topics. Most of this debate, however, has been focused on high schools. This is why this document is critical as it raises the level and quality of debate about STEM in primary.

The evidence is compelling in this report about the nature of the problem. We are going backwards in the international rankings both relatively and absolutely. The Year 4 TIMSS (Trends in International Mathematics and Science Study) shows few students met the advanced benchmark. The 15 year PISA results also show that Australian absolute mean performance in math and reading has declined consistently for the past 15 years, and remained stable in Science. More of the same cannot be the answer.

Yes there are many debates we need to have – whether there are sufficient jobs for an increased number of science and math graduates; should primary schools teach Engineering; why Technology is in this mix when many of the world's greatest technology solutions did not come from science and math; is it merely a matter of increasing teachers' subject matter knowledge; is it more or different testing; and how would we know we have turned the ship around?

Perhaps most critical is the nature of teaching in these subjects. One thing can be guaranteed, that unless we enhance or dramatically change the teaching of math and science we are unlikely to attract more students to venture into and stay in these domains. I note, for example, that there are an increasing number of jobs for math and science graduates with social skills but a decrease for those without social skills (Demming, 2013). Ergo, only developing science and math in classes without attending to the social interactions in explaining and interpreting solutions may not be in the student's best interest. How we teach is as important as what we teach.

There needs to be an alignment with more dialogical teaching, listening to student voice, privileging the processes of learning – and content matter. Doing one without the other is not going to make the difference. The focus needs to be constantly on the impact of the teaching; and teachers need time, resources, and to be collaboratively working together to ask about what they mean by impact, what the magnitude of the impact is (in terms of student progress), and how many students are gaining this impact. When we see impact, then there is a virtuous circle when lessons are tweaked and changed to continue to maximise the impact. Only if such thinking underlies the teaching, is it likely that greater content knowledge will make a difference.

This report is a welcome contribution to raising the debate about science in primary school as it highlights the importance of robust foundations in numeracy and scientific understanding and makes practical suggestions for improvement. I am intrigued with the recommendation to provide a specialist STEM teacher for every Australian primary school. In our TEMAG implementation, AITSL is grappling with implementing one aspect of this recommendation. Surely it does not merely mean that teachers become specialists if they have done more courses in science, maths or the teaching of science and maths – time on task is a poor substitute for quality.

Professor John Hattie

Director of the Melbourne Education Research Institute at the University of Melbourne and Chair of the Board at AITSL (Australian Institute of Teaching and School Leadership)

Does it mean that these specialist teachers do most of the teaching of these subjects? Or could it mean, they have an increased responsibility for knowing the impact of science and math in the school and work with all teachers to increase this impact. I do welcome the debate about how these specialists can work between schools to maximise this impact – in many ways the health of a school system can be indicated by the health of subject specialists organisations – at least they are passionate about their subject, want to increase its impact, but one hopes they do not also get distracted with yet again another curriculum reshuffle, an advocacy campaign about the right way to teach, or waste time creating yet more resources.

The second recommendation relates to enhanced professional development (PD). There is an interesting parallel in that we consider it worthwhile to make it compulsory for students to come to school to learn, but we do not make the same link about asking teachers to come to school to learn. Professional development is one of the biggest piñata's in our business – bashed from all sides, deemed a failure by too many, and usually done at the worst times (after an exhausting school day). The research evidence is clear that PD can make major differences – the overall effect-size from 14 meta-analyses (1016 studies, 2,888 effects) is a healthy 0.45 (an effect size of 0.40 represents one year's growth over the course of one school year) – but with much variability in the effects of PD. The major findings relate to: the involvement of external experts was more related to success than within-schools initiatives; effects on student learning were very much a function of professional development that challenged the teachers' prevailing discourse and conceptions about learning (and maybe we see too much thinking that some kids cannot do math or science, or worse, teachers being proud that they themselves cannot do math and science); PD is more successful when it relates to testing the impact of competing ideas and when discussions are grounded in artefacts representing student learning; and when school leadership is involved and supports the implementation. The most effective PD relates to teachers working collaboratively to evaluate their impact – in lesson design, in watching each other's classes through the eyes of students (never watch the teacher, watch the impact of the teacher on the students), through learning how to use student voice to inform practices and judgments, and modeling high impact interventions and then using deliberative practice to implement these interventions.

It will not surprise that, if implemented, the third recommendation will have most impact. That is the better use of interpretations of data for targeted teaching and enhanced learning in STEM. It is about evaluating our impact, preferably through teacher collaboration, that we can most powerfully enhance student learning. I would put more focus on the interpretations, as too much of our current fetish is to get the most accurate data possible – and schools already are awash with data. It is more impactful interpretation that is needed.

And this leads to the fourth recommendation – to increase the quality and quantity of STEM instruction in Australian primary schools. And how we would know – of course by the impact on students – not only higher surface and deep knowing, but students who want to learn maths and science, a sense of mastery and excitement from using scientific and mathematic ideas, and wanting to know more and continue in these courses.

The report concludes that Australia is at an inflexion point. We can choose more of the same and slip even further behind, or we can make major differences to how we teach science and maths. Perhaps we might consider abolishing all science from primary school – there is some evidence that poor teaching is a great turn off. But surely there are pockets of major success now and we must have the spine to reliably recognise the excellence that is so often all around us – and build a coalition of success to further the best impact teaching of maths and science – and then use this coalition to invite other teachers to join.

As the report notes, the recommendations outlined in this white paper are ambitious but attainable. There are costs involved, but they are not vast, and they pale in comparison to the costs of inaction. I congratulate the authors for raising these critical debates – the time is now; let's make a difference to primary math and science, and avidly seek to find the evidence to show that we are indeed making the difference.

"Australia is at an inflexion point. We can choose more of the same and slip even further behind, or we can make major differences to how we teach science and maths"

Executive summary

Australia needs a STEM capable workforce if we are going to continue to prosper in an increasingly complex and competitive world. The economic case is compelling; analysis by PwC has shown that shifting just 1% of the workforce into STEM roles would add $57 billion to GDP (net present value over 20 years).[1] But without a secure pipeline of STEM talent graduating from the education system into the workforce, these economic benefits will not be realised.

Yet many indicators point to systemic under-achievement in STEM education. In recent years, the performance of Australian students on international tests of science and mathematics attainment has declined in absolute and relative terms. Of even greater concern is the anaemic progress many students make in their numeracy between years 3 and 5. Analysis of NAPLAN numeracy scores finds that 27.7% of Australian schools can be considered to be 'coasting,' whereby satisfactory student achievement masks minimal *improvement* in performance. A further 21.3% of schools are considered 'low-performing,' whereby student achievement is poor *and* year on year progress is slight.[2]

Unless we take the necessary steps to reverse the stagnation and decline in primary mathematics and science progress and achievement, we risk sub-optimising our future productivity, competitiveness and growth.[3]

Figure 1: PwC Young Workers Index vs. PISA mean mathematics scores

[1] PwC Australia (April 2015) *A smart move. Future-proofing Australia's workforce by growing skills in science, technology, engineering and maths (STEM)*. Available at: www.pwc.docalytics.com/v/a-smart-move-pwc-stem-report-april-2015

[2] Ferrari, J. (2014) 'High scores hide schools failure to improve, *The Australian*, 9 December.

[3] Recent PwC analysis finds a strong positive correlation between countries with higher PISA mathematics scores and better outcomes for youth workers (such as lower unemployment and higher tertiary enrolment rates). PwC's Young Workers Index provides a high level assessment of how OECD countries are developing the potential of their younger workers over time relative to other countries.

We present four key recommendations that are a call to action to Government, teacher education providers and the teacher workforce to make STEM education a primary priority. PwC has engaged with a broad cross-section of the education sector, including senior policymakers in state and federal governments, leading education researchers, teacher education students and providers, and primary teachers themselves to develop this roadmap for reform.

To address the problems outlined in this Paper we make the following recommendations.

Each recommendation contains a number of practical strategies for consideration by Government, universities, and school leaders and teachers. Constraints and impediments to implementation are also considered.

We are well aware that there are costs attached to the delivery of some of these recommendations – STEM specialists in particular – but in the absence of comprehensive workforce data, a robust estimate of costs is frustratingly elusive. Better workforce data would also enable us to identify more precisely spending offsets. For instance, with better data, Commonwealth-funded teacher training places could be more efficiently matched to future workforce needs.

The hope is that this report will encourage dialogue between key groups and prompt bold policy changes in the coming 12 months and beyond.

Our recommendations

Provide access to a specialist STEM teacher for every Australian primary school by:

- *Incentivising new teaching entrants to complete rigorous STEM specialisations;*
- *Creating opportunities and incentives for existing career teachers to acquire a specialisation; and*
- *Fostering collaborations between schools to deliver universal access to STEM expertise.*

***Improve the standard of professional development in primary science and mathematics** for all teachers.*

***Better use of data for targeted teaching and enhanced learning in STEM** and beyond.*

***Increase the quality and quantity of STEM instruction** in Australian primary schools.*

Objectives of the report

This report aims to highlight the importance of high quality primary school science and mathematics education to Australia's future. We know that expanding our STEM (science, technology, engineering and mathematics) skills base is essential to economic growth and prosperity, yet the evidence points to a continuing failure to foster adequately these skills – a failure which begins in the very earliest stages of schooling.

