TRENDS IN INTERNATIONAL MATHEMATICS AND SCIENCE STUDY

# TIMSS

# 20 Years of TIMSS

## International Trends in Mathematics and Science Achievement, Curriculum, and Instruction

Ina V.S. Mullis
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# Executive Summary

TIMSS has measured student achievement in mathematics and science at fourth and eighth grades every four years since 1995, as well as in advanced mathematics and physics at less frequent intervals (1995, 2008, and 2015). TIMSS assessment and questionnaire data provide an authoritative account of how the world's students are currently performing in mathematics and science, how performance has evolved over the past 20 years, and the changes that have occurred in curriculum, instruction, and other aspects of education that affect learning. This report attempts to summarize the most important and interesting trends emerging from TIMSS across the past two decades.

The report is organized from macro to micro perspectives. The first chapter provides an overview of student achievement worldwide, with analyses of both long term and short term trends. The second and third chapters explore curriculum and instruction. Chapter 2 describes not only the evolution of mathematics and science curricula, but also how TIMSS itself has changed to stay in synch with curricular change. Chapter 3 explores the context of instruction, in particular the characteristics of schools, classrooms, and teachers in the local settings where instruction unfolds. The fourth and fifth chapters narrow the focus to two topics of interest among policymakers. Chapter 4 examines short term and long term trends in the distribution of achievement within countries. Chapter 5 investigates students' enjoyment of mathematics and self-confidence in studying the subject.

A thumbnail sketch of each chapter follows.

## Chapter 1: How Is the World Doing?

**2015 Results—**Five East Asian countries were the highest achieving countries in mathematics at fourth and eighth grades in TIMSS 2015—Singapore, Korea, Hong Kong SAR, Chinese Taipei, and Japan. In science at the fourth grade, the Russian Federation performed among the top four countries—including Singapore, Korea, and Japan. At the eighth grade, Singapore, Japan, Chinese Taipei, Korea, and Slovenia were the top five performers. The highest achieving countries scored around 600 points on the TIMSS scale, while the lowest achieving countries scored about 370 scale score points.

**Trends—**Long term and short term trends are up. In both subjects and at both grades, more countries registered increases than decreases from 1995 to 2015 and from 2011 to 2015. More students are now reaching the most challenging benchmarks.

**Gender—**In 1995, TIMSS reported small gender differences in mathematics at both the fourth and eighth grades. In countries with a difference, the boys had higher achievement. In science, there was a pronounced advantage for boys, with boys outperforming girls in about half the countries at fourth grade and almost all the countries at eighth grade. In 2015, TIMSS reported a different situation with far fewer countries where boys had higher achievement and quite a few countries where girls had higher achievement, especially in science. The 20 year trends for the countries that participated in both 1995 and 2015 generally support this change, showing reduced gender gaps, especially in science and especially at the eighth grade.

**TIMSS Advanced—**TIMSS Advanced 2015 revealed disappointing trends in advanced mathematics. Of the 6 countries with 20 year trend data, France, Italy, and Sweden had lower average achievement in 2015 than in 1995, while the Russian Federation, Slovenia, and the United States had no significant difference. As a bright spot, Norway and Sweden had upturns between 2008 and 2015. Achievement trends in physics were even more disappointing. Of the 6 countries with 20 year trend data, France, Norway, the Russian Federation, and Sweden experienced substantial decreases in average achievement since 1995, while Slovenia and the United States had no significant change. No country improved over the 20 year period.

## Chapter 2: How Is the Curriculum Changing?

**Curriculum Evolving—**Countries devote considerable energy and resources to updating their mathematics and science curricula. In each assessment at least half the countries report they are revising their curricula. During the 20 years of TIMSS, nearly all countries have implemented periodic curriculum reforms, ranging from updates to full scale revisions.

**Mathematics and Science Are Core Subjects—**According to the *TIMSS 2015 Encyclopedia*, mathematics and science are central to schools' overall academic program, allotted one-fourth to one-third of available instructional time. Curricular guidelines that include mathematics and science are even beginning to emerge in preprimary programs.

**Technology—**About 90 percent of the TIMSS 2015 countries reported initiatives for integrating technology into mathematics and science.

**Process Skills—**Countries are increasingly giving explicit attention to process skills in the curriculum, most notably problem solving, reasoning, and communicating in mathematics, and inquiry and investigation in science.

