Chapter 4
A Look at Singapore Mathematics Education Through the PISA and TIMSS Lenses

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Abstract Singapore participates in benchmark studies, like Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) to assess the state of its education system. Mathematics, being a subject that is used as a proxy indicator, is an assessment tool used in both studies. As such achievement in mathematics after every cycle of TIMSS and PISA is often of interest to mathematics educators in Singapore and elsewhere. The data collected from systems of schooling of the participating countries and economies offer opportunities for educators and researchers to infer and investigate their concerns. Educators and researchers in Singapore use the data to benchmark school mathematics curriculum against international standards, identify gaps in curriculum plans, envision future goals of the curriculum and incidentally also contribute towards excellence in education internationally.

Keywords TIMSS · PISA · Singapore · School Mathematics Curriculum · Low Attainers · Textbooks · International Systemic Benchmark

4.1 Introduction

International surveys such as TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment) assess the state of education systems. They do this through tests for curriculum subjects that have the most coherence internationally, such as mathematics, science and language, and questionnaires for students, teachers and policy makers. Both TIMSS

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and PISA offer information on the achievement of students in mathematics from participating countries. Such information allow participating countries to examine their student achievement that is essentially the attained curriculum and relate it to their intended and enacted curricula of mathematics (Robitaille et al., 1993). It also allows them to benchmark their students' achievement and mathematics curricula against that of other participating countries, use the international data to drive up education standards and examine features of education systems that are excelling (UCLES, 2017).

TIMSS is conducted by the International Association for the Evaluation of Educational Achievement (IEA), once in every 4 years. It is curriculum based and measures trends in fourth- and eighth-grade mathematics achievement in an international context. TIMSS 2015 was the sixth and most recent cycle of assessment. Singapore has participated in all six cycles of TIMSS so far. PISA was launched by the Organisation for Economic Co-operation and Development (OECD) in 1997. It is skills-based and evaluates education systems by assessing to what extent students at the end of their compulsory education can apply knowledge to real-life situations and be equipped for society. It is conducted once in every 3 years. Although in every cycle, mathematics, science and reading are assessed, only one subject is the focus. For example in PISA 2009, reading was the focus and in PISA 2012, mathematics was the focus and in PISA 2015 Science was the focus. Initially participants of PISA were OECD countries, but at present non-OECD countries like Singapore and economies like Shanghai are also participating. Singapore participated in PISA for the first time in 2009.

Kaur (2013a) noted that Singapore participates in TIMSS and PISA for four main purposes that are as follows:

- to benchmark the outcomes of schooling, viz-a-viz the education system against international standards;
- to learn from educational systems that are excelling;
- to update school curriculum and keep abreast of global advances; and,
- to contribute towards the development of excellence in education internationally.

In the following sections we look at the participation of Singapore's students in TIMSS and PISA, what affirmations these studies surface and also the contribution of these studies towards national as well as international aspects related to the teaching and learning of mathematics.

4.2 Singapore's Participation in TIMSS and PISA

In this section, we briefly present Singapore students' achievement in, two benchmark studies, namely TIMSS and PISA.

4.2.1 An Overview of Singapore's Participation in TIMSS

The achievement of Singapore's students in TIMSS, the first benchmark study Singapore students participated in since its inception, i.e. 1995 onwards has been presented in several publications ((Kaur, 2005, 2009a, 2009b, 2013b; Boey 2009; Kaur, Boey, Areepattamannil, & Chen, 2012; Kaur, Areepattamannil, & Boey 2013, Kaur, Zhu & Cheang, 2019). Here we provide an overview of their participation across the six TIMSS that have already taken place.

The performance of Singapore students in TIMSS for mathematics in the six cycles held so far has been consistently outstanding as shown in Table 4.1. Students who participated in TIMSS 2015 at the grade 8 level are from the same cohort of grade 4 students who participated in TIMSS 2011. Similarly, the 8th graders in TIMSS 2011 were from the same cohort of 4th graders in TIMSS 2007. This shows that the trend in performance has been consistent. In addition, as of TIMSS 2007 with the availability of international benchmarks data there is more insight to student performance. Proportions of students reaching the benchmarks are perhaps telling of certain strengths and weaknesses of mathematics education programmes of the country. The benchmarks delineate performance at four points of the performance scale.

