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

Ross Turner
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.

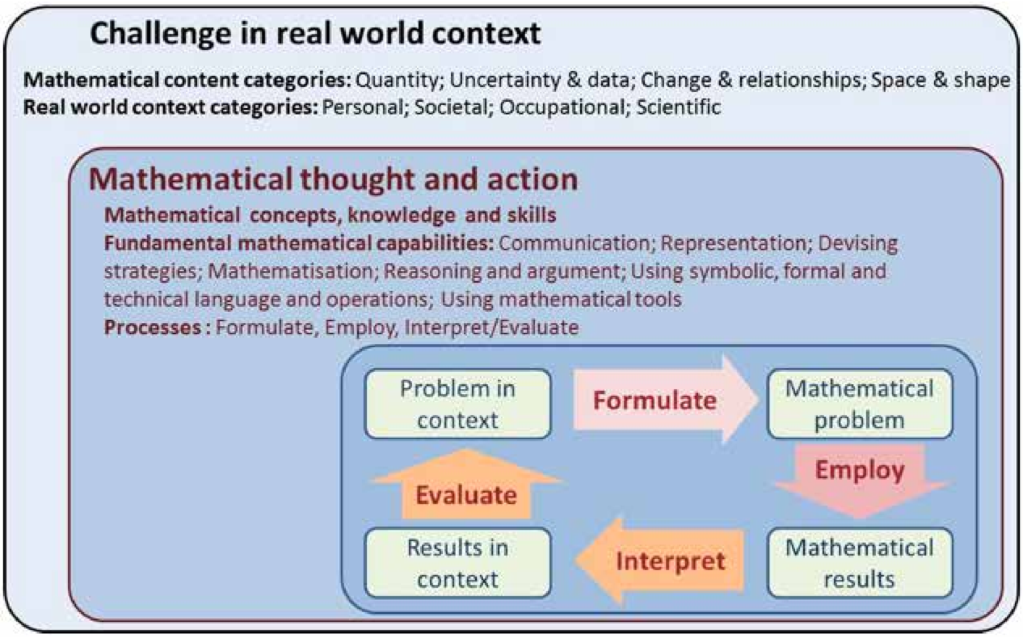


Figure 1 Representation of key elements of the PISA mathematics framework (from OECD, 2013a)

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.