**More Challenging—**Topics that once were the province of higher grades have moved down in grades. Data and statistics frequently are included in fourth grade mathematics, and in many countries fourth grade science has shifted from the general study of students' environments to life science, physical science, and Earth science.

**TIMSS Content—**TIMSS has experienced a consolidation of content areas and reduction in the number of specified topics within content areas. Perhaps as a result, there is evidence of increased alignment between the countries' intended curriculum and topics assessed by TIMSS. In fourth grade mathematics, for example, the average TIMSS country in 2007 included 63 percent of the TIMSS topics in its curricula. In TIMSS 2015, the average was 80 percent.

## Chapter 3: Is Instruction Keeping Pace with Curricular Changes?

**Safety—**Schools are safer places for children. The proportion of students attending "very safe and orderly" schools increased from less than half in 2007 to approximately two-thirds in 2015.

**Emphasis on Academic Success—**Schools place a greater emphasis on academic success. The percentage of fourth grade students attending schools that place a "high" or "very high" emphasis on academic success rose from 60 percent in 2007 to 72 percent in 2015. For eighth grade students, the percentage increased from 47 to 65 percent.

**Teacher Education—**Countries have been raising the requirements for becoming a teacher, particularly for primary school. Teachers were more highly educated in 2015 than in 2007. The percentage of fourth grade students whose teachers have bachelor's degrees increased from 78 to 85 percent, and the percentage with advanced degrees rose from 26 to 31 percent. At eighth grade, the percentage with advanced degrees increased from 25 to 30 percent.

**Instructional Time—**Fourth grade students spend more time receiving mathematics instruction than eighth grade students—151 annual hours at fourth grade compared to 130 hours at eighth grade in 2015. Eighth grade students spend more time receiving science instruction than fourth grade students—116 annual hours compared to 69 hours at fourth grade. Total instructional time devoted to the two subjects at both grades appears relatively stable from 1995 to 2015.

**Technology—**From 2007 to 2015, fourth grade teachers reported increased use of computers for science lessons but not for mathematics lessons, and eighth grade teachers reported decreased use for mathematics lessons and little or no change for science lessons. At both grades, the availability of computers for mathematics and science lessons did not increase.

**Satisfaction and Engagement—**In 2015, more than 90 percent of students had teachers who were "satisfied" or "very satisfied" with their jobs. From the students' perspective, more than 90 percent of the fourth grade students and 80 percent of the eighth grade students agreed that their teachers provided very engaging or engaging instruction.

## Chapter 4: Trends in the Distribution of TIMSS International Achievement

**Standard Deviations—**For the average TIMSS 2015 country that has participated in TIMSS long enough to establish a 12 year trend, the standard deviation of test scores in both mathematics and science contracted at fourth grade. At eighth grade, standard deviations were stable in both subjects.

**$10^{th}$ and $90^{th}$ Percentiles—**Long term trends indicate that the reduced gap between high and low achieving students in fourth grade was largely the result of greater gains among students in the $10^{th}$ percentile (low achievers). In fourth grade mathematics, $10^{th}$ percentile students gained an average of 34 scale score points from 1995 to 2015, while $90^{th}$ percentile students gained an average of 20 points. In fourth grade science, $10^{th}$ percentile students gained an average of 34 points, and a 9 point gain was registered at the $90^{th}$ percentile.

**Equity-Efficiency Tradeoff**—TIMSS data do not support the notion that equity and high achievement are at odds with each other. Many countries have been able to boost TIMSS scores across the continuum of achievement and some have reduced test score gaps as well. Policymakers are urged to monitor the achievement of students at all points in the distribution.

## Chapter 5: What Do Students Think About Mathematics?

**Puzzling Results—**A paradox surfaced in the first TIMSS data from 1995 and has reappeared ever since. Student self-confidence in mathematics and enjoyment studying the subject both are positively correlated with achievement. But when data are aggregated to the national level, many of the highest scoring countries on TIMSS rank near the bottom of all countries on both sentiments.

**Students Like Mathematics—**Contrary to what many people believe, most students like mathematics. From 1995 to 2015, more than 75 percent of fourth grade students and 65 percent of eighth grade students consistently expressed positive sentiments toward the subject. Fourth grade students' more positive sentiments compared to those of eighth grade students' also have been consistent.

