Mathematics learning: What TIMSS and PISA can tell us about what counts for all Australian students

Sue Thomson

Australian Council for Educational Research

Sue Thomson is a Principal Research Fellow at the Australian Council for Educational Research in the National and International Surveys research program.

Dr Thomson is the National Research Coordinator for Australia in the Trends in International Mathematics and Science Study (TIMSS), which measures achievement in mathematics and science for students in grades 4 and 8, the Progress in International Reading Literacy Study (PIRLS), which measures reading literacy of grade 4 students, and the National Project Manager for Australia for the OECD Programme for International Student Assessment (PISA), which examines reading, mathematical and scientific literacy of 15-year-old students.

Dr Thomson's research at ACER has involved extensive analysis of large-scale national and international data sets – the Longitudinal Surveys of Australian Youth (LSAY), as well as TIMSS and PISA.

Dr Thomson was engaged as an expert writer on the National Numeracy Review, and has consulted with DEEWR, FaHCSIA and the Victorian and ACT Departments of Education on a variety of data analysis projects related to TIMSS and PISA.

Before joining ACER, Dr Thomson lectured at a number of universities in Statistics and Research Methodology while she completed her PhD focusing on students' attributions and engagement in mathematics over the transition from primary to secondary school.

Dr Thomson has published a variety of articles and research reports based on her work at ACER (see also under Sue Fullarton), and has presented findings at conferences internationally and nationally.

Abstract

Teachers and school leaders will be familiar with NAPLAN – as a census of students in Years 3, 5, 7 and 9 it involves all educators. However, as part of the National Assessment Program, Australia also participates in two international assessments, PISA and TIMSS, which are, by design, light sample assessments and involve only a small proportion of schools. The students we are educating today will compete in a global market, and we have to be sure that the education we are providing them with is one that will provide them with a strong base, both in knowledge and skills and in the ability to apply those skills to real-world problems. In addition to the assessments, PISA and TIMSS collect a rich array of contextual information from students, teachers and schools – including background factors, and attitudes and beliefs about learning mathematics. What should be particularly interesting for educators is not just how well students perform on the international assessments, but how much the other information we gather can tell them about what Australian students can and can't do.

Introduction

In 1999, the Ministers responsible for school education, the Ministerial Council on Education, Employment, Training and Youth Affairs, agreed to a new set of *National Goals for Schooling in the Twenty-first Century* (MCEETYA, 1999). The aim of these goals was to provide Australian students with high-quality schooling to provide them with the necessary knowledge, understanding, skills and values for a productive and rewarding life. MCEETYA also set in train a process to enable nationally comparable reporting of progress against these *National Goals*. The *Measurement Framework for National Key Performance Measures* (MCEETYA, 2008) sets out the *National Assessment Program* as a basis for reporting ongoing progress towards the goals by drawing on agreed definitions of Key Performance Measures. The *Framework* is designed to be a living document, in that it will be updated to report on the most recent goals as defined in the *Melbourne Declaration on Educational Goals for Young Australians*, allowing it to respond to new goals and challenges.

The National Assessment Program encompasses all tests endorsed by MCEETYA, such as the national literacy and numeracy tests (NAPLAN), three-yearly sample assessments in science literacy, civics and citizenship, and ICT literacy, and Australia's participation in the international assessments PISA and TIMSS.

Teachers and school leaders are familiar with NAPLAN – as a census of students in Years 3, 5, 7 and 9 it involves all educators. However, many may not be aware of PISA and TIMSS, as they are light sample assessments which, by design, involve only a proportion of schools. In addition to the assessments, PISA and TIMSS collect a rich array of contextual information from students, teachers and schools – including background factors, and attitudes and beliefs about learning mathematics. What should be particularly interesting for educators is not just how well students perform on the international assessments, but how much the other information we gather can tell them about what Australian students can and can't do.

The presentation will be structured around the questions teachers often ask:

- What are PISA and TIMSS? Who participates?

- Why do we need these assessments as well as NAPLAN?
- What can these studies tell me about what our students learn compared to other countries?
- What can they tell me about our students' motivation, engagement and self-efficacy – and how this compares to other countries?
- What can these studies tell us about equity – both within Australia and internationally? Are some students disadvantaged in Australia, and is this common internationally?

