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# Trend Analysis on Mathematics Achievements: A Comparative Study Using TIMSS Data

**H. W. Ker**

Department of International Trade, Chihlee Institute of Technology,Wunhua Rd., Banciao District, New Taipei City, Taiwan
*Corresponding Author: hker@mail.chihlee.edu.tw



**Abstract** Research addressed the importance of mathematics education for the students' preparation to enter scientific and technological workforce. This paper utilized Trends in International Mathematics and Science Study (TIMSS) 2011 data to conduct a global comparative analysis on mathematics performance at varied International Benchmark levels. The countries in comparison are Chinese Taipei, Singapore, and the USA. Results show that the trends of mathematics performance for Chinese Taipei, Singapore, and the USA are dissimilar. The distribution of mathematics scores for Chinese Taipei students is bimodal, the distribution of mathematics achievement of Singapore is skew to the left, and the distribution of mathematics performance for the USA students is skew to the right. Overall, for all these three countries, at the same grade, the mathematics achievements of the students show improvement over time. However, students' abilities on mathematics deteriorate over their schools years.

**Keyword** International Large-Scale Assessment, Mathematics Performance, International Benchmark, TIMSS

## 1. Introduction

The effectiveness of a country's educational system plays an important role in establishing competitive advantages in the growing global economy nowadays. In this high-technology oriented era, a country with the lead on science and high technology would put great emphases on mathematics education. Educational policies have to respond to the impact of the globalization on economy and the rapidly evolving new technologies. One of the fundamentals of developing high-technology is solid mathematical abilities. Mathematics is a fundamental subject for learning its interdisciplinary knowledge such as science, technology and engineering, which are critical elements for a country to train creation and innovation of new scientific-technological professionals.

Educators address the importance on the high quality of mathematics education to facilitate students' values, professional skills/knowledge and attitudes necessary to enter scientific and technological workforce. Research addressed the importance of high ability in mathematics at the secondary schools for the well preparation of mathematics-related subjects and profession (e.g., engineering, and technology). Ages at secondary schools have been identified as a crucial period to develop interest and encourage students' learning in mathematics [1, 2]. Issues considered in improving mathematics education in secondary schools includes curriculum, educational policies, educational resources and support, pedagogy, teacher pre-service and training, professional development, and learning assessment have been widely discussed.

Large-scale international assessments can help policy-makers and professionals/practitioners related to education understand their educational practice as well as to make global comparison. Among those large-scale international assessments, Trends in International Mathematics and Science Study (TIMSS) is a highly regarded global assessment. It assesses the accomplishment of international students in mathematics and science at the 4th and the 8th grade levels.

Previous TIMSS reports [3, 4, 5] showed that remarkable percentages of Asian students (e.g., students from Chinese Taipei, Singapore, Korea, Japan, or Hong Kong) reached the Advanced International Benchmark level, which requires the high ability to solve problems involving complex topics, multi-phases, reasoning, and making generalization. However, research [6] also showed that the distributions of mathematics achievement for Chinese Taipei and Singapore are very different. This paper utilized TIMSS 2011 data to conduct a global comparative analysis on the trends of mathematics achievement and students' performance at the levels of International Benchmarks. TIMSS 2011 data for the 8th graders of Chinese Taipei, Singapore and the USA are used in this study. The two Asian countries continuously outscored other countries in international mathematics assessments and the United States experienced a decline in the number of freshmen selecting mathematics-and science related majors [7]. The results of this study aim to provide

comparative information about the trends of mathematics achievement for educators to consider the implication in instructional practices of mathematics in secondary schools. The dataset used to do this analysis is from TIMSS 2011 website: http://timss.com.

## 2. Trends in International Mathematics and Science Study

TIMSS is a project guided by International Association for the Evaluation of Educational Achievement (IEA), and is directed by the TIMSS & PIRLS International Study Center [8]. TIMSS is conducted on a 4-year-cycle base (in 1995, 1999, 2003, 2007, 2011, and with planning underway of 2015). TIMSS collects data from students, teachers, and school principals. Information includes the educational contexts such as gender performance, students' background, home environment, students' attitudes toward learning, school facilities, educational support, resource availability, curriculum and instructional approaches, and teacher preparation in teaching. TIMSS 2011 involved more than 60 countries with 600,000 students assessed [9].

In addition to student/teacher/school context, TIMSS 2011 provides four-point-scale international benchmarks that can be used to interpret how students' mathematical competence varies along their scores. TIMSS test items were designed to measure curriculum content in number, algebra, geometry and data, and cognitive processes in the knowing, applying, and reasoning domains. The cut-off points for the categories of Advanced International Benchmark, High International Benchmark, Intermediate International Benchmark, and Low International Benchmark are 625, 550, 475, and 400, respectively [9].

According to TIMSS 2011 mathematics report [9], at the eighth grade, the descriptions of these four levels of International Benchmark can be summarized as follows.

(1). Advanced International Benchmark: Students can use their mathematical knowledge in reasoning, drawing conclusion, solving multi-phases problems, and making generalization. Students can solve problems involving a variety of numbers (e.g., whole numbers, fractions, negative numbers, or proportions) in non-regular situations and validate their conclusions. Students can express their generalizations algebraically. They can solve problems containing linear equations, formulas, functions, and geometric figures.