This report benchmarks Australia's position based on student achievement in science and maths assessments and other indicators of educational quality. We identify current weaknesses, before detailing opportunities for practical and impactful reform to raise the standard of STEM instruction in Australian primary schools.

While our focus is STEM in primary schools, the recommendations potentially have broader application. Implemented effectively, they could help to improve the management of the teacher workforce at large, and enhance the quality of primary teaching and learning across the curriculum.

Australia stands to enjoy massive economic and societal gains if we can ensure that every child finishes primary school with fundamental STEM knowledge and skills.

This report signposts steps to this end.

What is STEM in the context of primary school?

STEM (science, technology, engineering, mathematics) is an acronym in increasingly wide circulation. But what does STEM mean in a primary setting?

- Is it sensible to talk of 'engineering' in the primary curriculum?
- What about technology?
- Should technology be taught as a subject in its own right? Or should it be used as a learning enhancement tool and enabler across the curriculum?
- Should we teach coding (the language of computer programming) for coding's sake? Or is coding simply another way of teaching the highly transferable and adaptive mathematical skill of logic?

These are difficult questions and the subject of sustained debate in education and policy-making circles. But whether one advocates a 'back to basics' approach, or embraces a framework of '21st century skills,' foundational numeracy and scientific proficiency must be a key focus in the early years of formal schooling. In much the same way that core literacy skills are a precursor to success in other disciplines – such as history or the performing arts – foundational numeracy and scientific skills are an indispensable preparation for the future study of chemistry, design technology, biomedicine, physics and much more.

As a consequence, the recommendations in this report predominately focus on improving student performance in science and mathematics, because these are the building blocks of understanding in other related disciplines like engineering and technology. These elementary skills are also a precursor to the sort of interdisciplinary STEM learning that research suggests is particularly valuable in the middle and upper years of schooling.

The role of technology in the primary classroom

In the course of discussions with policymakers and education leaders across Australia, the role of technology in primary classrooms came up time and again. Experienced and respected educators hold divergent views on this issue, but the overwhelming majority of stakeholders we met with endorsed technology as an enabling device across the primary curriculum, rather than a standalone discipline.

Technology's role in facilitating learning can be better understood through the paradigm of the SAMR model. An instructive tool for evaluating the pedagogical value of technology use in the classroom, it posits that the richest learning occurs in at the 'modification' and 'redefinition' stages.

Substitution: new technology simply replaces old technology to accomplish a set task with no functional improvement. For instance, writing a document using Microsoft Word, instead of using a pen and paper. This is use of technology for technology's sake; there are no learning gains, beyond mastery of the technology itself.

Augmentation: The use of technology does not fundamentally alter the learning activity, but enables elements of the task to be completed more easily. For example, editing and revising a document is more expeditiously and neatly accomplished using Microsoft Word than it is manually, using a pen and paper.

Modification: The use of technology changes and enhances the learning task itself. For example, Google Docs enables students to collaborate in real time to write and edit a document.

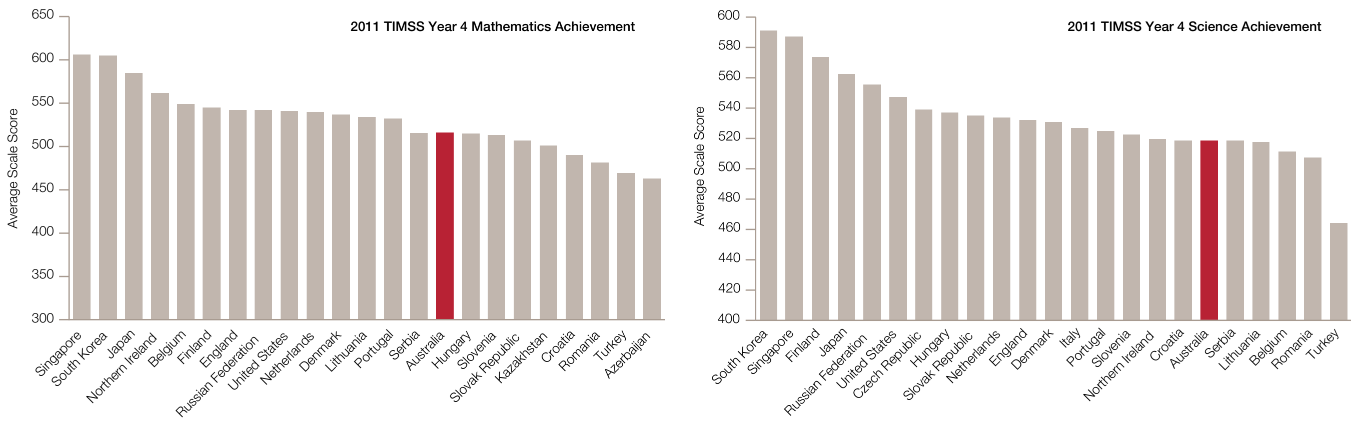
Redefinition: The entire learning task is transformed by the technology, enabling the completion of tasks that were previously inconceivable. For instance, Google Docs enables a group of students to collaborate to create a piece of writing in real time with another group of students anywhere in the world. The task may now encompass authentic cultural or linguistic exchange and collaboration.

The case for change

Where are we now?

Key indicators point to stagnation and missed opportunities in STEM education. Too many students are failing to reach minimum standards for numeracy and scientific literacy, while many others, especially those at the top of the achievement distribution, are not being pushed to excel:

Figure 2: Relative performance of Australian students on international tests of mathematical and scientific



Zero

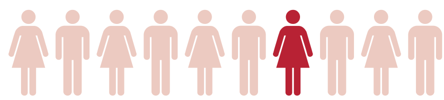
No overall improvement

There has been no overall improvement in Year 3 numeracy NAPLAN (National Assessment Program – Literacy and Numeracy) results between 2008 and 2015 and only marginal improvement in Year 5 numeracy.[4]

18th

out of 50 countries

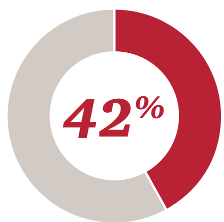
In the most recent round of Year 4 TIMSS (Trends in International Mathematics and Science Study) Australia came 18th out of 50 countries in mathematics and 25th out of 50 in science. We have fallen behind Canada, Ireland and many of our Asian neighbours.[5]



Just one in ten Year 12 students completed an advanced maths subject in 2014.[8]

Only 7% of Year 4 students met the TIMSS "Advanced" benchmark in science, while 29% reached the "Low" benchmark or no benchmark at all.[6]

In 2011 only 10% of Year 4 students met the TIMSS "Advanced" benchmark in mathematics while 30% meet the "Low" benchmark or no benchmark at all.



The latest PISA (Programme for International Student Assessment) results found that 42% of Australian 15 year olds failed to meet the nationally agreed minimum standard or mathematics compared to 36% in 2009.[7]

[4] Australian Curriculum, Assessment and Reporting Authority (2015) Preliminary NAPLAN 2015 Results. Available: www.reports.acara.edu.au/NAP/TimeSeries

[5] ACER (2012) *Highlights from TIMSS & PIRLS from Australia's perspective*. Available: http://rd/acer.edu.au/article/pisa-2012-how-australia-measures-up

[6] *Ibid.*

[7] Thompson, S. (2013) *PISA 2012: How Australia measures up*. Melbourne: Australian Council for Educational Research
Thompson, S. (2010) *Challenges for Australian Education: Results from PISA 2009*. Melbourne: Australian Council for Educational Research.

[8] Office of the Chief Scientist (2014) *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra.

Why is STEM so important?

The Australian economy is facing significant challenges – lower growth, declining productivity, downward pressure on real wages and an end to the mining boom. At the same time, Australian businesses are contending with the massive disruptive effects of digital technologies on business models, supply chains, and consumer behaviour. Using methodology pioneered by the University of Oxford, PwC has calculated that around 44% (5.1 million) current Australian jobs are liable to be affected by computerisation and advances in technology over the next 20 years.[9]

There are great potential benefits to be won from these rapid technological changes, provided Australia has a workforce capable of exploiting the opportunities these changes afford. Around 75% of the fastest growing occupations require STEM knowledge.[10] PwC estimates that shifting just 1% of the workforce into STEM roles would add $57 billion to GDP (net present value) over 20 years.[11]

In a global economy increasingly driven by data, digital technologies and innovation, Australian businesses need more employees with advanced STEM skills. Yet fewer Year 12 students are taking advanced mathematics, physics and chemistry and the number of STEM university graduates has flat-lined. Employers are struggling to find STEM employees.[12]

Given all of this, it is no surprise that Australia presently ranks a lowly 81st as a converter of innovation capability into desired business outputs.[13]

Reversing this "STEM-stagnation" would help meet workforce needs, drive innovation and productivity, and deliver economic growth.

Building a STEM capable workforce begins with education and the primary years are crucial in establishing foundational skills, knowledge and curiosity about STEM concepts.

Why focus on primary?