**Students Say They Usually Do Well in Mathematics—**Students are confident in mathematics. Since 1995 the percentage of fourth grade students disagreeing with the statement "I usually do well in mathematics" has never risen above 17 percent (in 2015, it was 13%). Eighth grade students' disagreement with the same prompt has never exceeded 28 percent (28% in 2015).

**Explanations for the Enjoyment-Achievement and Confidence-Achievement Paradoxes—**Four plausible explanations for the paradoxes are discussed, and implications for researchers and policymakers are offered.

# CHAPTER 1

# How Is the World Doing?

TIMSS has monitored student achievement in mathematics and science at fourth and eighth grades every four years since 1995, as well as in advanced mathematics and physics at less frequent intervals (1995, 2008, and 2015). As such, it is well positioned to provide an overview of countries' performance in 2015 in mathematics and science and how that performance has evolved over the past 20 years.

## Student Achievement in 2015

Five East Asian countries were the highest achieving countries in mathematics at both the fourth and eighth grades in TIMSS 2015. Singapore and Hong Kong SAR, followed by Korea, and then Chinese Taipei and Japan were the top performing countries at the fourth grade (Exhibit 1). There was a 23 point gap between these countries and the next highest scoring countries: Northern Ireland, the Russian Federation, Norway, Ireland, England, Belgium (Flemish), and Kazakhstan. At the eighth grade, Singapore had the highest average mathematics achievement, followed by Korea and Chinese Taipei, then Hong Kong SAR, and then Japan. These five countries outperformed all other countries in mathematics at the eighth grade as well as at the fourth grade, and the achievement gap between them and the next highest performers at the eighth grade was 48 scale score points. After the East Asian countries, the next highest performers in eighth grade mathematics were the Russian Federation, Kazakhstan, Canada, Ireland, the United States, and England (Mullis, Martin, Foy, & Hooper, 2016b).

In science, the five East Asian countries also were among the top performing TIMSS 2015 countries at both fourth and eighth grades, although they were joined by some other countries. Singapore and Korea had the highest average science achievement at fourth grade, outperforming all other countries. Japan and the Russian Federation had the next highest achievement, followed by Hong Kong SAR, Chinese Taipei, Finland, and Kazakhstan. Singapore was the top performer in eighth grade science, with Japan and Chinese Taipei having the next highest average science achievement. These were followed by Korea and Slovenia, and then Hong Kong SAR and the Russian Federation (Martin, Mullis, Foy, & Hooper, 2016).

**Exhibit 1: Top Performing Countries in TIMSS 2015**

| Fourth Grade | | Eighth Grade | |
|---|---|---|---|
| **Mathematics** | **Science** | **Mathematics** | **Science** |
| Singapore | Singapore | Singapore | Singapore |
| Hong Kong SAR | Korea, Republic of | Korea, Republic of | Japan |
| Korea, Republic of | Japan | Chinese Taipei | Chinese Taipei |
| Chinese Taipei | Russian Federation | Hong Kong SAR | Korea, Republic of |
| Japan | | Japan | Slovenia |

Although there generally were small differences from country to country when countries were ordered by average achievement, there was a substantial range in performance—around 250 scale score points—from the top performing East Asian countries to the lower performing countries. Whereas the highest achieving of the East Asian countries had average achievement around the 600 point mark in both subjects and grades, average achievement of the lowest scoring countries was around 370 points.

## Trends in Student Achievement

Looking at trends in student achievement, TIMSS shows positive gains both in the short term from 2011 to 2015 and the long term from 1995 to 2015, with more countries having increases than decreases in student achievement in both subjects and at both grades.

For short term trends at fourth grade, 41 countries had comparable data from 2011 that can be compared to 2015. In mathematics, about half of these countries (21) had higher average achievement in 2015 than 2011, and another 15 remained at 2011 levels. Only five countries had lower achievement in 2015. In science, more than one-third of the countries (17 of 41) had higher achievement in 2015, 16 remained at 2011 levels, and 8 had lower achievement in 2015. There were similar levels of short term improvement at eighth grade, with more than half the countries (18 out of 34) showing improvement in mathematics compared to 2011 and only 3 declining, and 15 out of 34 countries showing improvement in science and only 4 declining.