TIMSS and PISA – some details

The Trends in International Mathematics and Science Study (TIMSS) is a long-running study of achievement in mathematics and science, managed by the International Association for the Evaluation of Educational Achievement (IEA). The assessments occur every four years at Years 4 and 8, and Australia's participation in TIMSS 2011 will be our fifth since the combined mathematics and science assessment evolved from separate international assessments in 1985. Underpinning TIMSS is a research model in which the curriculum, broadly defined, is used as the major organisational concept in considering how educational opportunities are provided to students, and the factors that influence how students use these opportunities. The TIMSS curriculum model has three aspects: the *intended* curriculum (what society expects students to learn and how the system should be organised to facilitate this), the *implemented* curriculum (what is actually taught in classrooms, who teaches it and how it is taught) and the *achieved* curriculum (which is what the students have learned, and what they think about these subjects).

The Programme for International Student Assessment (PISA) is the other major international assessment included in the *National Assessment Program*, and Australia been a participant since the study began in 2000. PISA is managed by the Organisation for Economic Co-operation and Development (OECD); it tests competencies in reading, mathematics and scientific literacy, and occurs every three years. The underlying PISA model aims to measure how well 15-year-olds, approaching the end of their compulsory schooling, are prepared for meeting the challenges they will face in their lives beyond school. With its goal of measuring competencies, the PISA assessment focuses on young people's ability to apply the knowledge and skills they have learned throughout their school lives to real-life problems and situations.

In 2010/2011 more than 60 educational systems, from countries as diverse as Ghana, Saudi Arabia, England, Honduras, United States of America and Germany will participate in TIMSS. In the following year, 67 countries will participate in PISA, including all OECD countries plus a growing number of non-OECD or partner countries, again from locations as diverse as Shanghai, Qatar and Azerbaijan. The growing number of countries participating in one or both studies reflects the value that governments place on obtaining international comparative data.

NAPLAN, PISA and TIMSS

So why do we need NAPLAN *and* PISA and TIMSS? The answers lie in who are assessed, how the assessments are constructed, and the additional information gained from the international assessments.

In NAPLAN all students are tested, and the data provide results at the student level. NAPLAN is intended to provide diagnostic information about a student's individual progress against national standards. In contrast, a light sample (about 5% of all Australian students at each year or age level) of students is tested in the international assessments. This sample is a nationally representative random sample, stratified to ensure accurate data for each state, each school sector (government, Catholic and independent) and each geographic location band (metropolitan, regional, rural). These data enable us to examine our educational system against international standards.

In terms of what is assessed, the NAPLAN tests are informed by the National Statements of Learning in English and Mathematics that underpin the current state and territory learning frameworks; in contrast the TIMSS and PISA assessments are developed against frameworks developed at an international level. The TIMSS framework is developed after extensive consultation between representatives of all countries involved and an expert panel of mathematics educators, and represents those goals of mathematics education that are regarded as important in a significant number of countries. Mathematics in the TIMSS assessment is readily recognisable as the mathematics in most curricula – the content domains of *number, algebra, measurement, geometry* and *data* (*data display, geometric shapes and measures* and *number* at Year 4), and the cognitive domains k*nowing, using concepts, applying* and *reasoning* are familiar territory to teachers.

The PISA mathematical literacy framework revolves around wider uses and applications of mathematics in people's lives, and has three main dimensions: mathematical *content*, mathematical *processes* and the *situations or contexts* in which mathematics is used. Mathematical content is defined in terms of Steen's (1990) deep mathematical ideas, adapted as *overarching ideas*. These overarching ideas are *quantity, space and shape, change and relationships,* and *uncertainty*. The PISA framework also identifies a number of competencies – labelled as the *reproduction* cluster (relatively familiar items that require essentially the reproduction of knowledge already acquired), the *connections* cluster (problems that extend or develop from familiar settings to a minor degree) and the *reflection* cluster (builds further on the connections cluster – items require some insight or creativity in identifying solutions).

So all three studies are embedded in different models – NAPLAN and TIMSS in curriculum models, but one national and the other international, and PISA as a yield study, looking at whether students have in fact learned what we expect them to have learned over the cumulative years of education.