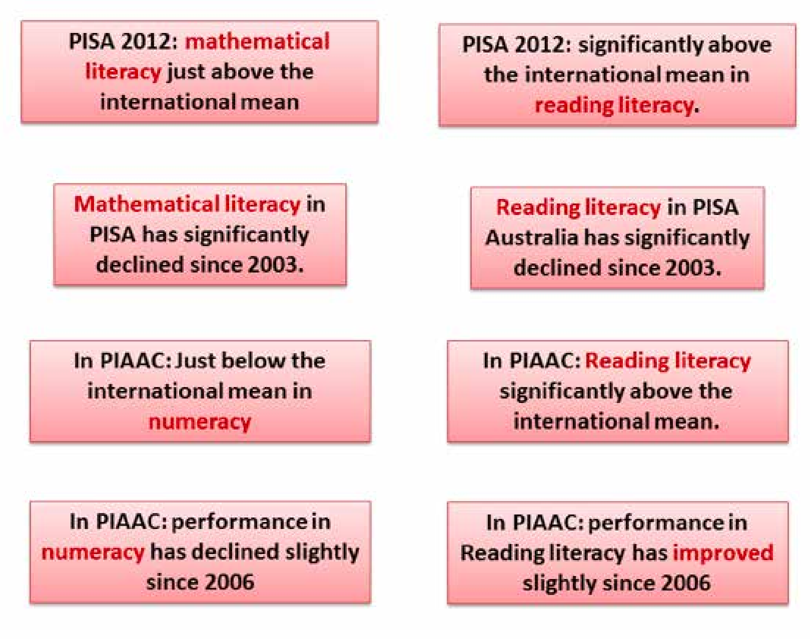


Figure 2 Some recent PISA and PIAAC outcomes

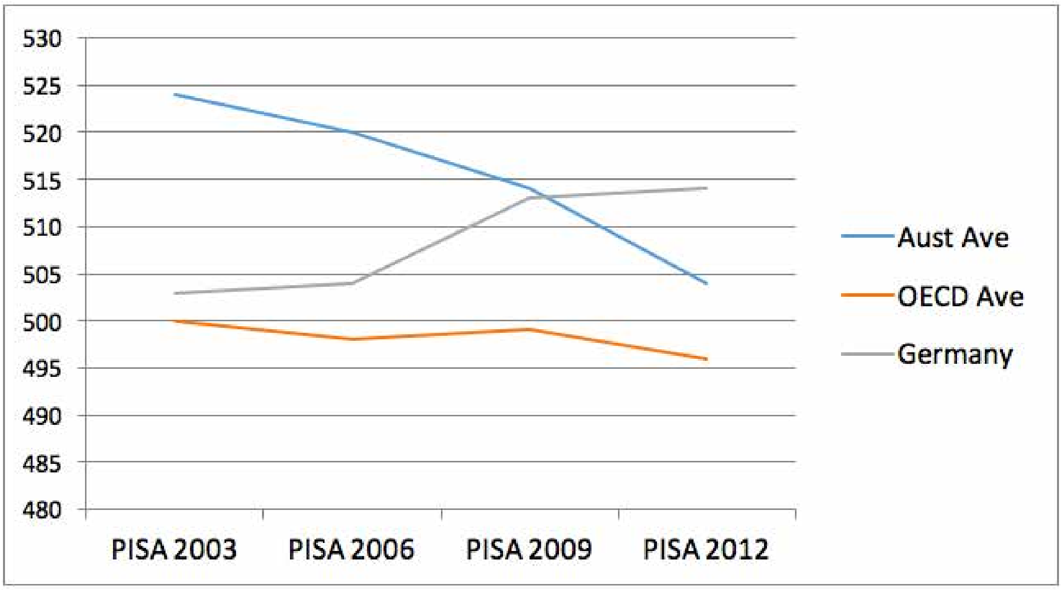


Figure 3 PISA mathematics decline 2003–2012

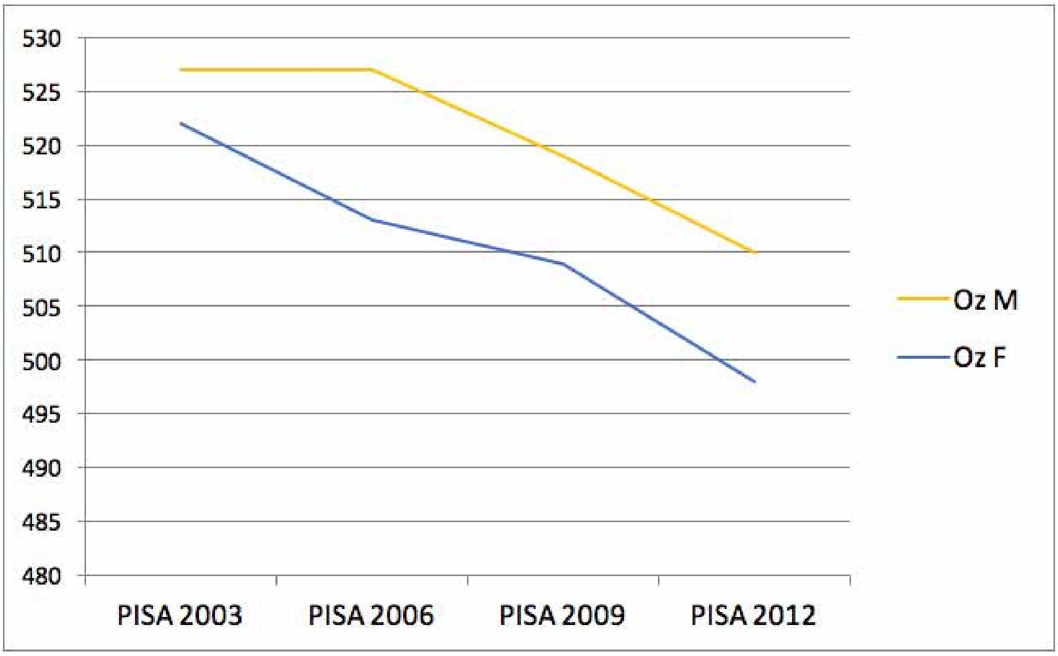


Figure 4 PISA mathematics trend lines for Australian female and male students 2003–2012

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.