The long term trends over the past 20 years show an even more encouraging picture. As shown in Exhibit 2, of the 17 countries with 20 year trend data (1995 to 2015) at fourth grade, 14 had higher average mathematics achievement in 2015 than 1995, just 2 had lower achievement, and 1 was unchanged. In science, 11 countries had higher achievement in 2015, 4 were unchanged over the period, and 2 had lower achievement. There were 16 countries with 20 year trend data at the eighth grade (Exhibit 3), and in both mathematics and science there were 9 countries with higher achievement in 2015, 3 countries with lower achievement, and 4 countries where average achievement was unchanged.

**Exhibit 2: 20 Year Trends from 1995–2015, Fourth Grade**

| Mathematics | | | Science | | |
|---|---|---|---|---|---|
| **Countries Improving** | **Countries Unchanged** | **Countries Declining** | **Countries Improving** | **Countries Unchanged** | **Countries Declining** |
| Australia | Hungary | Czech Republic | Cyprus | Australia | Netherlands |
| Cyprus | | Netherlands | England | Czech Republic | Norway |
| England | | | Hong Kong SAR | New Zealand | |
| Hong Kong SAR | | | Hungary | United States | |
| Iran, Islamic Rep. of | | | Iran, Islamic Rep. of | | |
| Ireland | | | Ireland | | |
| Japan | | | Japan | | |
| Korea, Rep. of | | | Korea, Rep. of | | |
| New Zealand | | | Portugal | | |
| Norway | | | Singapore | | |
| Portugal | | | Slovenia | | |
| Singapore | | | | | |
| Slovenia | | | | | |
| United States | | | | | |

**Exhibit 3: 20 Year Trends from 1995–2015, Eighth Grade**

| Mathematics | | | Science | | |
|---|---|---|---|---|---|
| **Countries Improving** | **Countries Unchanged** | **Countries Declining** | **Countries Improving** | **Countries Unchanged** | **Countries Declining** |
| England | Australia | Hungary | Hong Kong SAR | Australia | Hungary |
| Hong Kong SAR | Ireland | Norway | Ireland | England | Norway |
| Iran, Islamic Rep. of | Japan | Sweden | Japan | Iran, Islamic Rep. of | Sweden |
| Korea, Rep. of | New Zealand | | Korea, Rep. of | New Zealand | |
| Lithuania | | | Lithuania | | |
| Russian Federation | | | Russian Federation | | |
| Singapore | | | Singapore | | |
| Slovenia | | | Slovenia | | |
| United States | | | United States | | |

## Performance at the TIMSS 2015 International Benchmarks

To provide information about the mathematics and science that students at various levels of achievement in TIMSS know and can do, TIMSS reports achievement at four points along the scale as international benchmarks: Advanced International Benchmark (625), High International Benchmark (550), Intermediate International Benchmark (475), and Low International Benchmark (400).

In mathematics at the fourth grade, the five East Asian countries had the best performance at the TIMSS International Benchmarks. These countries had at least 93 percent of their students reaching the Intermediate Benchmark and 32 to 50 percent reaching the Advanced Benchmark. Students at the Advanced Benchmark in mathematics could apply their understanding and knowledge in a variety of relatively complex situations and explain their reasoning. As shown in Exhibit 4, almost all students reached the Low International Benchmark (93% median across all countries) but only 6 percent internationally reached the Advanced Benchmark.

**Exhibit 4: TIMSS 2015 International Benchmarks—Mathematics, Fourth Grade**

| | | % Students Reaching Benchmark |
|---|---|---|
| **Advanced (625)** | Can apply understanding and knowledge in a variety of relatively complex situations and explain their reasoning | 6% |
| **High (550)** | Can apply knowledge and understanding to solve problems | 36% |
| **Intermediate (475)** | Can apply basic mathematical knowledge in simple situations | 75% |
| **Low (400)** | Have some basic mathematical knowledge | 93% |

Remarkably, 13 of 17 countries with 20 year trends raised mathematics achievement across their entire fourth grade distribution, improving at each of the four benchmarks from Low to Advanced. In 2015 compared to 2011, 14 countries improved at the Low Benchmark, 17 improved at the Intermediate Benchmark, and 16 improved at the High and Advanced Benchmarks.