The foundations of STEM competence are laid in early childhood.[14] Engaging children in science before the ages of 11 to 14 is critical to generating long-term interest in the discipline.[15] Yet despite the critical importance of early STEM instruction, we don't teach enough STEM in Australian primary schools, and many primary teachers lack the expertise and confidence to teach STEM content well:

- Australian primary school teachers are required to spend only 1.5-2.5 hours on science and technology in the 30 hour school week.[16] According to the Chief Scientist, less than 3% of total primary school teaching time is devoted to science instruction.[17] By contrast, in Western Europe the average is 9% of total teaching time.[18]
- The 2015 federal government review of the Australian Curriculum found that the primary curriculum is cluttered with 'extras,' which sap time and focus from core priorities like numeracy, literacy, science and technology.[19]
- Deficiencies in the content knowledge and qualifications of some secondary STEM teachers in Australia have been widely reported. Over a third of Years 7 to 10 mathematics teachers have not studied tertiary mathematics or how to teach it.[20] While national data on the STEM qualifications of primary school teachers is very limited – a problem in itself – it can be safely assumed that the primary school workforce has an even greater deficit of STEM-trained teachers. Experts have speculated that a sizeable number of primary school teachers have no Year 12 qualification in mathematics or science.[21]
- A recent analysis of the Year 12 STEM qualifications of teaching aspirants in NSW between 2001 and 2013 returned some alarming results. For students receiving university offers to study teaching, the proportion with no mathematics at HSC tripled (4.8 to 15.6%); while the proportion of students having 2 Unit (intermediate) maths halved (30.6 to 14.2%) as it did with extension courses (9.5 to 5.46%).[22]

[9] PwC Australia (April 2015) *A smart move. Future-proofing Australia's workforce by growing skills in science, technology, engineering and maths (STEM)*.
[10] Office of the Chief Scientist (2014) *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra.
[11] PwC Australia (April 2015) *A smart move. Future-proofing Australia's workforce by growing skills in science, technology, engineering and maths (STEM)*. Available at: www.pwc.docalytics.com/v/a-smart-move-pwc-stem-report-april-2015
[12] Australian Industry Group (2013) *Lifting our Science, Technology, Engineering and Maths (STEM) Skills.*
[13] Office of the Chief Scientist (2014) *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra.
[14] Australian Council of Learned Academies (2013) *STEM: Country Comparisons,* ACARA, Australia.
[15] Mullis, I., Martin, M., Foy, P and Arora, A. (2012), *TIMSS 2011 International Results in Mathematics*, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.
[16] Office of the Chief Scientist (2014) *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra.
[17] Chubb, Ian (2013) *Keynote Address by the Chief Scientist to the Seventeenth National Engineering Heritage Conference*, National Portrait Gallery, Canberra, November 18th.
[18] Office of the Chief Scientist, (2014) *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra.
[19] Donnelly, K. & Wiltshire K. 2014, *Review of the Australian Curriculum Final Report*, Department of Education, Canberra.
[20] Office of the Chief Scientist (2014) *Benchmarking Australian STEM*. Australian Government, Canberra.
[21] Dinham, Stephen (2014) *Keynote Address to Australian College of Educators National Conference*, Adelaide 11th September, 2014.
[22] Wilson R. and Mack, J. (2014) 'Declines in high school mathematics and science participation: Evidence of students' and future teachers' disengagement with maths'. *International Journal of Innovation in Science and Mathematics Education*, 22(7), 35-48.

Intervening early in the educational process is also fiscally prudent. Decades of research by Nobel Prize winning economist James Heckman shows that the earlier governments invest in education, the greater the economic dividends.[23] While boosting Australia's STEM capacity has become a focus of policymakers in recent times, very few initiatives have specifically targeted the primary years. Moreover, the impact of STEM programs in secondary and tertiary education will be curtailed if our primary schools fail to engender fundamental numeracy and scientific curiosity in all students.

Why better teaching is the key

Of all the in-school influences on student learning and achievement, we know that the quality of teaching has the biggest impact.[24] Improving teacher effectiveness by 20-30% would increase Australia's long-run GDP growth by about 0.4% per annum, adding $240 billion to GDP by 2050.[25] PwC's own analysis finds that reforming Australia's school education system in line with best practice internationally would yield $3.2 trillion in benefits over the lifetime of the generation born in 2012.[26] The top performing systems in the world are all ones that value and develop teacher expertise.[27]

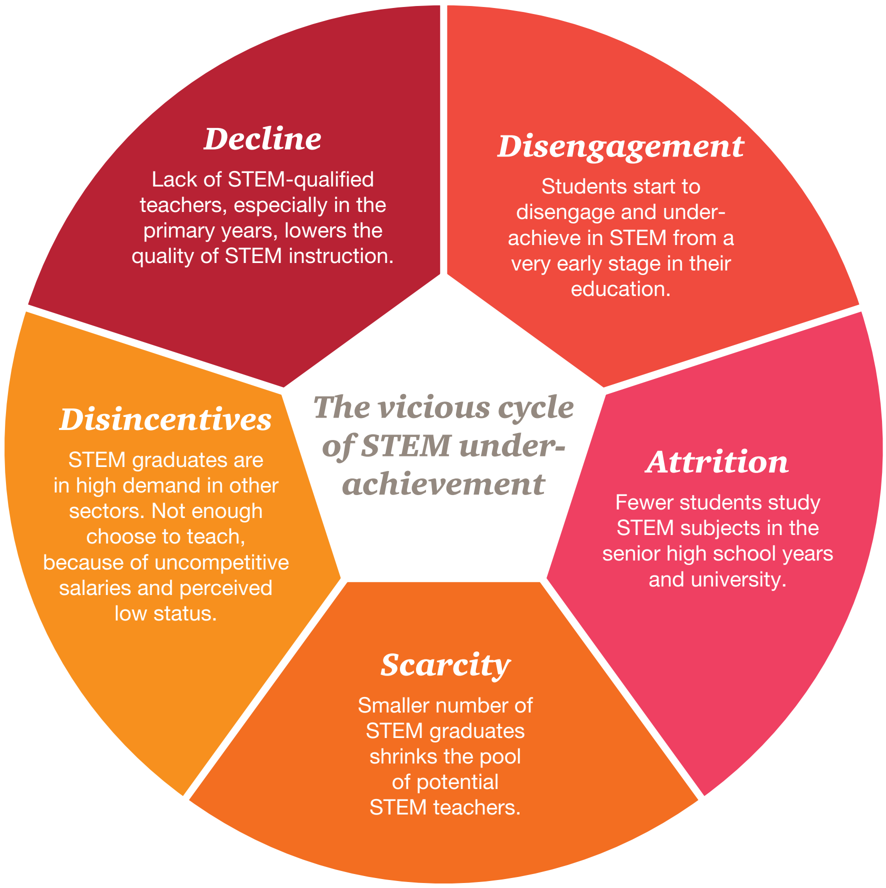
Yet despite the massive gains to be had, Australia is struggling to recruit, train, reward and retain the school workforce we need to remain internationally competitive. The academic aptitude of new entrants to the teaching profession has declined in recent decades. In 1983 the average female entering an undergraduate teaching degree scored 70% on a standardised test. By 2003 it was just 59%.[28] In 2012, at least 69% of new entrants into undergraduate teaching degrees had an ATAR below 80; 13% had an ATAR below 60.[29] More concerning still are the findings of the federal government review of teacher education that training programs are not consistently equipping beginning teachers with the evidence-based strategies and skills they need to teach effectively.[30]

The professional development of in-service teachers is equally questionable. Between 37% and 42% of Australian teachers report that professional development has little or no impact on their teaching.[31]

All of this must change if we want the sort of education system we need to maintain our current standard of living.

We are presently trapped in a cycle of educational complacency. The cycle begins in the earliest years of schooling, and its effects are especially acute in the STEM disciplines. Breaking this cycle will not be easy, but it can be done if practical measures targeting each stage are implemented.

Figure 3: The vicious cycle of STEM under achievement



[23] Heckman, James (2008) *Schools, Skills and Synapses*, IZA Discussion Paper No. 3515.
[24] Hattie, J. (2009) *Visible Learning: A synthesis of over 800 meta-analyses relating to achievement*, London: Routledge.
[25] Jensen, B. & Reichl, J. (2012) *Implementing a Performance and Development Framework*, Melbourne: Grattan Institute.
[26] PricewaterhouseCoopers (2012) Applying the methodology set out in *Improving productivity through education,* PwC Australia.
[27] Hattie, J. (2015) *What doesn't work in education: The politics of distraction*, Pearson.
[28] Leigh, A. and Ryan, C. (2008) 'How and why has teacher quality changed in Australia?' *Australian Economic Review*, 41:2
[29] Australian Institute of Teaching and School Leadership (2014) *Initial Teacher Education Data Report,* AITSL, Melbourne; N.B. It is important to note that in 2012 only 28% of prospective domestic teachers entered undergraduate courses on the basis of their ATAR. The basis for the other 72% of admissions is worryingly opaque.
[30] Teacher Education Ministerial Advisory Group (2014) *Action Now: Classroom Ready Teachers*, Australian Department of Education, Canberra.
[31] OECD (2014) *Australia Country Note: Teaching and Learning International Survey 2013*, Paris: OECD.