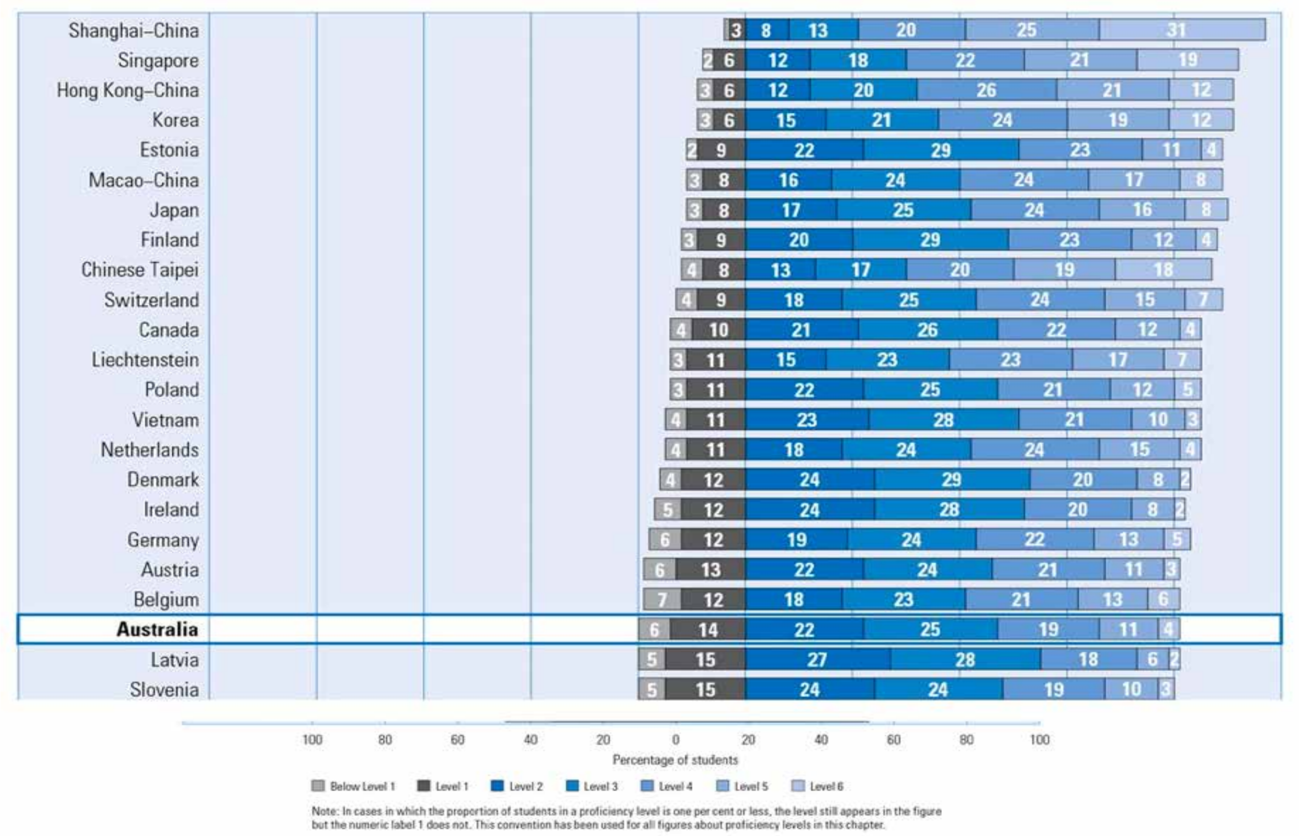


Figure 5 Percentage of PISA mathematics students by level for several countries, highlighting the comparison for percentages reaching Level 2 and above

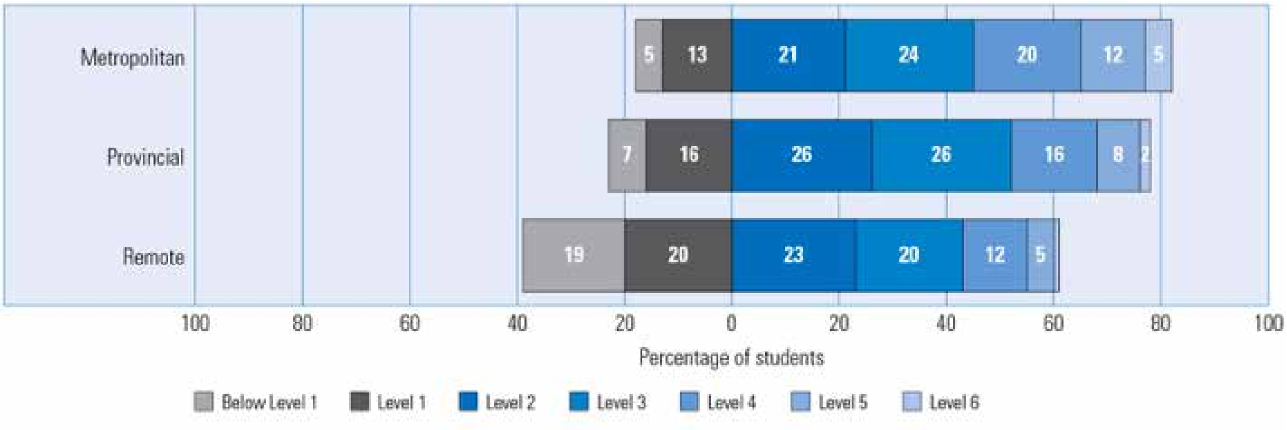


Figure 6 Proficiency profile of Australia's mathematics students by location type