(2). High International Benchmark: Students can apply their mathematical knowledge in a variety of highly complicated situations. Students can use varied information to solve problems involving the operations of different types of numbers such as whole numbers, decimals, fractions, whole number exponents, or prime factorization of a given number. They can simplify algebraic expressions and solve linear equations. They can use lines, angles, triangles, rectangles, and rectangular prisms to solve problems. They can analyze and interpret data in a variety of graphs such as pie charts, line charts, or bar charts. They also can compute some descriptive statistics such as averages or medians.

(3). Intermediate International Benchmark: Students can solve problems involving decimals and fractions, understand simple algebraic expression, and relate two-dimensional diagrams to three-dimensional objects. They can interpret the data in a table and use them to construct graphs. They also can compute the probabilities of an outcome in a simple event.

(4). Low International Benchmark: Students have some knowledge of operating whole numbers and decimals, and understand basic graphs.

## 3. Trends in International Benchmarks on Chinese Taipei, Singapore and USA

TIMSS 2011 provides international benchmarks that can be used to interpret students' competence and conduct global comparative studies of students' in mathematics. Table 1 presents average scale scores and the percentages of students at Advanced and Low International Benchmark categories for Chinese Taipei, Singapore, and United States.

At the eighth grade, the top three countries with average mathematics achievement are Korea, Singapore, and Chinese Taipei [9]. The United States is at the 9th place. The average scale scores for Singapore, Chinese Taipei, and the USA are 611, 609, and 509, respectively. The international average score is 500. The mean scale scores of Chinese Taipei and Singapore are far above the international average. As previous TIMSS results, there was a substantial gap in average mathematics achievement between these two Asian countries and the United States.

In the benchmark studies, this result also revealed that Chinese Taipei and Singapore have very high percentages of students reaching or above the Advanced International Benchmark for mathematics. Table 1 showed that the percentages in Advanced International Benchmark for mathematics at the eighth grade of Chinese Taipei, Singapore and the United States are 49%, 48% and 7% respectively. The percentages of Advanced International Benchmark of these two Asian countries are about seven times of the percentage of the USA. The percentages of Low International Benchmark of these two Asian countries (12% and 7% for Chinese Taipei and Singapore, respectively) are far less than that of the USA (32%). This again, evidences the outperformance of mathematics achievement of Asian students.

**Table 1.** Average scale scores and the percentages of students at Advanced and Low International Benchmark categories for Chinese Taipei, Singapore, and United States.

| Benchmark | Chinese Taipei | Singapore | United States | International Average |
|---|---|---|---|---|
| Advanced | 49 | 48 | 7 | - |
| Low | 12 | 7 | 32 | - |
| Average Scale Score | 609 | 611 | 509 | 500 |

Note. From TIMSS 2011 International Results in Mathematics (p.42, p.114), by Mullis, I.V.S., Martin, M.O., Foy, P. & Arora, A, 2012, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

**Table 2.** Percentages of Chinese Taipei, Singapore and USA on Advanced and Low International Benchmark at 4th grade and 8th grade of TIMSS 2003, TIMSS 2007, and TIMSS 2011

| | Low International Benchmark | | | | | | Advanced International Benchmark | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| country | Chinese Taiei | | Singapore | | USA | | Chinese Taiei | | Singapore | | USA | |
| grade | 4th | 8th | 4th | 8th | 4th | 8th | 4th | 8th | 4th | 8th | 4t | 8th |
| 2003 | 8 | 15 | 9 | 7 | 28 | 36 | 16 | 38 | 38 | 44 | 7 | 7 |
| 2007 | 8 | 14 | 8 | 12 | 23 | 33 | 24 | 45 | 41 | 40 | 10 | 6 |
| 2011 | 7 | 12 | 6 | 7 | 19 | 32 | 34 | 49 | 43 | 47 | 13 | 7 |

Note. From TIMSS 2011 International Results in Mathematics (p.90~p.93, p.118~p.119) , by Mullis, I.V.S., Martin, M.O., Foy, P. & Arora, A, 2012, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

# 4. Cohort analysis: Fourth Grade to Eighth Grade

The cohort of the 4th-grade students assessed in 2003/2007 would reach the 8th grade by 2007/2011. These assessments across years can be used to examine what's the relative change of performance as the 4th grader of 2003/2007 become the 8th graders of 2007/2011. Table 2 presents percentages of Chinese Taipei, Singapore and the USA on Advanced and Low International Benchmark at the 4th grade and the 8th grade of TIMSS 2003, TIMSS 2007, and TIMSS 2011. Findings from this analysis are:

(1). In TIMSS 2007, at the 4th grade, the percentages of the students in Low Benchmark for Chinese Taipei, Singapore and the United States are 8%, 8% and 23%, respectively. This cohort became the 8th graders in 2011. The percentages in Low International Benchmark at the eighth grade of Chinese Taipei, Singapore and the United States are 12%, 7% and 32% respectively. These statistics revealed that when most of the Chinese Taipei and American students grow older, they became less competent in mathematics.