It is apparent from Table 4.1, that as the cohorts of students progressed from 4th to 8th grade higher proportions of the students reached the advanced international benchmark. 41% of grade 4 students at the advanced international benchmark in TIMSS 2007 compared to 48% grade 8 at the same benchmark in TIMSS 2011 and

Table 4.1 Ranking of Singapore's students for Mathematics in TIMSS for the six cycles & Percentage of the students in last three cycles of TIMSS at the respective benchmarks for mathematics achievement

TIMSS	Grade	Rank	International benchmarks[a]			
			Advanced (625)	High (550)	Intermediate (475)	Low (400)
2015	4	1	50 (2.1)	80 (1.7)	93 (0.9)	99 (0.3)
2011	4	1	43 (2.0)	78 (1.4)	94 (0.7)	99 (0.2)
2007	4	2	41 (2.1)	74 (1.7)	92 (0.9)	98 (0.3)
2003	4	1	–	–	–	–
1999	4	–	–	–	–	–
1995	4	1	–	–	–	–
2015	8	1	54 (1.8)	81 (1.5)	94 (0.9)	99 (0.2)
2011	8	2	48 (2.0)	78 (1.8)	92 (1.1)	99 (0.3)
2007	8	3	40 (1.9)	70 (2.0)	88 (1.4)	97 (0.6)
2003	8	1	–	–	–	–
1999	8	1	–	–	–	–
1995	8	1	–	–	–	–

() – standard errors
– TIMSS 1999 did not test grade 4 students
Source: Mullis et al. (2016) Exhibits 2.3 and 2.10
[a]International benchmarks data was only available from TIMSS 2007 onwards

43% grade 4 at the advanced international benchmark in TIMSS 2011 compared to 54% grade 8 at the same benchmark in TIMSS 2015. Table 4.1 also shows that percentages of grades 4 and 8 students reaching the high and advanced benchmarks have steadily increased over the last three cycles of TIMSS. However, for the low international benchmark level, the proportion of students below it decreased by 1% from 2007 to 2011 but remained the same at 1% from 2011 to 2015.

4.2.2 An Overview of Singapore's Participation in PISA

Although PISA came into being in 2000, Singapore only participated from 2009 onwards. Since participation, Singapore has been amongst the top-performing countries in PISA for the last three cycles. Several publications detail the achievement of Singapore students in PISA (Kaur, 2011; Kaur & Areepattamannil, 2012; Kaur, Zhu & Cheang, 2019). Table 4.2 shows that Singapore has maintained high positions in PISA overall rankings from 2009 to 2015.

PISA 2012 focused on mathematics. Singapore ranked second with a mean score of 573 points that was significantly lower than Shanghai-China and significantly higher than Hong Kong that ranked third. For PISA 2012, Table 4.3 shows that on average across OECD countries, 13% of students were top performers in mathematics with proficiency Levels 5 or 6. These students have the capacity of developing and working with models for complex situations, and they can work strategically using broad, well-developed thinking and reasoning skills (OECD, 2013). Two-fifths (40%) of students from Singapore were at these levels. On the other side, 23% of students in OECD countries did not achieve Level 2 in PISA mathematics. Level 2 is stated as the baseline level on the mathematics proficiency scale that is required for full participation in modern society (OECD, 2013). The percentage of low achievers who were below Level 2 was 8.3% for Singapore and this is of concern to educators in the country as its only natural resource for survival is its people.

Curriculum specialists at the Ministry of Education in Singapore noted that the results of the 2015 and past PISA cycles reflected outcomes of the deliberate curricular shifts made over the years. These shifts included greater emphasis on higher-order, critical thinking skills, and pedagogical shifts in moving learning beyond content to mastery and application of skills to solve authentic problems in various

Table 4.2 Global features of Singapore performance in PISA 2009, 2012 and 2015

Year	Focus	Mathematics		Reading	Science
		Average Score	Rank	Average Score and Rank	Average Score and Rank
2009	Reading	562	2	526 (5)	542 (4)
2012	Mathematics	573	2	542 (3)	551 (2)
2015	Science	564	1	535 (1)	556 (1)

Source: OECD (2009, 2012, 2015)

Table 4.3 Percentage of students from Singapore and the OECD average in PISA 2012 at each level of mathematics proficiency

Country	Rank	Average	International benchmarks				
			Above Level 2 (420)	Above Level 3 (482)	Above Level 4 (545)	Above Level 5 (607)	Above Level 6 (669)
Singapore	2	573 (1.3)	91.7	79.5	62.0	40.0	19.0
OECD average		490 (0.4)	77.0	54.5	30.8	12.6	3.3

() – standard errors
Source: OECD (2012)

contexts in the school curriculum in Singapore schools (Ministry of Education, 2016a,b).