What improvement do we need to see?

Past governments have set ambitious targets for Australian achievement in international tests. In 2012, then Prime Minister Gillard declared a desire to see Australia in the world's top five ranked schooling systems by 2025 based on performances in PISA reading, science and mathematics tests.[32] Fixating on a relative ranking may help to concentrate minds and galvanize disparate groups behind a common goal. Indeed, there is no doubt that Australia's relative position in educational rankings will affect our long-term economic competiveness.

But targeting a ranking says nothing of the improvement *in real terms* that we need to see to ensure that all Australian students reach the minimum level of mathematical and scientific proficiency required to participate fully in the economy and society. Nor does it explicitly address the current failure to ensure that all students are being pushed to achieve their full potential in mathematics and science.

Analysis of NAPLAN scores shows that too many students make limited progress in numeracy between years 3 and 5. Around 27.7% of Australian schools can be considered to be 'coasting,' whereby a high level of student achievement against national benchmarks masks minimal year on year *improvement* in performance. A further 21.3% of schools are considered 'low-performing,' whereby student achievement is poor *and* year on year progress in numeracy from years 3 to 5 is slight.[33]

Along with Hattie and the Grattan Institute, we contend it is more constructive to focus on – and frame reform efforts around – maximising student *progress* in science and mathematics.[34] By definition, boosting progress raises achievement. Moreover, a focus on progress holds all educators accountable, not just those teachers and schools who are struggling to raise the tail of low achievers. The phenomenon of sub-optimal progress plagues schools across the socio-economic spectrum, at all points of the achievement distribution and within the government and non-government sectors.[35]

Maximising student progress requires teachers to be (a) expert in diagnosing where students are at, (b) capable of crafting effective interventions to promote learning, and (c) adept at evaluating which methods of teaching have been successful and why.[36] Analysis by the Grattan institute suggests that if all Australian teachers effectively targeted their teaching to maximise student progress, the international test results and rankings would take care of themselves. PISA scores would increase sufficiently to place us in the top 5 performers, based on 2012 results.[37]

For these reasons, this report focuses on ways to recruit, foster and retain the teacher expertise required to engender maximal student progress in primary mathematics and science.

[32] Ferrari, J. (2012) "Labor's 'top five' goal for schools," *The Australian*, 3 September.
[33] Ferrari, J. (2014) 'High scores hide schools failure to improve, *The Australian*, 9 December.
[34] Hattie, J. (2015) *What works best in education: The politics of collaborative expertise*, London: Pearson.
Goss, P. & Hunter, J. (2015) *Targeted teaching: How better use of data can improve student learning*, Melbourne: Grattan Institute.
[35] Hattie, J. (2015) *What works best in education: The politics of collaborative expertise*, London: Pearson.
[36] Hattie, J. (2015) *What works best in education: The politics of collaborative expertise*, London: Pearson.
[37] Goss, P. & Hunter, J. (2015) *Targeted teaching: How better use of data can improve student learning*, Melbourne: Grattan Institute.

Our recommendations

STEM specialists for Australian primary schools

Primary school teachers are rightly proud of their achievements as generalists; delivering subject matter expertise across a diverse curriculum and range of student needs is a challenging and vital role. This Paper does not seek a wholesale replacement of the existing model of primary teaching, however we strongly believe supplementary action is required to ensure the delivery of exemplary content knowledge and pedagogical practice in primary STEM education.

In an ideal world, every primary school teacher in Australia would be highly proficient in maths, science and technology and know how to teach these subjects in an engaging and effective way. However, the 2014 federal government report on initial teacher education found evidence that many new primary school teachers lack confidence and competence in these areas.[38] The Office of the Chief Scientist noted that 79% of respondents to a 2014 survey of mathematics teacher educators reported that students entering their courses had either a poor mathematical background, or significant gaps in their mathematical knowledge.[39]

While there is a great deal more to good primary teaching than raw academic aptitude, a teacher cannot teach what they themselves have not understood. At the very least, it is unlikely that generalist primary teachers approach all subjects with the same enthusiasm and aptitude.

Recognition of this fact partly accounts for a growing appetite for specialism amongst primary principals and teachers. A recent study of attitudes towards specialism conducted in NSW found that 73% of surveyed primary principals endorsed the use of specialists to teach certain disciplines, including science, technology and computing. The authors also reported that specialists are already commonly engaged to deliver other areas of the curriculum such as physical education, visual arts and music.[40] A separate study found that many primary teachers in NSW (60% of those surveyed) supported the use of specialists to teach science, technology and computing, among other subjects.[41]

To boost the quality of primary science and mathematics instruction, measures need to be taken both to upskill the existing workforce and to attract and train new entrants with STEM expertise.

Providing every Australian primary school with access to a STEM specialist is an idea that has gained considerable traction recently. It was a recommendation of the 2014 Chief Scientists' report and following a recent review of initial teacher education, the Federal Government has mandated that higher education providers must equip all primary pre-service teachers with at least one subject specialisation, with priority given to maths and science. Primary specialisation is commonplace in leading education systems such as Singapore, Taiwan, Finland and Hong Kong.[42]

Last year the Victorian Government announced $27 million to train 200 primary school mathematics and science specialists to work with students alongside other teachers in Victoria's most disadvantaged schools.[43] To date, however, there has been very limited detail on how STEM specialisation might be practically implemented in a national context.

We recognise there are not inconsiderable costs involved in the proposals that follow. While patchy workforce data precludes a robust estimate of the cost of STEM specialists, we are confident that considerable offsets can be found, for example through a better matching of Commonwealth-funded teacher training places with actual workforce needs.

[38] Teacher Education Ministerial Advisory Group (2014) *Action Now: Classroom Ready Teachers*, Australian Department of Education, Canberra.
[39] Prinsley, R. & Johnston, E. (2015) *Transforming STEM teaching in Australian primary schools: everybody's business,* Office of the Chief Scientist.
[40] Ardzejewska, K., McMaugh, A. & Coutts, P. (2010) *'Delivering the primary curriculum: the use of subject specialists and generalist teachers in NSW'* Issues in Educational Research, 20:3
[41] Morgan P. & Hansen, V. (2007) *Recommendations to improve primary school physical education: Classroom teachers' perspectives*. The Journal of Educational Research 101:2, pp. 99-111.
[42] Driskell, N. (2014) *How the Top Performing Countries Prepare Primary Teachers*, Centre on International Education Benchmarking.
[43] Victorian Government (2015) *Education State: Schools*, Melbourne: Victorian Department of Education and Training.

What role should STEM specialists play?

The precise role of a primary STEM specialist will vary according to such factors as the size of the school and the particular skill profile of the staff. We believe there are two key aspects to the role:

- The first duty of the STEM specialist is to develop and directly deliver rigorous and engaging STEM content and devise mechanisms for measuring, tracking and accelerating student learning across the whole primary school.
- The second duty of the specialist is to enhance the STEM teaching capacities of non-specialists. This would encompass preparation of science and mathematics resources and lesson plans, team-teaching, lesson observations and feedback, and coordinating evidence-based, impactful professional development opportunities to enhance the practices of the entire primary staff.

An example of this model can be found in the UK, where trained specialist mathematics leaders have responsibility within their schools for assisting all teachers to improve their mathematics pedagogy and for developing effective and engaging learning resources.[44]

The different aspects of the STEM specialist role will have various implications for workforce management, timetabling and industrial relations. Similarly, depending on the particular balance struck between time spent directly delivering STEM lessons and coaching and mentoring of non-specialist colleagues, there may be a trade-off between the depth and the scope of impact on student achievement.

Case study
STEM competency

The empirical findings of Griffith University mathematics lecturer, Stephen Norton, underscore the challenges of competence and confidence:

Dr Norton tested the maths ability of all 125 students who enrolled in a Griffith University graduate diploma of education – a one-year course for those who have a bachelor degree in another field – last year and this year, as well as 40 students in the third year of a bachelor of education course in 2013. Barely half the would-be teachers knew how to convert 5.48km into metres – and 17% failed to convert 6kg into grams. Only 16% could convert temperatures from degrees Celsius to Fahrenheit, using a formula written on the test paper. Just one in four knew how to convert a fraction to a percentage.

The Australian, 6 December 2014

[44] Australian Council of Learned Academies (2013) *STEM: Country Comparisons,* ACARA, Australia.

Table 1: Potential impacts of introducing STEM specialism

	Direct delivery of STEM lessons	Team teaching STEM lessons with non-specialist	Lesson observations and feedback with non-specialist	Whole of school coordination of STEM PD
Workforce implications	Need to identify existing number of STEM-qualified teachers to ascertain which schools are without a potential specialist; Additional salary cost in some jurisdictions	Minimal	Minimal	Minimal
Timetabling adjustments	Timetable adjustments required to enable STEM Specialist to teach science and mathematics content to multiple classes	Team-teaching to a larger group of students; mitigates need to bring in additional staff as staff-student ratio remains the same	Need to find time for feedback and discussion shortly after observation has taken place	Free up time for high quality professional learning by reducing time teachers spend in administrative meetings, yard duty and pastoral matters.
Industrial relations implications	Acceptance of differentiated pay for STEM specialists who attain Highly Accomplished status. (NSW has already linked Australian Professional Standards for Teachers to teacher salaries)	Cultural change required in some schools away from total teacher autonomy to collaborative professionalism	Cultural change required in some schools. Need to open classroom door and work collaboratively	Cultural change required in some schools.