(2). The percentages of the students in Advanced International Benchmark at the fourth grade of Chinese Taipei are 16%, 24% and 34% for TIMSS 2003, TIMSS 2007, and TIMSS 2011, respectively. The percentages of Advanced International Benchmark for mathematics at the eighth grade of Chinese Taipei are 38%, 45% and 49% for TIMSS 2003, TIMSS 2007, and TIMSS 2011, respectively. This fact showed that students of Chinese Taipei make remarkable progress on mathematics achievement. The same trends can be found at the 4th grades and 8th grades of Singapore and USA. That is, overall, at the same grade, the mathematics achievement is improving over years.

(3). In TIMSS 2011, the statistics on Advanced International Benchmark and low International Benchmark at the 4th and the 8th grades for Chinese Taipei revealed that the percentage of high-level students and low-level students on mathematics both increased. For example, the percentages at Advanced International Benchmark at the 4th and the 8th grades are 34% and 39%, respectively. The percentages at low International Benchmark at the 4th and the 8th grades are 7% and 12%. This evidence showed that the percentages of students with less mathematics ability increased over their school years. That gives a bimodal distribution which has two peaks at both ends. That is, an "M" shape on average mathematics achievements for Chinese Taipei students. The same distributions can be found in TIMSS 2003 and TIMSS 2007 mathematics performance.

(4). In TIMSS 2011, for Singapore, the percentages of students on Advanced International Benchmark are higher at 8th grade than 4th grade (47% vs 43%). The percentages of students on Low International Benchmark at the 8th grade and 4th grade are approximately the same (7% vs 6%). This fact shows that the growth of mathematics achievement of Singapore students is quite stable. The distribution is skew to the left which has high percentage of well-performed students and low percentage of less-performed students. The distribution skew to the left can also be found in TIMSS 2003 and TIMSS 2007 data.

(5). In TIMSS 2011, the percentages of students on Advanced and Low International Benchmark at the 4th and the 8th grades revealed that in the United States, less able students increased while well-performed students decreased. For example, the percentages on Advanced International Benchmark at the 8th grade and the 4th grade are 7% and 13%, respectively. The percentages on Low International Benchmark at the 8th grade and the 4th grade are 32% and 19%, respectively. The distribution is skew to the right

which has high percentage of low-achievement students. Compared with Chinese Taipei and Singapore, the USA has less high-competence students and more less-able students in mathematics. American educators have to put this phenomenon in concern. The facts are the same as in TIMSS 2003 and TIMSS 2007 results

## 5. Discussion and Conclusion

The results from international large-scale assessments provide an opportunity for educational policy makers to realize the educational phenomenon of their countries. The data released from the studies of international large-scale assessment are valuable research resources. This study shows that, in TIMSS 2011, the distributions of mathematics performance for students of Chinese Taipei, Singapore, and USA are different. Chinese Taipei students, though ranked top, actually have bimodal distribution on mathematics achievement, with two peaks at high-performance and low-performance scores. This situation is pretty consistent with the results of TIMSS 2007 and TIMSS 2003 mathematics assessment.

The performance of mathematics achievement of Singapore students is quite stable, with a distribution skew to the left. Singapore has high percentage of well-performed students and low percentage of less-performed students. On the contrary, the distribution of mathematics performance for the USA students is skew to the right, with high percentage of low-performed students and low percentage of well-performed students. Again, the results of TIMSS 2011 are in accordance with the results of TIMSS 2007 and TIMSS 2003.

Overall, for all these three countries, the mathematics achievements of the students show improvement over time. However, students' abilities on mathematics deteriorate over their school years, which means as students grow older, their mathematics competence decrease. The phenomena of mathematics achievement of the 4th graders in 2003 to the 8th graders in 2007 are pretty consistent with that of the 4th graders in 2007 to the 8th graders in 2011.

From this study, it can be found that the math performance for the students of Chinese Taipei, Singapore, and America are quite diverse. The averages of math achievement of Chinese Taipei students and Singaporean students are similar. The math accomplishment of the students from both countries outscored other countries in every assessment of TIMSS. However, the distributions of math performance of these two countries are quite different. As aforementioned, Chinese Taipei has high percentages of well-performed students and low-performed students. This signifies that educational opportunities or resources are not equally distributed to all students. Having high percentage of well-performed students may represent math education is successful in some ways. However, the most important thing in education is to improve the competence of low-performed students. In terms of improving math education, educators of Chinese Taipei should focus on meliorating the math abilities of these low-performed students.

Singapore has high percentage of brilliant-performed students and low percentage of less able students. It seems that Singapore has the most successful math education among these three countries. The math distribution of the American students is contrary to that of Singaporean students.

How to improve mathematics education has always been a big issue. Governments of many countries are struggling in considering how to provide best mathematics education for their students. Mathematical competence plays an important role in learning many other subjects, for example, subjects related to engineering or science. Educators have to address the importance in new modes of curriculum, pedagogy, and learning assessments, to improve students' learning.

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