4.3 Impact of TIMSS and PISA on the Teaching and Learning of Mathematics

In this section we examine how the data from TIMSS and PISA has affirmed and also identified gaps specific to the teaching and learning of mathematics in Singapore schools. We also examine how the same has provided evidence and knowledge for mathematics education elsewhere.

4.3.1 National Level Outcomes Arising from Participation in TIMSS and PISA

At the national level, item analysis of all released items after every cycle of TIMSS is of interest to mathematics educators in Singapore. Such an analysis helps to check the performance of students on items with respect to the content and cognitive domains. This analysis provides insights on how well students do on specific content strands and cognitive domains. For PISA, the achievement of students at the international benchmark levels are informative about students' mathematical literacy. Such knowledge allows for a critical appraisal of the school mathematics curriculum during its periodic cycles of revision (Kaur, 2015). The following sub-sections illustrate how data from past cycles of TIMSS and PISA have led to changes to the teaching and learning of mathematics in Singapore schools.

Content - Probability	
Before 2007 (UCLES, 2006)	Grade 10 (Secondary 4) - probability as a measure of chance - probability of single events - probability of simple combined events - addition and multiplication of probabilities - mutually exclusive events and independent events
2007 onwards (Ministry of Education, 2006)	Grade 8 (Secondary 2) - probability as a measure of chance - probability of single events
	Grade 10 (Secondary 4) - probability of simple combined events - addition and multiplication of probabilities - mutually exclusive events and independent events

Fig. 4.1 Content of Probability in the School Mathematics Curriculum

4.3.1.1 Alignment of Content with International Trend

One specific example of content alignment with international trends that resulted from Singapore's participation in TIMSS was the partial shift of the topic. Probability that was taught in grade 10 prior to 2006 to grade 8 in 2007 as shown in Fig. 4.1. This was necessary as questions in the TIMSS tests for grade 8 tested basic knowledge of probability that was beyond intuition of many students.

Figures 4.2 and 4.3 show the performance of students on two data and chance items before and after the curriculum alignment for the topic Probability in the Singapore school mathematics curriculum. It is apparent from Fig. 4.2 that in TIMSS 2003 and TIMSS 2007 close to almost half of the students from Singapore that participated in the TIMSS tests managed to answer the item correctly. There may be several reasons for them doing so despite minimal formal exposure to the content domain of the item. However, as shown in Fig. 4.3, after students had basic knowledge of probability, their performance for a similar content and cognitive domain item improved significantly, in fact being the best amongst all participating students in TIMSS 2011.

4.3.1.2 Developing Future Ready Citizens

Unlike TIMSS, PISA tests students' mathematical literacy, when they are about to complete secondary schooling. Singapore's participation in PISA and students' achievement in PISA has had a two-fold outcome. The first is an affirmation that mathematical concepts and skills together with mathematical processes are critical components of mathematical literacy and that our students are able to apply mathematical knowledge in varying contexts to resolve mathematical tasks of real-life contexts. The second is an attempt to heighten emphasis on the generative aspect of mathematical knowledge – a significant move away from algorithmic knowledge.

Content Domain Data and Chance
Cognitive Domain: Applying
Item ID M032688

Roland's spinner has three sectors of different colours, orange, purple, and green. Roland spins the pointer 1000 times. The chart below shows how many times the pointer stops on each section.

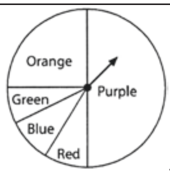
Colour	**Times Stopped**
Orange	510
Purple	243
Green	247

Draw lines on the spinner above to make the three sectors the approximate size you would expect them to be. Label them orange, purple, and green.

Country	% Full Credit TIMSS 2003	TIMSS 2007
Rep of Korea	68.2	50.5
Japan	65	70.4
Singapore	48.9	53.7
Chinese Taipei	47.4	39.6
Hong Kong SAR	47.3	46.6
International Average	32.1	27.3

Fig. 4.2 TIMSS 2003 and TIMSS 2007 data and chance item

Content Domain Data and Chance
Cognitive Domain: Applying
Item ID M032507



The spinner is for Steve's new game. Out of 600 spins, approximately how many times should he expect the arrow to land on the red sector?

A. 30
B. 40
C. 50
D. 60

Country	% Correct TIMSS 2011
Singapore	70
Rep of Korea	68
Japan	60
Chinese Taipei	55
Hong Kong SAR	55
International Average	31

Fig. 4.3 TIMSS 2011 data and chance item

Benchmark level examinations of mathematics at grades 10 and 12 have incorporated mathematical tasks on problems in real-life contexts. This outcome is aimed at allowing every child access to the new economic future (Heng, 2012).