The international assessments also provide us with a wealth of contextual information – because the focus is not just on what a particular student is able to do, and because for such studies the context of learning is considered as important as the learning itself. Both TIMSS and PISA collect background data on students – the educational resources to which they have access, the educational experience of their parents, and their attitudes towards and beliefs about schooling and themselves as learners, in particular in relation to mathematics. TIMSS collects data from mathematics teachers as well, as TIMSS is sampled on intact classes, whereas PISA samples 15-year-old students randomly across classes within a school.

What can we learn from PISA and TIMSS?

If you have heard of PISA and TIMSS in Australia, it is most likely that you will have heard where we rank, or which countries score higher than us, or how our scores compare to those in New Zealand (or Kazakhstan[1]). There is, of course, a lot more that is published in our national reports, and this paper will present some of these results. Largely, this paper will report result in terms of proficiency levels for PISA and benchmarks for TIMSS. In PISA, six proficiency levels have been described, representing a continuum of mathematics achievement. MCEETYA have set proficiency level 3 as the minimum standard for Australian students. In TIMSS, there are four benchmarks ranging from low to high, also representing a continuum of mathematics achievement. While no base levels have been set by MCEETYA for TIMSS, students performing at the low benchmark or not achieving the low benchmark must be thought of to be at risk, particularly at Year 8.

Content

It's important that any assessment of mathematics should reflect the maths that it is most important for students to learn. What do PISA and TIMSS tell us that our students know well, and in what areas are they lagging behind internationally?

PISA results from 2003, which was the last full assessment of mathematical literacy (enabling us to report on subscales), show that Australian 15-year-old students have a generally high level of overall mathematical literacy, significantly higher than the OECD average. Australian students overall also scored at a level significantly higher than the OECD average on each of the subscales – not quite as well in *quantity* but better in *uncertainty*. But in terms of proficiency levels, one-third of Australian students did not achieve proficiency level 3 on the overall mathematical literacy scale. While this is clearly better than the OECD average of 42 per cent of students, we can aim to do better. In Hong Kong, for example, one of the highest performing countries, only 25 per cent of students did not achieve proficiency level 3.

At Year 8, in TIMSS 2007, Australian students performed at around the international average in mathematics overall. In the content domain of *data and chance*, Australian students performed at a level significantly higher than the international average; however. in the content areas of *algebra* and *geometry*, Year 8 students in Australia performed at a level significantly lower than the international average. Thirty-nine per cent of Australian Year 8 students were either at the low benchmark or did not achieve the low benchmark in mathematics overall.

Australian Year 4 students achieved at a level significantly higher than the international average in TIMSS 2007, with performance in *data and chance* significantly higher than the international average, and performance in *number* at a level significantly lower than the international average. Around 30 per cent of Australian students achieved at or below the low benchmark in mathematics overall.

Summing up, Australian students perform better than the international average at all levels in topics related to *data and chance*, while achievement in the areas of *number* and *algebra* are potentially weaker than in other countries. However, these data indicate that there is a substantial proportion of students exhibiting poor levels of mathematical understanding in Australian schools at all year levels.

Equity

Mathematics is no longer just a prerequisite subject for science and engineering students, but a fundamental literacy requirement for the 21st

1 Many of the headline reports (even in broadsheets such as The Australian) for the last release of the TIMSS 2007 results were along the lines of "Borat's kids beat Aussie kids in maths and science"

century. Equity implies that every student has an opportunity to learn the mathematics that is assessed. Can PISA and TIMSS help identify subgroups of students who are not achieving as well as we would hope? What else can we find out about these groups of students that may provide some clues as to why achievement is lower than could be expected?

While the Australian PISA and TIMSS data are generally reported by gender, Indigenous background, immigrant status, socio-economic background and geographic location of school in the national and international reports, this paper will focus on two important factors.

Gender

In PISA 2003, mathematical literacy was in many countries a male-oriented subject, with boys in 28 out of the 41 countries significantly outperforming girls. Only in Iceland did girls outperform boys. In Australia no significant gender differences were found on the overall mathematical literacy scale. Unpacking this a little further, however, it was also found that while there were no differences overall, or in the subscales for *quantity* or *change and relationships*, Australian boys performed significantly better than girls on the subscales *space and shape* and *uncertainty*. There were no gender differences in the lower proficiency levels, with 33 per cent of both male and female students not achieving proficiency level 3. At the higher levels of achievement slightly more boys (7%) than girls (4%) achieved the very highest proficiency level, but the same proportion of male and female students achieved at the next two highest achievement levels.