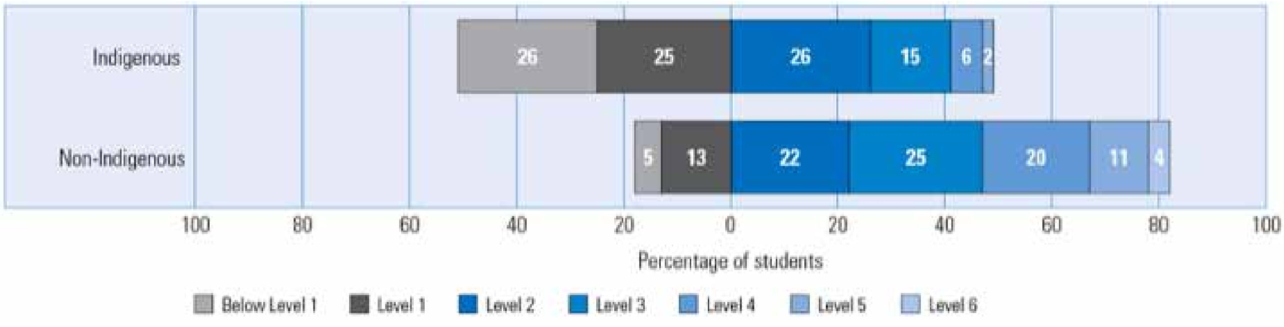


Figure 7 Proficiency profile of Australia's mathematics students by indigeneity

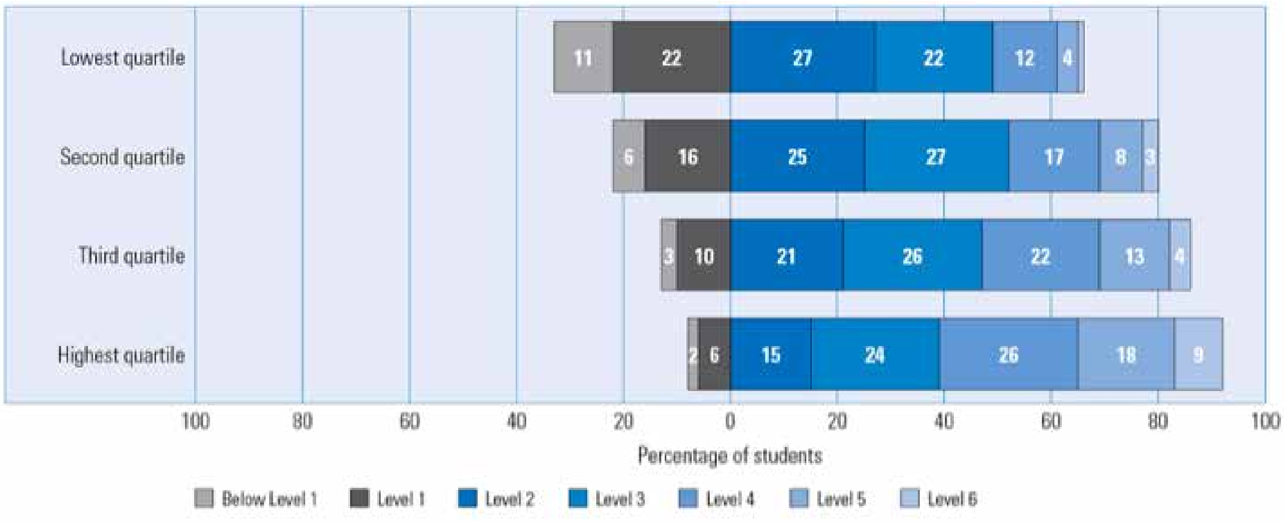


Figure 8 Proficiency profile of Australia's mathematics students by family socio-economic category

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.

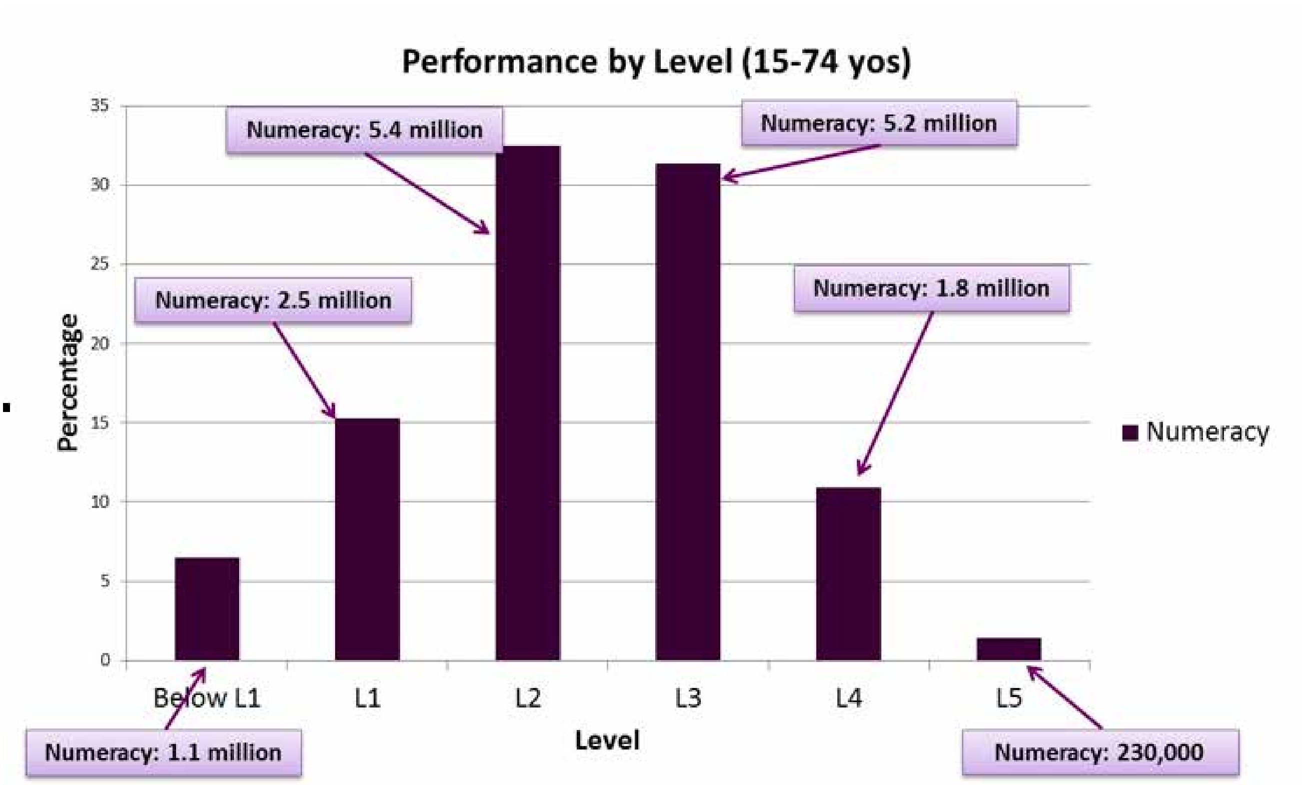


Figure 10 Performance by level in numeracy in PIAAC 2012. Total Australian population aged 15–74 years