4.3.1.3 Belief that Very Child Can Achieve!

From Table 4.1 it is apparent that the percentage of students reaching the advanced international benchmark has steadily increased from 41 in 2007, to 43 in 2011 to 50 in 2015. This significant positive student outcome has been linked to the periodic revisions of the school mathematics curriculum from the year 2000 onwards that placed heightened emphasis on problem solving and mathematical processes such as thinking skills and reasoning (Ministry of Education, 2016a,b). However, for the low international benchmark level, the proportion of students reaching it improved by 1% from 2007 to 2011 but remained the same at 99% from 2011 to 2015. In addition, data from PISA 2012 showed that 8.3% were below Level 2 of the international benchmark. Inferring from the PISA international benchmarks, students below Level 2 of the benchmark:

> can[not] interpret and recognise situations in contexts that require no more than direct inference. They can[not] extract relevant information from a single source and make use of a single representational mode. Students at this level can[not] employ basic algorithms, formulae, procedures or conventions to solve problems involving whole numbers. They are [in]capable of making literal interpretations of the results (OECD, 2018, pp. 63–64).

These findings have been of concern to policy makers and educators in Singapore as they believe that every child can achieve. It may be said that the revisions of the curriculum have had limited impact on the learning of mathematics by the mathematically least able students. Two exploratory studies, funded by the MOE, were carried out to investigate possible causes for low attainment in mathematics. The first was on low attainers in primary mathematics (Kaur & Ghani, 2012) and the second on teaching and learning mathematics in the classrooms of low ability secondary school students (Toh & Lui, 2014). Findings from these studies together with knowledge of mathematics curriculum specialists at the MOE have led to the *Improving Confidence And Numeracy* (ICAN) project. This project spearheaded by the MOE started in 2013. It assists teachers of low attainers (essentially the bottom 15% of each cohort) in mathematics, by enhancing their capacity to facilitate the learning of mathematics by such students. The project advocates eight pedagogical principles that are 1. Establish classroom norms conducive for learning, 2. Check and diagnose students' pre-requisite knowledge, 3. Create a motivating environment, 4. Focus on the fundamentals of mathematical knowledge, 5. Provide direct and explicit instruction, 6. Simplify and scaffold, 7. Provide guided practice – encourage reasoning and communication, and 8. Provide individual practice and review (Toh & Kaur, 2019). Teacher development is in the form of workshops, mentoring, network meetings, provision of pedagogical resources for whole class use, and an annual symposium. Concerted efforts are been expanded in terms of building the capacity and sustaining the project by growing the pool of mentors and mentees at the national level.

4.3.1.4 The Sky's the Limit!

In tandem with concerns about improving the learning of mathematics by low attainers has been the quest to engage the more able students in the disciplinary aspect of mathematics. The revised school mathematics syllabuses for secondary schools (Ministry of Education, 2018) to be implemented in 2020 and the primary schools (Ministry of Education, 2019) to be implemented in 2021 advocates teaching for Big Ideas, where a Big Idea is a statement of an idea that is central to the learning of mathematics, one that links numerous mathematical understandings into a coherent whole" (Charles, 2005, p. 10). This has sparked a conversation about what is central to mathematics learning amongst teachers, curriculum developers, educators and researchers. By 2026, when the next mathematics curriculum review is due these conversations would have crystalized into "knowledge" to guide the next leg of our journey of teaching and learning of mathematics.

4.3.2 International Level Outcomes Arising from Participation in TIMSS and PISA

As noted by Kaur (2013a), one of the purposes of Singapore's participation in the international benchmarks studies, TIMSS and PISA is to contribute towards the development of excellence in education internationally. It is worthy to note that this purpose is incidental and came about after Singapore students' remarkable achievement in mathematics in both TIMSS and PISA. In the following sub-sections we discuss the contribution of Singapore mathematics textbooks internationally and also Singapore's mathematics education as a systemic benchmark for excellence.