What constitutes a STEM specialisation?

PwC consulted widely across the school education sector about what skills and qualifications should constitute a STEM specialisation. There was general consensus that the following pathways could qualify an individual as a primary STEM specialist:

- A tertiary degree in STEM discipline and a recognised teaching qualification; or
- A Bachelor of Education that encompasses a major in a STEM discipline which meets the following criteria:
  - six designated units in the specialisation
  - The units are focussed on content knowledge, not studies of subject pedagogy
  - The units build sequentially on one another to ensure that subject expertise is cumulatively and logically developed
  - The units are taught by subject matter experts, not educationalists (for instance, biology units ought to be taught by a higher degree-holder in biology or biochemistry, not an educationalist who has taught some high school science)
- Significant STEM industry experience (for example, 5+ years working as a software designer or pharmacist) with content knowledge to be verified by a rigorous exam developed and overseen by AITSL or state/territory teacher registration bodies and a recognised teaching qualification.

Additionally, given the considerable responsibilities that STEM specialists will have for mentoring and coaching non-specialist colleagues, and for assessing and promoting growth in student learning across the school, we expect that specialists would hold, or be working towards, Highly Accomplished status within the Australian Professional Standards for Teachers. Highly Accomplished status reflects the superior instructional leadership capacities required of STEM specialists. Moreover, in jurisdictions such as NSW, where salary structures have been formally linked to the new AITSL standards, becoming a STEM specialist would thereby carry a significant financial incentive.

Another option governments and registration authorities ought to consider is the progressive phasing out of stand-alone Bachelor of Education courses in favour of combined degrees, for example:

- A Bachelor of Education completed alongside a Bachelor of Science or Bachelor of Arts; or
- A Bachelor of Arts or Bachelor of Science followed by a Master of Education in primary or secondary teaching.

While this would be a more radical – and more expensive – approach, it would have the virtue of very directly ensuring that all new entrants into teaching had a *bone fide* specialism. This is the model used in Canada (with some provincial variation) – a system that routinely outperforms Australia on international measures of primary student attainment.[46]

Another option worthy of consideration is the system of differentiated teacher certification used in Japan. Teachers who complete an undergraduate degree in education receive a second-class certificate. Those who complete a bachelor's degree in a subject discipline and then go on to teacher training receive a first class certificate. While a second-class certificate holder can seek licensure and employment anywhere, employing prefectures generally prefer first-class certificate holders.[47]

Where will the specialists come from?

Incentives to boost the pipeline of primary STEM specialists

Recent reviews of Australia's higher education system have found that previous financial incentives to induce STEM graduates into teaching have had limited impact. Discounting course fees for science and mathematics degrees and HECS-HELP debt reductions for STEM graduates who became teachers had lower than expected take-up rates.[48] It appears that neither of these schemes offered sufficiently compelling financial incentives to have a widespread influence on career decision-making.[49]

Financial incentive schemes do seem to be influencing decision-making elsewhere, however. Following the introduction of joint initiative between the UK government and the Institute of Physics to provide generous teacher training scholarships and bursaries (up to £25,000) to physics graduates with first or upper-second degrees, the number of top physics graduates entering the profession increased by 50%.[50] Similar bursaries have since been instituted in concert with the Royal Society of Chemistry and the Institute of Mathematics (with a particular focus on recruiting primary maths specialists). Rates of entry into teaching via these bursaries have been similarly impressive.[51]

Case study *ReMSTEP*

If high quality specialisations are to be instituted in primary teaching degrees, much closer collaboration between education and STEM discipline faculties will be essential. An example of this sort of collaboration is the federally funded 'ReMSTEP' (Reconceptualising Mathematics and Science Teacher Education Programs) initiative, involving the science, mathematics and education faculties of the University of Melbourne, Monash University, Deakin University and La Trobe University.

Under ReMSTEP new mathematics and science electives and student pathways will be introduced to ensure that teacher education aligns with current knowledge and practices in STEM disciplines.[45]

The following lessons can be drawn from the UK example:

- Financial incentives should target relevant discipline degree holders with top results.
- A generous cash payment during post-graduate teacher training is more attractive than future debt-forgiveness because it mitigates the immediate opportunity cost of undertaking a year of full time teacher training.[52]

[45] See http://remstep.org.au/about-the-project/index.html.
[46] Driskell, N. (2014) *Global Perspectives: How the Top Performing Countries Prepare Primary Teachers'*, Centre on International Education and Benchmarking. Available: http://www.ncee.org/2014/11/global-perspectives-how-the-top-performing-countries-prepare-primary-teachers/
[47] Driskell, N. (2014) *How the Top Performing Countries Prepare Primary Teachers*, Centre on International Education Benchmarking, Available: http://www.ncee.org/2014/11/global-perspectives-how-the-top-performing-countries-prepare-primary-teachers/
[48] Bradley, D. *et al* (2008) *Review of Higher Education*, Canberra: Australian Government;
Lomax-Smith, J. *et al* (2011) *Higher Education Base Funding Review*, Canberra: Australian Government.
[49] Kemp, D. & Norton, A. (2014) *Review of the Demand-Driven System,* Canberra: Department of Education.
[50] National Science Learning Centre (2012) *The Future of STEM Education*, York: National Science Learning Centre. Available; https://www.sciencelearningcentres.org.uk/media/filer_public/7f/d3/7fd32ef0-a746-452b-a681-8e5d15f5a1da/the_future_of_stem_education_-web.pdf
[51] UK Department for Education (2013) *Bigger bursaries and scholarships to attract more top graduates into teaching*, 17 October 2013. Available: https://www.gov.uk/government/news/bigger-bursaries-and-scholarships-to-attract-more-top-graduates-into-teaching
[52] Scott, Milam, Stuessy, Blount & Bentz (2006) Math and science scholars (MASS) program: A model program for the recruitment and retention of pre-service mathematics and science teachers. *Journal of Science Teacher Education*, 17, 389–411.

- Collaboration with the Professional Bodies allows joint funding, but even more crucially, it enables teachers to engage with the activities and insights of the learned academies throughout their careers. Evidence suggests that the high-level, subject specific professional development provided by the learned academies is effective in retaining talent within the system.[53]

A similar scholarship scheme has just been introduced in NSW. This is a thoroughly welcome development but it remains to be seen how effective the program will be given that the scholarships are not explicitly targeted at top graduates of STEM degrees and are significantly less generous financially.

Drawing on the lessons of the UK experience, we believe there is a strong case for the introduction of a national STEM scholarship scheme to support top graduates of STEM degrees to undertake post-graduate primary teacher training, and high school graduates with top scores in Year 12 STEM subjects to undertake undergraduate primary teacher training.

The Office of the Chief Scientist's recent Occasional Paper also recommends the establishment of a prestigious national public-private scholarship including the completion of a degree in a STEM discipline followed by appropriate pedagogical training and employment "provided as loans, and written off according to the number of years spent in primary teaching".[54]

Differentiated pay?

A case can be made for differentiated and higher pay for STEM-specialists because STEM graduates generally face a larger potential income sacrifice in choosing to teach than graduates of other disciplines. External labour market dynamics are one of the main reasons the shortage of STEM expertise in Australian schools is so acute.[55] However, there is no guarantee that simply offering higher salaries to all STEM-qualified teachers of primary mathematics and science would attract, or appropriately reward, the full gamut of expertise required to raise student progress and achievement. We propose the following instead:

1. All Australian jurisdictions follow the lead of NSW in explicitly linking teacher salaries to the Australian Professional Standards for teachers. Under the NSW framework, teachers who demonstrate superior instructional and leadership capacities can apply to be recognised as Highly Accomplished or Lead teachers and receive a commensurately higher salary. This is a significant cultural watershed for the profession because it embraces the principle of rewarding teacher quality rather than longevity of service; and
2. Stipulate that STEM specialists hold or are working towards holding Highly Accomplished or Lead status in addition to their specialism, thereby accruing a higher salary commensurate with their recognised discipline and pedagogical expertise.

As outlined, this is but one option worth consideration. Above all we must reflect on a range of financial and non-financial levers that have potential to attract high achievers to specialise in STEM. For instance, the Chief Scientist's Occasional Paper notes that in the best school systems in the world "selection occurs before the start of teacher training".[56] To that end, our own school systems could consider guaranteeing to STEM specialists, ahead of other candidates, a permanent job at the end of their degree, pending the achievement of the necessary academic requirements.