In science at the fourth grade, Singapore, Korea, the Russian Federation, and Japan had the best performance at the TIMSS International Benchmarks, with 90 percent or more of their students reaching the Intermediate Benchmark and 19 to 37 percent reaching the Advanced Benchmark. This is in contrast to the situation for most countries, where 77 percent of students reached the Intermediate Benchmark and 7 percent reached the Advanced Benchmark (Exhibit 5). Students reaching the Advanced Benchmark could communicate understanding of life, physical, and Earth sciences and demonstrate some knowledge of the process of scientific inquiry.

**Exhibit 5: TIMSS 2015 International Benchmarks—Science, Fourth Grade**

| | | % Students Reaching Benchmark |
|---|---|---|
| **Advanced (625)** | Communicate understanding of life, physical, and Earth sciences and demonstrate some knowledge of the process of scientific inquiry | 7% |
| **High (550)** | Communicate and apply knowledge of life, physical, and Earth sciences in everyday and abstract contexts | 39% |
| **Intermediate (475)** | Show basic knowledge and understanding of life, physical, and Earth sciences | 77% |
| **Low (400)** | Show basic knowledge of life and physical sciences | 95% |

Almost half (8 of 17) of the countries with 20 year trends raised science achievement since 1995 across their entire fourth grade distribution, with increased percentages of students at all four international benchmarks. A further five countries raised achievement in the lower half of the achievement distribution—at the Low and Intermediate Benchmarks. In 2015 compared to 2011, more countries showed improvement at the Intermediate (20) and High Benchmarks (16) than at the Low (15) and Advanced Benchmarks (9).

In mathematics at the eighth grade, students at the Advanced Benchmark could reason with information, draw conclusions, make generalizations, and solve linear equations. The five East Asian countries had 34 to 54 percent of their students reach the Advanced Benchmark. There was a substantial gap to the next highest result—15 percent in Kazakhstan. As shown in Exhibit 6, only 5 percent of students across all countries reached the Advanced Benchmark.

**Exhibit 6: TIMSS 2015 International Benchmarks—Mathematics, Eighth Grade**

| | | % Students Reaching Benchmark |
|---|---|---|
| **Advanced (625)** | Can apply and reason in a variety of problem situations, solve linear equations, and make generalizations | 5% |
| **High (550)** | Can apply understanding and knowledge in a variety of relatively complex situations | 26% |
| **Intermediate (475)** | Can apply basic mathematical knowledge in a variety of situations | 62% |
| **Low (400)** | Have some basic knowledge of whole numbers and basic graphs | 84% |

Five of the 16 countries with 20 year trends raised mathematics achievement across their entire eighth grade distribution, with increased percentages of students at all four international benchmarks. Among the 16 countries, the number of improving countries increased at each higher benchmark—5 at Low, 6 at Intermediate, 8 at High, and 10 at Advanced. In 2015 compared to 2011, the results for the 34 countries had a different pattern with more countries showing improvement at the lower benchmarks—14 at Low, 16 at Intermediate, 14 at High, and 9 at Advanced.

In eighth grade science, Singapore had the best performance at the TIMSS International Benchmarks, with 42 percent of students reaching the Advanced Benchmark, followed by Chinese Taipei (27%) and Japan (24%). In these countries, 86 percent or more reached the Intermediate Benchmark. Students reaching the Advanced Benchmark in eighth grade science could communicate understanding of complex concepts related to biology, chemistry, physics, and Earth science in practical, abstract, and experimental contexts. As shown in Exhibit 7, the TIMSS countries generally performed well below these levels, with just 7 percent reaching the Advanced Benchmark, and 64 percent reaching the Intermediate Benchmark.

**Exhibit 7: TIMSS 2015 International Benchmarks—Science, Eighth Grade**

| | | % Students Reaching Benchmark |
|---|---|---|
| **Advanced (625)** | Communicate understanding of complex concepts related to biology, chemistry, physics, and Earth science in practical, abstract, and experimental contexts | 7% |
| **High (550)** | Apply and communicate understanding of concepts from biology, chemistry, physics, and Earth science in everyday and abstract situations | 29% |
| **Intermediate (475)** | Demonstrate and apply knowledge of biology, chemistry, physics, and Earth science in various contexts | 64% |
| **Low (400)** | Show some basic knowledge of biology, chemistry, physics, and Earth science | 84% |

Four of the 16 countries with 20 year trends raised science achievement across their entire eighth grade distribution, improving at each of the four international benchmarks. Among the 16 countries, 8 countries showed increased percentages of students at one or more benchmarks since 1995, and 5 countries showed a decrease. In 2015 compared to 2011, more countries showed improvement than decline at each benchmark, particularly at the Advanced Benchmark, where 10 countries improved and no country declined.