4.3.2.1 Adoption and Adaptation of Singapore Mathematics Textbooks

Singapore's mathematics education gained international recognition following repeated good performance in TIMSS. The data of the studies showed that not only did the average Singapore students perform very well against international benchmarks they also had a positive attitude towards the learning of mathematics (Kaur, Zhu & Cheang, 2019). As part of interest in Singapore's mathematics education a study of mathematics textbooks used in Singapore schools was carried out by the American Institutes for Research (Ginsburg, Leinwand, Anstrom & Pollock, 2005). The study found that in textbooks used in Singapore schools the topics were treated in depth, with appropriate illustrations and mathematical representations. It also made apparent that of all the elements of Singapore's successful mathematics system, its textbooks were the easiest to transfer to US schools, certainly with adaptations. This led to the adoption of 'Singapore Math', a teaching method primarily based on the Concrete-Pictorial-Abstract approach that pervades teaching of maths in Singapore schools, by textbook writers in the United States. Like the United States many other countries, such as Indonesia, Philippines, Israel and others, have also adopted and adapted Singapore mathematics textbooks for use in their schools. It must be noted that textbooks are only tools of the teacher as without comprehensive understanding of the underlying philosophy of the books the implementation may be problematic. Therefore in many of these countries, educators from Singapore are invited to provide professional development for key instructional leaders in mathematics.

4.3.2.2 Singapore as an International Systemic Benchmark

To improve educational practices and move up the educational value chain Singapore always benchmarks itself with the best systems in the world. For example Singapore's mathematics curricula were developed after reviewing mathematics research and practice from around the world. Following participation in TIMSS (1995, 1999, 2003, 2007 and 2011) and PISA 2009 and 2012 Singapore has become notably an international benchmark for others in the world.

In a report entitled: *How the world's best performing school systems come out on top* by Mckinsey & Company (Mourshed, 2007), lessons that the world can learn from Singapore as one of the world's best performing school system are detailed. In another report produced by OECD for the US entitled: *Strong performers and successful reformers in education: Lessons from PISA for the United States* (OECD, 2011) a case study of Singapore's education system is presented as an example of a nation that has had rapid improvement followed by strong performance. In yet another, OECD publication, *Ten questions for Mathematics Teachers … and how PISA can help answer them* (2016) the Singapore school mathematics curriculum framework is presented as a robust model for teaching mathematics (p. 16). The framework shown in Fig. 4.4 draws attention to five aspects that are critical for the learning of mathematics so as to develop mathematical problem solvers (for an in-depth discussion on how mathematics education has evolved in Singapore, see Chap. 7). These reports and the many other research papers that have drawn on Singapore's data present succinctly Singapore as an international systemic benchmark worthy of emulation by nations desiring change and growth.

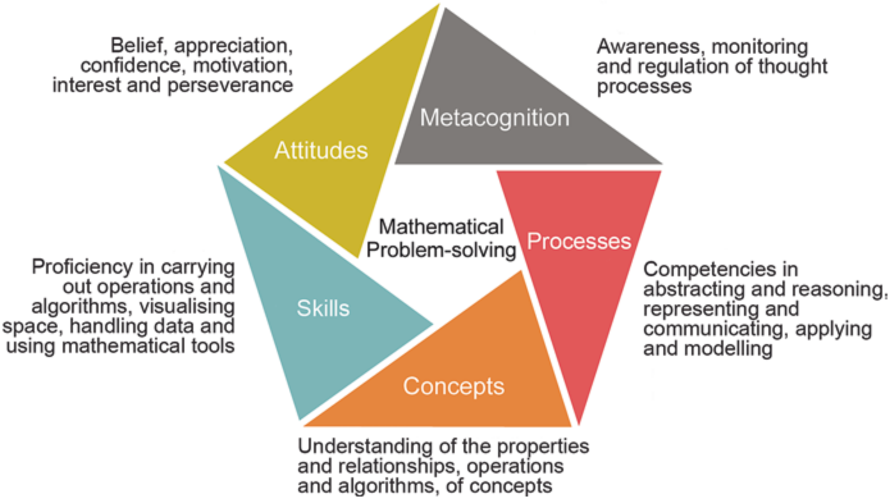


Fig. 4.4 Framework of the school mathematics curriculum

4.4 Conclusion

In tandem with a quest to improve and perfect the teaching and learning of mathematics in Singapore schools, data from benchmark studies such as TIMSS and PISA has been drawn on to affirm and identify gaps in the intended school mathematics curriculum. However, the outstanding achievement of Singapore's students in both PISA and TIMSS has not signalled in any way to educators and policy makers to rest on their laurels. They have continued to scan the international landscape and assess economic needs of Singapore and input into the periodic review of the school mathematics curriculum. These periodic reviews have culminated in continued refinements to the school mathematics curriculum. Within the larger context of school curriculum, the role of mathematics as a compulsory school subject has also been continually re-visited to align with the needs of the nation so as to produce future ready citizens of not only Singapore but also of the world.

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