In our own survey of 3rd and 4th year Bachelor of Education (Primary) students, 93% of respondents indicated that guaranteeing positions would make them more likely to complete a STEM specialisation.[57]

[53] Wolstenhome, C., Coldwell, M,, and Stevens A., (2012) *The impact of science learning centre continuing professional development on teachers' retention and careers: final report*.
[54] Prinsley, R. & Johnston, E. (2015) *Transforming STEM teaching in Australian primary schools: everybody's business,* Office of the Chief Scientist.
[55] Productivity Commission (2012) *Schools Workforce*, Canberra: Productivity Commission.
[56] Prinsley, R. & Johnston, E. (2015) *Transforming STEM teaching in Australian primary schools: everybody's business,* Office of the Chief Scientist.
[57] Survey of 3rd and 4th year Bachelor of Education (Primary) students at major University.

Upskill existing teachers to become STEM specialists

Targeting STEM specialism at the pipeline of new entrants to the profession is an essential strategy, but it is a long-term and low volume (at least initially) means of attaining the stated aim of providing every school with access to a STEM specialist. To effect change across the system and get the best and brightest into these roles, a STEM specialist policy must capitalise on the existing, and perhaps latent, capabilities and talents of the current primary workforce. The opportunity to upskill to attain specialist status should be made available to existing teachers. State governments, sector bodies and Principals should be promoting and championing it.

Though we have little information on the discipline backgrounds of the existing primary workforce, previous professional backgrounds or predispositions to STEM specialism, it can be assumed that many teachers would be interested in science or mathematics specialism, particularly if it were linked to development pathways for Highly Accomplished accreditation within the Australian Professional Standards for Teachers framework. A clearly defined and well-communicated pathway to STEM specialism is required to attract, upskill and accredit existing teachers as specialists.

This pathway would need to show alignment to the Highly Accomplished teacher accreditation standard and coherence with the requirements of entry-level STEM specialism. Therefore we suggest a subsidised Masters-level qualification in science and mathematics to be taken alongside existing teachers' professional responsibilities.

Such an approach has been trialled in the UK – the MaST Programme is a two-year Masters-level programme delivered through partnerships between higher education institutions (HEIs) and local authorities (LAs) and accessible to existing primary teachers interested in becoming Maths specialists. It focuses on three key and significant areas to improve mathematics in schools – subject knowledge including progression across the Key Stages, pedagogy, and collaborative working with colleagues. To achieve their MaST qualification participants must complete five days face-to-face contact with the Higher Education Institution provider, six local authority run half-day events, 11 days in-school classroom focused work and work alongside colleagues as well as self-supported study.

At this early stage in the programme the impact on student attainment is yet to be established by statistically significant improvements on standardised tests. MaST has however been qualitatively assessed through surveys of Principals, local authorities, teacher colleagues, pupils and the participants themselves. There is empirical evidence to suggest that the MaST Programme has fostered deeper subject knowledge in participating teachers, raised the confidence of participants in their personal numeracy and mathematics pedagogy and strengthened the priority afforded to mathematics teaching and learning at a whole of school level. The initiative is also relatively inexpensive; the lifetime programme cost for each school that acquired one or more MaST-qualified teachers was only £7,111 GBP, or a little over $15,000 AUD.

Some Australian jurisdictions are pursuing similar initiatives to the MaST scheme, such as NSW, which has instituted scholarships to subsidise up to 320 existing teachers to re-train in science and mathematics. Similarly, the Victorian government has recently pledged $27 million to re-train 200 primary school mathematics and science specialists to work with students alongside other teachers in disadvantaged schools.[58]

These efforts are welcome, but we see considerable virtue in a nationally co-ordinated approach to specialist upskilling, especially in light of the federal government's superior leverage over the higher education sector and the strategic importance of STEM to national fortunes.

[58] NSW Department of Education (2015) *Science and Mathematics Scholarships*, Available: https://www.teach.nsw.edu.au/enhanceyourcareer/science-and-mathematics-scholarships.
Victorian Government (2015) *Education State: Schools*, Melbourne: Victorian Department of Education and Training.

School collaboration for implementation efficiency

There is a great diversity across the primary system and the distribution and utilisation of STEM specialists needs to take this into account. We believe flexible collaboration between schools can help to at least partly mitigate resourcing challenges and represents the most efficient means of providing STEM expertise. Moreover, the act of collaborating gives teachers and students access to a pooled network of information and opportunities that may otherwise be unavailable within the confines of an individual school.[59]

A fundamental impediment to implementing collaborative networks through which to deliver STEM specialists is the poor quality of school workforce data. We need to know the present number and distribution of STEM-qualified teachers and how many may be in the training pipeline, but state and territory registration authorities do not systematically collect information about teachers' Year 12 subject completions, specialisations within teacher education courses, or other tertiary qualifications.[60] Without this information it is very difficult to anticipate future workforce needs, and allocate resources or craft incentives in order to meet them. As such, creating a comprehensive, nationally consistent workforce database should be a top priority for federal, state and territory governments.

Data concerns notwithstanding, the geographical proximity of schools gives an indication of how readily schools may be able to cluster and collaborate to efficiently capitalise on STEM teaching expertise. By geo-coding the address of every school in Australia, PwC's geospatial economic modelling has shown that 90% (or 8,171) schools are within 10km of another school. Furthermore, the modelling shows that a very small minority of schools are 'remote' and would thus face significant geographical barriers to collaboration; only 288 schools (or 3.16%) are not within 30km of another school. This research underlines clearly that the overwhelming majority of schools could in principle share specialist resources and that, despite Australia's size, geography is only a major barrier for a fraction of schools.

Whilst access to a pool of mobile STEM specialists is a plausible notion for most schools, other barriers to collaboration must be overcome. Industrial relations, timetabling, workforce budgeting, sectoral discordance (both real and perceived), unfamiliarity with students and fear of the unknown are all valid reasons for caution. Nonetheless, enterprising schools are already working together more closely to provide their students and staff with access to the best teaching and best practice in their regions.

Case study in collaboration *University of Melbourne Network of Schools*

An example of the sort of collaboration we envisage is the University of Melbourne's Network of Schools, which brings together primary and secondary schools from all three sectors. The Network aims to improve the learning of students at participating schools through a structured program informed by the evidence base and expertise of the University of Melbourne. The Network provides efficiencies of scale and a framework for productive collaboration, enabling schools to 'achieve things together that they may not be able to achieve on their own.'[61]

[59] Bentley, T. & Cazaly, C. (2015) *The Shared Work of Learning: Lifting Educational Achievement through Collaboration*, Melbourne: Mitchell Institute.
[60] Teacher Education Ministerial Advisory Group (2014) *Action Now: Classroom Ready Teachers*, Australian Department of Education, Canberra.
[61] Melbourne Graduate School of Education, (2015) *University of Melbourne Network of Schools*, Available: http://education.unimelb.edu.au/community/university_of_melbourne_network_of_schools.

Enhance the quality of STEM professional development

There is not the fiscal or workforce capacity in the foreseeable future for STEM specialists to teach primary mathematics and science to all students all of the time. Therefore *every* primary teacher needs to be equipped to teach science and mathematics to a satisfactory baseline level.

Upskilling the sizeable proportion of the profession who lack expertise and confidence in their science and maths teaching abilities will require high quality and ongoing professional learning. Similarly, even teachers who enter the profession with solid knowledge and skills need to keep abreast of the massive advances in STEM knowledge, understanding and practice that are sure to accrue over the course of a long teaching career.

We want to see STEM specialists playing a leading role the professional learning of non-specialist teachers in all Australian primary schools, thereby improving the standard of mathematics and science teaching across the board. Reducing the high degree of variance in teacher effectiveness within schools must be a major focus of policy-makers.[62]

There is a critical role for external PD led by experts, but these opportunities should be auxiliary to the sustained, focussed and collaborative professional learning that ought to be occurring in schools. More rigorous oversight of the quality of external professional development (PD) provision is also essential.

STEM specialists to drive whole-of-school improvement in mathematics and science instruction

The ultimate objective of any program of professional learning must be enhanced student learning. International research indicates that too often PD focuses on teacher mastery of subject knowledge and skills at a remove from the desired endpoint: a positive impact on student learning. Timperley's meta-analysis of professional learning, undertaken for the New Zealand Department of Education, has shown the benefits of setting clear objectives for PD and rigorously assessing its impact on student attainment.[63]

We believe that STEM specialists should take a leadership role in delivering, facilitating and assessing the whole-school impact of PD in their subject specialism. It would be the responsibility of the STEM specialist to set the appropriate targets for learning and deliver high quality professional development relevant to these targets and engage additional external expertise where required.

Crucially, it would fall on them to continually review the impact of the PD against the original objectives to evaluate effectiveness. As Timperley points out, there can be "no guarantee that any specific approach to teaching will have the desired outcomes for students" so constant evaluation of impact is essential. The preparatory programmes for STEM specialism would build and hone the evaluative skills required to perform this role, focusing on developing assessment for professional inquiry in particular. Likewise, increased collaboration and the proposed network of STEM specialists offer opportunities for the sharing of best practice and resources across schools.

There is no doubt that finding the time to engage in the sort of collaborative and sustained professional learning required is a challenge. But as the Grattan Institute has convincingly demonstrated, freeing teachers from obligations such as yard-duty, pastoral care and supervising extra-curricular activities would provide much of the time teachers need to collaborate in the pursuit of better practice.[64] Equally, the introduction of dedicated STEM specialists provides additional impetus and capacity for schools to institute sustained programs of high impact, context – and discipline – specific PD.