Mathematics in TIMSS 2007 was generally not as gendered internationally. At Year 4 level, there were significant gender differences in 20 of the 37 participating countries. In 12 of those countries the gender differences were in favour of boys and the remaining 8, in favour of girls. Australia was one of the 18 countries in which there were no significant gender differences in the composite mathematics score. Within the subscales, however, boys significantly outperformed girls in *number*, while girls significantly outperformed boys in *data display*.

In 25 of the 49 countries participating in TIMSS 2007 at Year 8 there were no gender differences. In 16 of the countries there were significant gender differences in favour of girls, and in only 8 countries, of which Australia was one (Algeria, Lebanon, Syria, El Salvador, Tunisia, Ghana and Columbia were the others), were there significant differences in favour of boys. The national TIMSS 2007 report (Thomson, Wernert, Underwood & Nicholas, 2008) noted that this was not because of an increase in the scores of boys, but a decline in the average score for girls. Contrary to the findings internationally, in which girls performed significantly better than boys in all domains other than number, Australian boys outscored girls in *data and chance*, and *number*, while there was no significant difference in the other domains. More boys than girls were achieving at the higher benchmarks in both year levels (Year 4 and Year 8) in TIMSS 2007.

To summarise, Australian boys outperformed girls in PISA 2003 in the areas of *space and shape* and *uncertainty*, in TIMSS 2007 at Year 4 in *number*, and in Year 8 in number and *data and chance.* Girls outperformed boys in TIMSS 2007 at Year 4 in *data display*. There were no significant gender differences on any other subscale. Given these few differences, it is interesting to look at students' attitudes and beliefs about mathematics.

In PISA 2003, 15-year-old Australian girls reported significantly lower levels of *instrumental motivation, self-concept in maths, self-efficacy* and *interest in maths*, and significantly higher levels of *maths anxiety*. This finding holds even when students achieving at the same proficiency level are compared. It also held internationally – in all countries (even Iceland) boys had higher levels of *self-concept* and *self-efficacy*, and in the vast majority of countries (there were approximately two exceptions) *interest in mathematics* and lower levels of *mathematics anxiety*.

Similarly in TIMSS 2007 at Year 4 in Australia, there was a significantly higher proportion of boys reporting high levels of self-confidence in mathematics (with no associated difference in score between male and female students). At Year 8 just 39 per cent of girls compared to 51 per cent of boys reported high levels of self-confidence – and almost one-quarter of girls (24%) reported low levels. This was broadly the case in most participating countries[2]. In further analysis (see Thomson, Wernert, Underwood & Nicholas, 2008), the effect of gender on achievement was found to be substantially explained by the differences in self-confidence in learning mathematics. In other words, it is not being a girl in and of itself that makes the difference, but that being a girl means a student is less likely to have high levels of self-confidence that can lead to higher levels of achievement in mathematics.

2 However, at Year 8 in a number of Middle-Eastern countries (Oman, Qatar, Palestine, Bahrain, Saudi Arabia and Kuwait), girls significantly outperformed boys and in general had higher levels of self-confidence than boys – significantly so in Qatar, Bahrain and Saudi Arabia. There were only four countries in which a significantly higher proportion of girls reported high levels of self-confidence than boys, in contrast to the 26 countries in which the opposite was reported.

These are important findings for teachers and researchers. Why is it that there are still gender differences in favour of males in so many countries in all areas of mathematical literacy, as shown in PISA, while a more curriculum-based assessment such as TIMSS finds gender differences in favour of boys in some countries and girls in others? Why are boys more self-confident and have higher levels of self-concept and lower levels of anxiety in mathematics, even when girls outperform them? Conversely, why do girls still doubt their abilities even when they are clearly achieving at a high level? If girls do not see mathematics as an area of strength, despite their achievement levels, and suffer from higher levels of anxiety, then it is unlikely that they will continue their studies through to university level.