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:

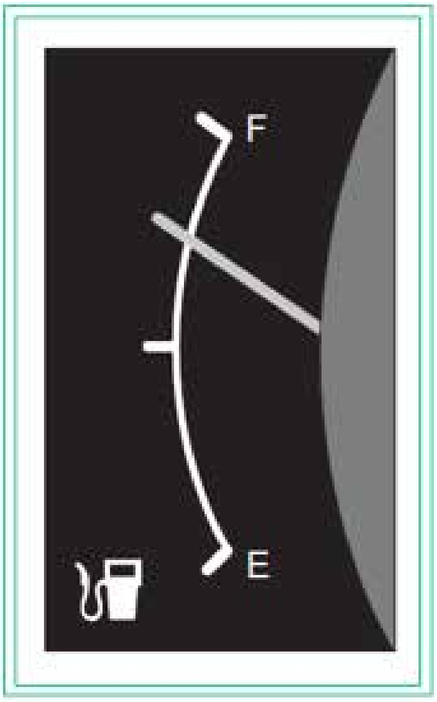
Tasks at this level are set in concrete, familiar contexts where the mathematical content is explicit with little or no text or distractors and that require only simple processes such as counting, sorting, performing basic arithmetic operations with whole numbers or money, or recognizing common spatial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

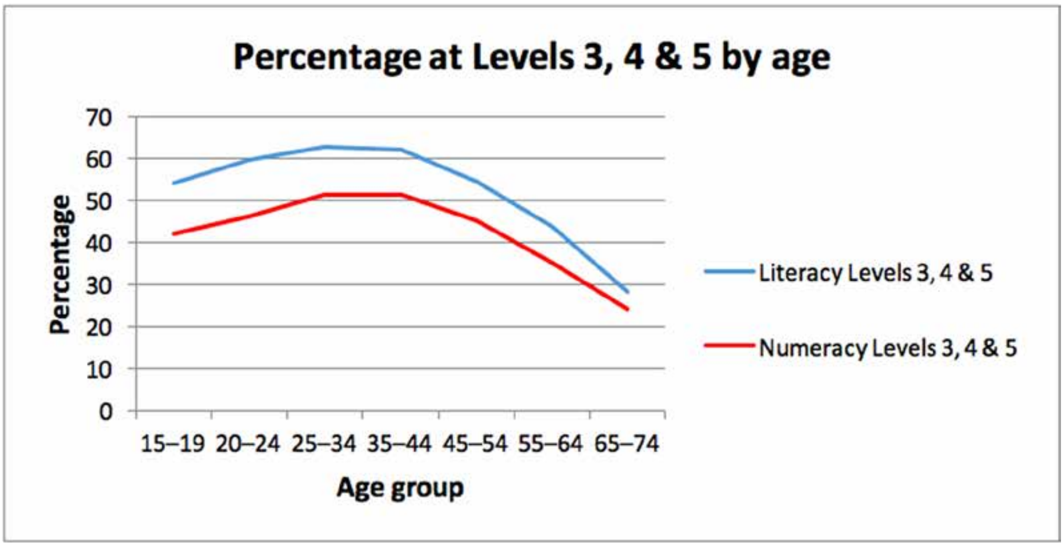


Figure 11 Percentage of Australian PIAAC cohort at the upper proficiency levels, by age

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.