[62] Hattie, J. (2015) *What doesn't work in education: The politics of distraction*, London: Pearson.
[63] Timperley, H., (2008) *Teacher professional learning and development*, International Academy of Education, Brussels.
[64] Jensen, B., Hunter J., Sonnemann, J. & Cooper, S. (2014) *Making time for great teaching*, Melbourne: Grattan Institute.

A rigorous accreditation and quality assurance framework for external professional development

Australian jurisdictions invest considerable time and money in external courses, seminars and workshops for teachers, but the impact of much of this PD is limited. Between 37% and 42% of surveyed Australian teachers reported that the PD had little or no impact on their teaching.[65] Our stakeholder consultations confirmed a widespread perception that too much PD is poorly delivered, or insufficiently practical. We found a worrying lack of oversight of PD provision, accreditation and evaluation. There was general consensus amongst stakeholders that with the notable exception of the *Primary Connections* program, high quality primary science PD and curriculum support is scarce and that schools lack leadership in relation to the delivery and evaluation of PD.

Of course, the PD needs of teachers vary greatly according to prior experience and qualifications. PD priorities are also informed by the learning needs of students and the school context in which teachers operate. Consequently, a degree of teacher autonomy to tailor programs of professional learning must be retained in any new framework for PD accreditation. At the same time, however, teachers need assurances that whichever external programs they choose, the content will be evidence-based and practically oriented. Right now, there are few such assurances.

According to advice from the federal Department of Education, only NSW and the ACT formally accredit or endorse professional development providers. In both jurisdictions the process is paper-based and involves no consideration of the quality or impact of the PD delivery. Providers are encouraged but not mandated to collect evidence of their impact on the classroom practices of participants. Oversight in all other Australian jurisdictions is even more lax. The absence of robust feedback loops on the quality of PD offerings makes it difficult for teachers to prospectively identify the most effective programs. It is more likely than not that scarce time and resources are being expended on ineffective programs. The school system can ill-afford this waste and we recommend immediate action to institute a much more robust framework for the accreditation of external professional development programs in all Australian jurisdictions.

[65] OECD (2014) *Australia Country Note: Teaching and Learning International Survey 2013*, Paris: OECD.

Using data to enhance assessment and learning in STEM and beyond

The transformative role that data has played across a range of sectors and industries, both in private and public spheres, has generated much speculation and raised expectations about its potential as both a disruptor and an enabler in education. Indeed the data revolution is well and truly underway in schools; Principals and teachers legitimately point to a surfeit of assessment information in subjects like literacy and numeracy. Yet the revolution has been unequal in its impact across subjects and uneven in its distribution across Australian primary schools.

We believe data is essential to driving improvements in STEM education in primary schools, and improvements in schools more widely. Effective collection and use of data is fundamental at the classroom level; as Hattie has outlined, the single most effective way to improve student learning is to enhance the quality of feedback teachers garner from students about their impact on learning.[66] Likewise, data will be fundamental at the system level; the wealth of information we now have on students in terms of attainment, participation and background has myriad and, at present, unrealised applications.

Unless data is properly harnessed by all primary schools, through improved collection, application, distribution and analysis, its much-vaunted transformational properties are destined to remain unrealised.

Using data more effectively

Across all areas of learning, teachers need to know where students are at and what they are ready to learn next. This is especially important to the teaching of numeracy, where the acquisition of knowledge and skills is a cumulative process. Data plays a crucial role in informing teachers about student learning and progression, but the existence of data will not lead to improvements in student progress alone; "schools are awash with data. But too often the data schools have is not the information teachers need and it does not improve teaching."[67] Effective use of data is reliant on capturing the right information, drawing the correct conclusions from it and understanding the required steps to ensure progression.

Outstanding teachers know what data to use to identify where students are at in their learning. It is our expectation that STEM specialists will be trained in 'clinical' approaches to student assessment; in other words, they will be able to: (a) correctly diagnose what each student already knows or can do; (b) determine what each student is ready to learn next; (c) implement teaching strategies to ensure that learning occurs (d) evaluate the of impact of the teaching on each students' learning.

Case study
PLASST

The PLASST is a tool that the Department of Education and Communities NSW is developing to assist teachers and learning and support teams in profiling the educational needs of students who may need personalised learning and support associated with disability. The purpose of the tool is to provide an intuitive and simple process to guide teachers as they identify individual student's educational needs and implement personalised learning and support for their students. Whilst this is a trial at present, its user friendly approach and synthesis of information should be used s a model for other such diagnostic tools.

[66] Hattie, J. (2009) *Visible Learning: A synthesis of over 800 meta-analyses relating to achievement*, London: Routledge.
[67] Goss, P. & Hunter, J. (2015) *Targeted teaching: How better use of data can improve student learning*, Melbourne: Grattan Institute.

Specialists and teachers alike would benefit from more sophisticated assessment tools and "we need more research on how to create reports drawn from test results which teachers and students can interpret accurately, and which teachers can use to work out what their next teaching interventions should be."[68] Here there is a role for governments and system leaders to support this research to inform the creation and distribution of effective assessment tools that will help all teachers perform diagnostic analysis in a quick and simple way. Many of these tools may already be in existence abroad and at home and these should be evaluated and, where their impact is corroborated, scaled across Australian primary schools.

These tools must be user-friendly and accessible, but as the Grattan Institute has rightly pointed out, they will only be partially effective unless we build teacher and school leader capacity to target teaching and track student progress. Teachers need to be coached on how to "use the tools, interpret the results, and adjust their teaching in response to the evidence of student learning needs."[69] We believe there is a role here for STEM specialists, to coach their peers in this targeted teaching approach. As proponents of better use of data in STEM subjects they could also influence other areas of the curriculum by example and osmosis.

Building a bedrock of data on Science

Primary school teachers, like their secondary counterparts, report that they are suffering from assessment fatigue with a growing battery of tests (and acronyms) to navigate. NAPLAN, PISA, PIRLS and TIMSS at regular intervals offer a relatively robust macro picture of Australian student achievement in numeracy and literacy.

However, data on primary level science attainment is scarce by contrast. The Year 4 TIMSS (Trends in International Mathematics and Science Study) assessments are conducted every four years, giving only the broadest of system-level snapshots for use primarily by policy makers. The test serves no useful diagnostic purpose for teachers or students. NAPLAN testing of Year 6 students for science literacy is triennial, making it only marginally more regular.

The lack of formative and summative assessment of science in primary schools means that teachers, school leaders and governments have no real picture of attainment or progression in this key discipline. More alarming than this is the lack of consensus on what is acceptable or desirable student progression in this subject. As Hattie suggests "there needs to be debate and agreement among educators about what a year's progress looks like" at different levels of primary science.[70] There are many benefits that would arise from such a debate, at a school and national level.

Case study
E-Health records

The eHealth record system was introduced nationally in July 2012 as collaboration between Department of Health and National E-Health Transition Authority (NEHTA), with PwC helping to develop and implement a framework for ensuring its successful realisation.

An eHealth record is a secure online summary of an individual's health information. They will give healthcare providers access to patient information such as medications, test results, discharge summaries, allergies and immunisations. This will help ensure health care is delivered more efficiently and effectively by minimising unnecessary repeat tests, managing medication better and improving continuity of care.

We believe a similar model could be used for school students, to allow for a more tailored approach and smoother management of transition points in the schools system.

[68] Hattie, J. (2015) *What works best in education: The politics of collaborative expertise*, London: Pearson.
[69] Goss, P. & Hunter, J. (2015) *Targeted teaching: How better use of data can improve student learning*, Melbourne: Grattan Institute.
[70] Hattie, J. (2015) *What works best in education: The politics of collaborative expertise*, London: Pearson.

Better management of transition points

Our stakeholder consultations have consistently shone a light on how student data is siloed as a result of poor system connectivity. The feedback from educators and policy makers is that student information can be poorly distributed within schools (between teachers and at year transitions), between schools, sectors and states. Whilst this is not an expressly STEM or primary problem, the highly sequential nature of knowledge and skill acquisition in subjects like mathematics means that poor information migration has a particularly acute impact on student learning and the ability of teachers to implement targeted teaching.

Practices pertaining to the transfer of student data from year-to-year vary worryingly from school to school. As for transitions from one school to another or from primary to secondary education, there are significant challenges "including efficiently transferring and accessing student information, establishing and maintaining effective communications and monitoring student outcomes."[71] Poor transition of information results in duplications and omissions and means that student progress can be slowed, arrested or even reversed.

We recommend the consideration of a universal pupil record system to address these problems. Such a database would be linked to existing student identifiers and would contain information on participation, attainment, regulated teacher comments and other student characteristics, most of which is collected presently, but not routinely aggregated or provided in an accessible or useful format. Access to these records should be restricted to approved users and strict guidance given on the correct use of such a resource. We see a range of potential benefits; from providing primary school teachers a deeper understanding of their students' progress, to offering secondary schools much needed, if basic, information on their intake. Used properly, the ultimate beneficiaries will be students, as teachers will be better placed to cater to individual learning needs.