Indigenous students

A special focus of both PISA and TIMSS in Australia has been to ensure that there is a sufficiently large sample of Indigenous students, so that valid and reliable comparisons can be made. In both studies, the random selection of students in PISA and classes in TIMSS ensures that some Indigenous students are part of the main sample. In addition to this, however, all eligible Indigenous students (i.e. 15-year-olds in PISA, and Year 4 or Year 8 students in TIMSS) are sampled and asked to participate. The National Centre and the Education Ministers communicate with school principals to explain the purpose of this extra sample and to convey to them the importance of encouraging Indigenous students to attend the assessment session.

It has been widely reported that the achievement levels of Indigenous students continue to lag well behind those of non-Indigenous students. In mathematical literacy in PISA 2003, Indigenous students performed 86 score points lower on average than non-Indigenous students (De Bortoli & Thomson, 2009). This represents more than one full proficiency level difference. The score gap between Indigenous and non-Indigenous was similar across all subscales.

In an international perspective, this places our Indigenous students at a level significantly lower than students in 30 other countries, the same as students in Greece and Serbia, and higher than students in Turkey, Uruguay, Thailand, Mexico, Indonesia, Tunisia and Brazil.

In terms of achievement at proficiency levels, 70 per cent of Indigenous students, compared to 32 per cent of non-Indigenous students were not achieving at the MCEETYA standard of level 3 or above. Forty-three per cent of Indigenous students were not achieving at the basic OECD acceptable standard of level 2 or above, that they argue is a baseline level of proficiency at which students begin to demonstrate the type of skills that they need to be able to fully participate in society beyond school. About 5 per cent of Indigenous students were, however, achieving at the highest two proficiency levels.

At both Year 4 and Year 8 in TIMSS 2007, non-Indigenous students scored at a substantially higher level than Indigenous students – 91 score points at Year 4 and 70 score points at Year 8. At Year 4, Indigenous students' scores were, on average, almost one standard deviation lower than those of non-Indigenous students in *number*, and around three-quarters of a standard deviation lower in *data display* and *geometric shapes and measures*. At Year 8 also, Indigenous students scored at a significantly lower level (between 54 and 67 score points) than non-Indigenous students in each of the subscales.

However, in terms of attitudes and motivation amongst Indigenous students, there were some interesting findings, recently described in DeBortoli & Thomson (2010). Amongst Australian 15-year-old students in PISA 2003, as previously described, there were significant gender differences in *instrumental motivation, self-concept in maths, self-efficacy* and *interest in maths*, and *maths anxiety*. Amongst Indigenous students, however, there were no significant gender differences in *interest, instrumental motivation or anxiety*, although Indigenous girls had very high scores on this latter construct, reflecting levels of anxiety in mathematics much higher than the OECD or the Australian average. In *self-concept in maths*, significant differences were found for Indigenous students, but they were smaller in magnitude than those for non-Indigenous students.

In TIMSS 2007, there were significantly greater proportions of Australian boys than girls in the high levels of both *self-confidence* and *valuing mathematics*. However, amongst the Indigenous population, this was not the case, with similar proportions of boys and girls reporting high levels of both.

Further investigation is needed to examine these findings – to find out whether they reflect actual differences in beliefs amongst Indigenous boys and girls or whether it is simply an artefact of the sample size, since standard errors are larger for the Indigenous sample. PISA 2012 will, we hope, provide some of these answers – the focus is again on mathematics, and Australia is implementing a different sampling methodology which we hope will result in a much bigger sample of Indigenous students than ever before.

In terms of factors influencing the achievement of Indigenous students, the effect of socio-economic background is substantial. However, the effect of strong, positive attitudes and beliefs is also significant, and can be encouraged through school programs. Also important is attendance at school – Indigenous students were found to be far more likely than non-Indigenous students to be late to school on a regular basis, to miss consecutive months of schooling and to change schools several times. In addition to lower levels of home educational resources and parental education experience, the gaps that appear at the beginning of primary school widen as a result of poor attendance at school.

Summary

It is sometimes difficult for teachers and school leaders to see the purpose of PISA and TIMSS. However, the students we are educating today will compete in a global market, and we have to be sure that the education we are providing them with is one that will provide them with a strong base, both in knowledge and skills and in the ability to apply those skills to real-world problems. PISA and TIMSS provides us with that information, and much, much more.

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