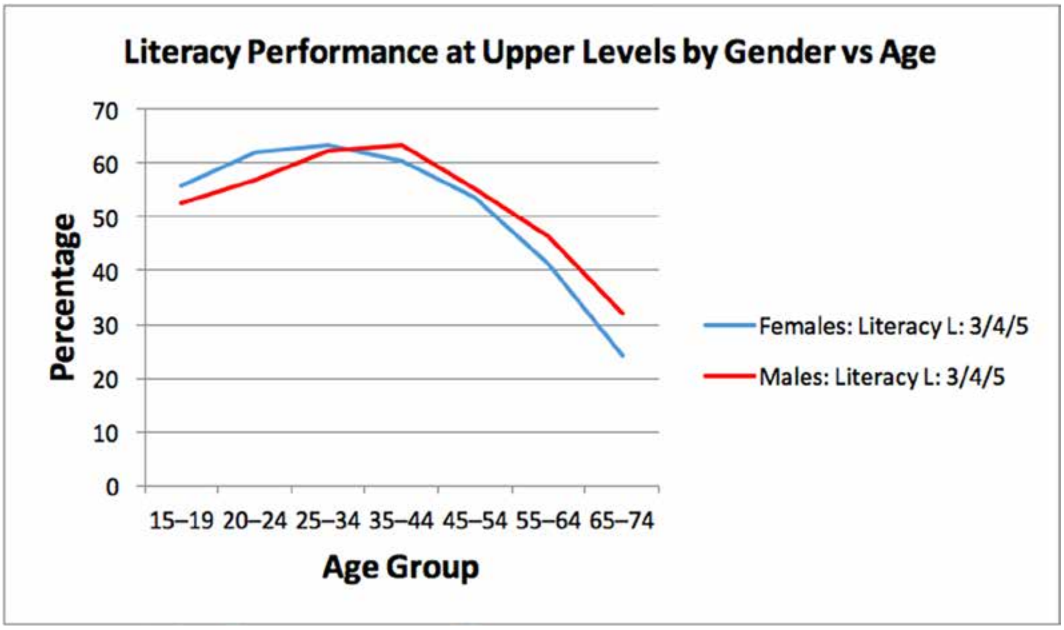


Figure 12 Age-group profile for PIAAC literacy for females and males

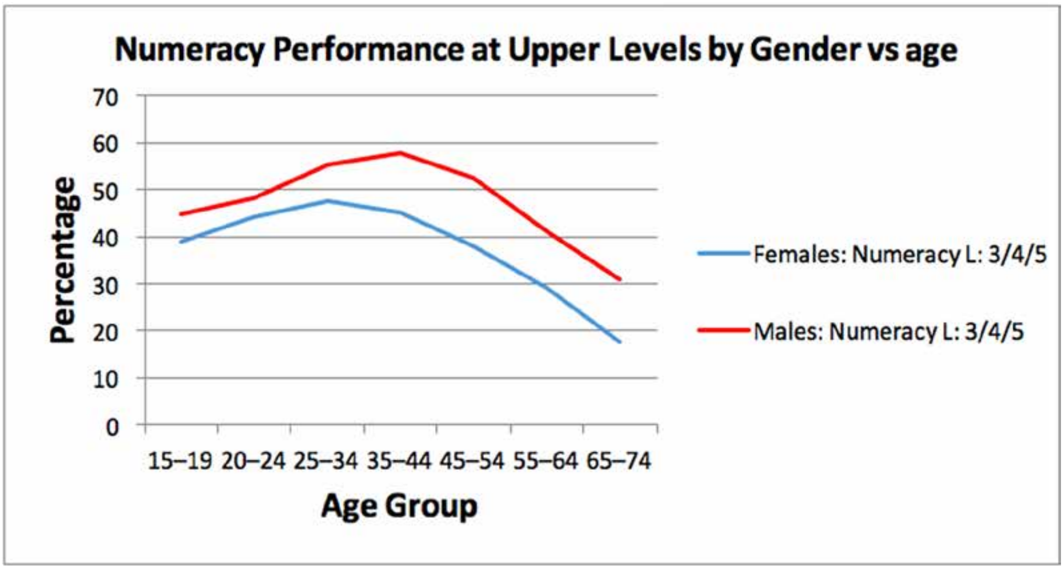


Figure 13 Age-group profile for PIAAC numeracy for females and males

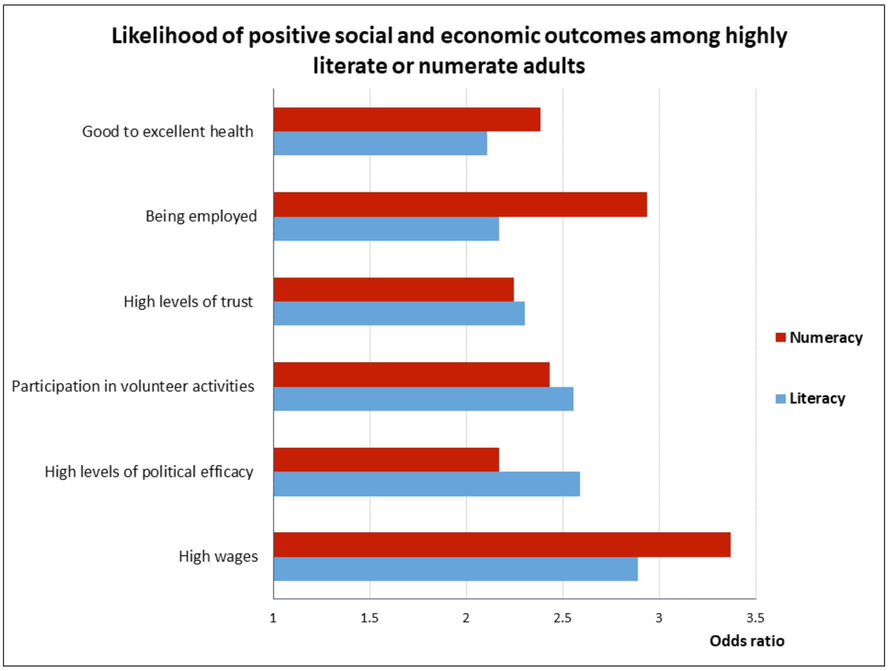


Figure 14 Likelihood of positive social and economic outcomes among highly literate or numerate adults (OECD, 2013b)