Sharing data for research

We should be prepared to admit that we do not fully understand all the drivers of under-achievement in STEM education. Whilst part of the solution surely lies in high quality teaching, a great deal else is very much up for debate.

The advent of the sharing economy has reinforced in other sectors the application and benefits of allowing access to data. Whilst pupil data is rightly a sensitive topic, alarmism and misconceptions should give way to informed discussion. Other OECD countries have already taken steps to make pupil data accessible to a range of stakeholders and organisations. In the UK the National Pupil Database has collected several decades' worth of pupil information and it is now accessible to registered researchers.

We have to become more willing to share what is and isn't working. Australia's diverse schools landscape has fostered an unwillingness to share information. This must be challenged. A more comprehensive database of educational indicators should be compiled on a national basis and made available to academic researchers in much the same way as the Household Income and Labour Dynamics of Australia and Longitudinal Survey of Australian Youth datasets (HILDA).

[71] Victorian Auditor-General (2015), *Education Transitions*, Victorian Government Printer.

Increase the quality of and quantity of STEM instruction

A wide range of stakeholders has lamented the crowded primary school curriculum. This concern was echoed by the recent federal government review of the National Curriculum.[72] The primary curriculum has been burdened with "extras" such as 'drugs, healthy food, racism, environmental concerns, weed identification, driver education and stranger danger' and while it can be argued that each of these issues is important, the inevitable cumulative effect is a diminution of teaching time for core academic priorities.[73]

Certainly, the amount of time devoted to primary science would seem to have suffered, with the Chief Scientist finding that in an average week, science instruction occupies less 3% of primary teaching time and mathematics around 18%.[74]

We believe a set of meticulously developed, clearly sequenced and universally accessible science modules would boost the confidence of non-specialists to teach more science to a higher standard. Careful consideration also needs to be given the rigor of the primary science and mathematics curricula, given that leading systems internationally tend to teach more complex topics at earlier ages.

Rationalise the primary curriculum to give priority to Science and Maths

The primary curriculum clearly needs to be 'de-cluttered' to make time for essential science and maths learning. One of the many potential benefits of the introduction of STEM specialists is that time for science and mathematics instruction may be more formally timetabled than it is presently, and less likely to be sacrificed to make room for the 'extras' that clamour for time and resources. Encouraging national and in-school debate on what a year's progress in science looks like would also likely support better assessment and increase the amount of teaching time devoted to the subject, given that what gets measured tends to get done.

"Science instruction occupies less 3% of primary teaching time and mathematics around 18%"

[72] Donnelly, K. & Wiltshire K. (2014), *Review of the Australian Curriculum Final Report*, Department of Education, Canberra.

[73] Dinham, Stephen (2014) 'Primary Schooling in Australia: Pseudo-Science Plus Extras Times Growing Inequality Equals Decline,' Keynote Address, Australian College of Educators National Conference, Adelaide, 11th September.

[74] Chubb, Ian (2013) *Keynote Address by the Chief Scientist to the Seventeenth National Engineering Heritage Conference*, National Portrait Gallery, Canberra, November 18th.

More prescriptive and comprehensive resources to support STEM instruction by non-specialists

There is a lack of comprehensive, 'teacher-friendly' classroom resources to assist in delivering science content in particular. We see a role for detailed, prescriptive 'plug and play' modules of work to support non-specialist primary teachers to overcome their lack of confidence and discipline knowledge to deliver rigorous instruction. The Primary Connections program, developed by the Australian Academy of Science, comes close to delivering the sort of product we envisage, but the resources do not cover the full gamut of the primary curriculum and must be purchased by individual schools or teachers. Leading researcher, Hattie, likewise entertains the use of 'explicit instruction scripts' (with associated evidence of impact) for primary science as a cost-efficient and quick means of attaining an acceptable baseline quality and quantity of science instruction, given the constraints of the current workforce.

While there is an abundance of science teaching resources, the vast bulk of these materials is not organised into coherent modules or sequences of lessons. Teachers need considerable discipline expertise to discern high quality materials from dross and to integrate these resources into pedagogically sound modules. Survey evidence and stakeholder feedback suggest that many teachers lack confidence in their ability to parse the available resources for quality and then incorporate them into lesson sequences. Teachers' uncertainty about how to make effective use of resources was a frequently cited reason for eschewing science instruction. The introduction of meticulously developed, sequenced and universally accessible primary science modules would boost the confidence and efficacy of non-specialist teachers.

A more rigorous curriculum?

There is evidence that the Australian primary mathematics and science curriculum is unambitious relative to that of world-leading jurisdictions. The recent review of the Australian Curriculum found that students in East Asia are tackling more advanced mathematical and scientific concepts and content at an earlier age than their Australian counterparts.[75]

Instating a more rigorous primary maths and science curriculum would boost our long-term competitiveness but needs to be carefully considered alongside the capacity constraints of the current and future workforce and a justified 'change-fatigue' due to major curriculum overhauls in recent years.

[75] Donnelly, K. & Wiltshire K. 2014, *Review of the Australian Curriculum Final Report*, Department of Education, Canberra.

Implementation considerations

These recommendations need to be strategically implemented. There are a number of ways to achieve each recommendation, which presents policy makers and school leaders with a variety of options. We have therefore taken the options and given initial thought to some implementation considerations.

Table 2: Possible challenges of our recommendations

Recommendation	ID	Options to achieve recommendation	Implementation challenges
Provide access to a specialist STEM teacher for every Australian primary school	1a	Differentiated pay for specialists	Potential opposition relating to industrial relations
	1b	Revised ITE requirements for STEM specialism	Need cooperation from teacher education providers. Cost of delivering additional elements (mostly borne by teacher education students)
	1c	Retraining of existing teachers as specialists	Change resistance from existing teachers Identification of suitable candidates Incentivising existing teachers to specialise
	1d	Pilot of school collaboration, followed by wider roll-out	Change resistance from school leaders Sectoral barriers
Improve the standard of professional development for all teachers of primary science and mathematics	2a	Rationalising of STEM PD modules	Inter-state differences in standards
	2b	Training of specialists to deliver targeted PD	Cost of developing the required assessment and leadership capabilities
Better use of data for targeted teaching and enhanced learning in STEM and beyond	3a	National Pupil database	Privacy concerns; integration of different state databases
	3b	Re-skilling of teachers on data use	Change resistance from current teachers; need to find expert instructors to teach the teachers in data collection and interpretation
Increase the quality and quantity of STEM instruction in Australian Primary schools	4a	De-cluttering the curriculum	Vested interests will not want their ‘non-core’ or ‘extras’ topics removed
	4b	Development and delivery of ‘plug and play’ direct instruction modules and resources	Determining which level of government will fund and sponsor
	4c	Revision of curriculum to make it more rigorous	Change resistance from current teachers

These options should be prioritised according to the ease of implementation, combined with the anticipated magnitude of impact. We also need to consider the agents involved and the need for collaborative action between state and federal governments, ITE providers and statutory authorities.

Conclusion

Australia is at an inflexion point. Either we prepare the next generation to thrive in an increasingly technologically complex and competitive global economy or we acquiesce to lower productivity, slower growth and declining standards of living. The task of equipping the future workforce with the STEM skills, knowledge and curiosity required to prosper in an era of technological disruption begins in primary school.

The recommendations outlined in this white paper are ambitious but attainable. There are costs involved, but they are not vast, and they pale in comparison to the costs of inaction.

Likewise, the implementation challenges are surmountable, provided key stakeholders accept that the interests of students are paramount and that goodwill can be established across different educational sectors and different levels of government. To do otherwise endangers Australia's future prosperity and relinquishes our chance to lead the STEM innovation of the future.

"Either we prepare the next generation to thrive in an increasingly technologically complex and competitive global economy or we acquiesce to lower productivity, slower growth and declining standards of living."

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Authors of the paper

Sara Caplan

Sara has over 25 years of experience in the education sector in Australia and internationally. Sara has worked as Maths lecturer and as a Partner in the PwC UK Consulting practice led the firm's Education and Skills business. Sara has been a professional consulting leader since 2001 and prior to this spent 10 years in both delivery and senior management roles within in the UK Education Sector.

Helen Baxendale

Helen is a former advisor to the Australian Minister for Education and she is currently undertaking an MPhil in Comparative Social Policy at the University of Oxford as a Rhodes Scholar. Helen has taught in secondary schools in Australia and holds a Post-Graduate Diploma of Teaching.

Philip Le Feuvre

Philip specialises in education and public policy, having been a primary school teacher in two schools in areas of high socio-economic deprivation in the UK. He has also served as a Governor for primary schools undergoing periods of rapid improvement and is a leadership coach for teachers.

Contacts

Sara Caplan
National Skills Leader

sara.a.caplan@pwc.com
+61 2 8266 3882

Tony Peake
Government and Public Sector Leader

tony.peake@pwc.com
+61 3 8603 6248

David Sacks
National Education Leader

david.sacks@pwc.com
+61 3 8603 6151

Philip Le Feuvre
Senior Manager

philip.le.feuvre@pwc.com
+61 2 8266 3661