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

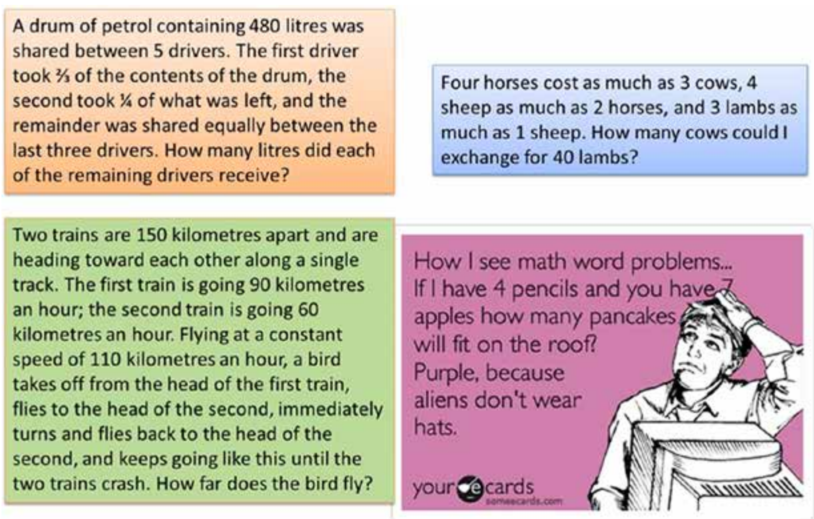


Figure 15 The wrong approach

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.

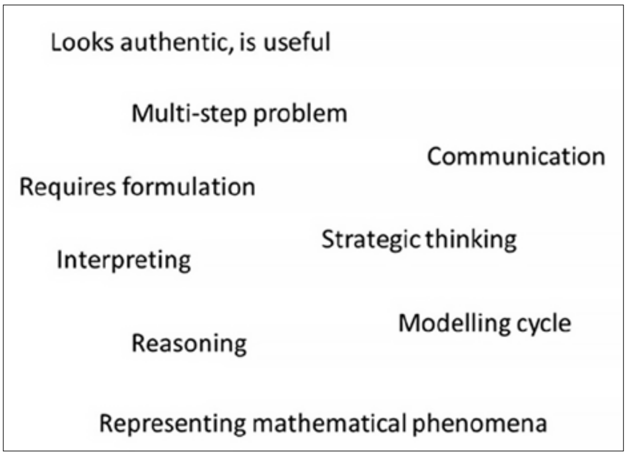


Figure 17 Desirable characteristics of good mathematics tasks

References

ACARA. (2015). *Measurement framework for schooling in Australia.* http://www.acara.edu.au/_resources/Measurement_Framework_for_Schooling_in_Australia_2015.pdf

Australian Bureau of Statistics. (2013). *Programme for the International Assessment of Adult Competencies.* (cat. no. 4228.0). Canberra: Australian Bureau of Statistics.

Bynner, J. & Parsons, S. (2005). *Does numeracy matter more?* London: National Research and Development Centre for Adult Literacy and Numeracy.

Gal, I. & Tout, D. (2014). *Comparison of PIAAC and PISA Frameworks for Numeracy and Mathematical Literacy*. OECD Education Working Papers, No. 102. Paris: OECD Publishing.

Hoyles, C., Wolf, A., Molyneux-Hodgson, S. & Kent, P. (2002), *Mathematical Skills in the Workplace*. London: Science, Technology and Mathematics Council. http://eprints.ioe.ac.uk/1565/1/Hoyles2002MathematicalSkills.pdf

OECD. (2012). *Literacy, Numeracy and Problem Solving in Technology-Rich Environments: Framework for the OECD Survey of Adult Skills*. Paris: OECD Publishing.

OECD. (2013a). Mathematics Framework. In OECD, *PISA 2012 Assessment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy*. Paris: OECD Publishing.

OECD. (2013b). *OECD skills outlook 2013: First results from the survey of adult skills*. Paris: OECD Publishing.

OECD. (2013c). *PISA 2012 results: What students know and can do: Student performance in reading, mathematics and science,* (Vol. I.) Paris: OECD Publishing.

Stacey, K. and Turner, R. (Eds.). (2015). *Assessing Mathematical Literacy: The PISA Experience*. Switzerland: Springer. doi: 10.1007/978-3-319-10121-7

Thomson, S., De Bortoli, L. & Buckley, S. (2013). *PISA 2012: How Australia measures up. The PISA 2012 assessment of students' mathematical, scientific and reading literacy*. Melbourne: Australian Council for Educational Research.

Turner, R. (2016). Lessons from PISA 2012 about mathematical literacy: An illustrated essay. *PNA, 10*(2), 77–94.

STEM and Indigenous students

Professor Elizabeth McKinley
University of Melbourne

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).

References

Aikenhead, G. S. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 27*, 1–52.

Aikenhead, G. S. (2006). *Science education for everyday life: Evidence-based practice.* New York: Teachers College Press.

Bang, M., Medin, D., Washinawatok, K. & Chapman, S. (2010). Innovations in Culturally-based Science Education through Partnerships and Community. In M. Khine & I. Saleh (Eds.). *New Science of Learning: Cognition, Computers and Collaboration in Education* (pp. 569–592). New York: Springer.

Bishop, R., Berryman, M., Wearmouth, J., Peter, M., & Clapham, S. (2012). Professional development, changes in teacher practice and improvement in Indigenous students' educational performance: A case study from New Zealand. *Teaching and Teacher Education, 28,* 694–705.

Boon, H. J. & Lewthwaite, B. E. (2015). *Signatures of quality teaching for Indigenous students.* Paper presented at the Australian Association of Research in Education (AARE), 29 Nov–2nd Dec., University of Notre Dame, Fremantle, Western Australia.

Dreise, T. & Thomson, S. (2014). *Unfinished business: PISA shows Indigenous youth are being left behind*. Melbourne: Australian Council for Educational Research. https://www.acer.edu.au/occasional-essays/unfinished-business-pisa-shows-indigenous-youth-are-being-left-behind

Freeman, B., Marginson, S. & Tytler, R. (Eds.). (2015). *The Age of STEM: Educational Policy and Practice Across the World in Science, Technology, Engineering and Mathematics.* New York: Routledge.

Giroux, H. A. (1992). *Border crossings: Cultural workers and the politics of education.* New York: Routledge.

Greenfield, P. M., Keller, H., Fuligni, A. & Maynard, A. (2003). Cultural pathways through universal development. *Annual Review of Psychology, 54,* 461–490.

Greenfield, P. M., Quiroz, B. & Raeff, C. (2000). Cross-cultural conflict and harmony in the social construction of the child. In S. Harkness, C. Raeff & C. M. Super (Eds.). *Variability in the social construction of the child* (pp. 93–108). New Directions in Child Development, No. 87. San Francisco: Jossey-Bass.

Gutierrez, K. D. & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher, 32*(5), 19–25.

Knighton, T., Brochu, P. & Gluszynski, T. (2010). *Measuring up: Canadian results of the OECD PISA Study – The performance of Canada's youth in reading, mathematics and science, 2009. First results for Canadians aged 15*. Ottawa: Human Resources and Skills Development Canada, Council of Ministers of Education Canada, and Statistics Canada.

Lewthwaite, B. E., Lloyd, N. & Boon, H. J. (2015). *Effective teaching practices reported by Aboriginal parents, students and their teachers: Comparisons and contrasts.* Paper presented at the Australian Association of Research in Education (AARE), 29 Nov–2nd Dec., University of Notre Dame, Fremantle, Western Australia.

Marginson, S., Tytler, R., Freeman, B. & Roberts, K. (2013). *STEM: Country comparisons*. Australian Council of Learned Academies (ACOLA).

McConney, A., Oliver, M., Woods-McConney, A., & Schibeci, R. (2011). Bridging the Gap? A Comparative, Retrospective Analysis of Science Literacy and Interest in Science for Indigenous and Non-Indigenous Australian Students. *International Journal of Science Education, 33*(14), 2017–2035.

McKinley, E. & Gan, M. (2014). Culturally responsive science education for Indigenous and ethnic minority students. In N. G. Ledermann & S. K. Abell, (Eds.). *Handbook of Research on Science Education Volume II.* New York: Routledge.

McKinley, E. & Stewart, G. (2009). Falling into place: Indigenous science education research in the Pacific. In S. Ritchie (Ed.). *Science education research in Australasia.* World of Science Education Series. Rotterdam: Sense Publishers.

Meaney, T., Trinick, T. & Fairhall, U. (2011). *Collaborating to meet language challenges in Indigenous mathematics classrooms.* Dordrecht, Heidelberg, London, New York: Springer.

Ministerial Council for Education, Early Childhood Development and Youth Affairs (MCEECDYA). (n.d.). *Aboriginal and Torres Strait Islander Education Action Plan 2010–2014.* Victoria, Australia: MCEECDYA.

Nam, Y., Roehrig, G., Kern, A. & Reynolds, B. (2013). Perceptions and practices of culturally relevant science teaching in American Indian classrooms. *International Journal of Science and Mathematics Education, 11*, 143–167.

Rozek, C.S., Hyde, J.S., Svoboda, R.C., Hulleman, C.S., & Harackiewicz, J.M. (2015). Gender differences in the effects of a utility-value intervention to help parents motivate adolescents in mathematics and science. *Journal of Educational Psychology, 107*(1), 195–206.

Song, S., Perry, L. B. & McConney, A. (2014). Explaining the achievement gap between Indigenous and non-Indigenous students: An analysis of PISA 2009 results for Australia and New Zealand. *Educational Research and Evaluation. An International Journal on Theory and Practice, 20*(3), 178–198.

Webber, M., McKinley, E. & Rubie-Davies, C. (2016). Making it personal: Academic counseling with Māori students and their families. *Contemporary Educational Psychology.* doi:10.1016/j.cedpsych.2016.03.001

Woods-McConney, A., Oliver, M., McConney, A., Maor, D., & Schibeci, R. (2013). Science Engagement and Literacy: A Retrospective Analysis for Indigenous and Non-Indigenous Students in Aotearoa New Zealand and Australia. *Research in Science Education, 43*, 233–252.

Woods-McConney, A. & McConney, A. (2014). *Indigenous Student Success in Science.* Perth: Murdoch University, School of Education.