## Gender Differences in Mathematics and Science Achievement

Twenty years ago, in the most comprehensive international assessment of student achievement at that time, TIMSS 1995 found that gender differences in mathematics achievement were generally small or negligible at both fourth and eighth grades. However, there were some countries with significant gender differences, and in these countries it was always boys who had higher achievement than girls (Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996a; Beaton, Mullis, Martin, Gonzalez, Kelly & Smith, 1996b). In science achievement the boys' advantage was more pronounced, with boys outperforming girls in about half the countries at fourth grade and in almost all countries at eighth grade (Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996a; Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996b). These findings of a larger gender gap favoring boys in science than in mathematics and especially in eighth grade science compared to fourth grade were in agreement with earlier IEA international studies of mathematics and science, and seemed to confirm a solid and even enduring advantage for boys in terms of science achievement. Twenty years later, TIMSS 2015 provides an ideal opportunity to examine how gender gaps may have changed.

Exhibit 8 summarizes the TIMSS 2015 gender differences in mathematics and science achievement at fourth and eighth grades, showing the number of countries with significant gender differences as well as the average achievement difference. Compared to 1995, these results portray quite a different situation with regard to gender differences, with far fewer countries having gender differences favoring boys and quite a few countries where girls outperformed boys, particularly in science, where boys previously had a substantial advantage.

**Exhibit 8: Gender Differences in Achievement in 2015**

| | Fourth Grade | | Eighth Grade | |
|---|---|---|---|---|
| | Mathematics | Science | Mathematics | Science |
| Countries where boys had higher achievement than girls | 18 (37%)<br>Avg. Diff:<br>9 points | 11 (23%)<br>Avg. Diff:<br>8 points | 6 (15%)<br>Avg. Diff:<br>9 points | 5 (13%)<br>Avg. Diff:<br>11 points |
| Countries with no achievement difference between boys and girls | 23 (47%) | 25 (53%) | 26 (67%) | 20 (51%) |
| Countries where girls had higher achievement than boys | 8 (16%)<br>Avg. Diff:<br>18 points | 11 (23%)<br>Avg. Diff:<br>24 points | 7 (18%)<br>Avg. Diff:<br>17 points | 14 (36%)<br>Avg. Diff:<br>28 points |
| Number of countries | 49 | 47 | 39 | 39 |

Across mathematics and science at fourth and eighth grades, TIMSS 2015 found gender equity in average achievement in about half the countries, ranging from 47 percent of the countries (23 of 49) for fourth grade mathematics to 67 percent (26 of 39) for eighth grade mathematics. This represented a considerable evolution since 1995, particularly with regard to science.

At fourth grade, boys outperformed girls in mathematics in 18 countries (about one-third), which was rather more than in 1995. However, there also were eight countries (about one-sixth) where girls outperformed boys, and the average achievement difference (18 points) was higher in these countries than in the countries where boys scored higher (9 points). In science, the boys outperformed the girls in 11 countries (about one-fourth), which was, proportionally, considerably less than in 1995, and girls performed better than boys in 11 countries (about one-fourth), which was a new development. Similar to mathematics, the average achievement difference in schools where boys outperformed girls was 8 points, but in countries where girls had higher achievement, the difference was much bigger (24 points).

At eighth grade, the change from 1995 in the pattern of gender differences was even more pronounced than at fourth grade. In mathematics, boys outperformed girls in just 6 countries, with an average achievement difference of 9 points, and there were 26 countries (two-thirds of the countries) with no gender difference in achievement. In the most noticeable development, there were 7 countries where girls outperformed boys, and here the average difference was 17 points. The results in science show an even bigger contrast. In 1995, boys had higher science achievement than girls in almost all countries, whereas in 2015 boys outperformed girls in just five countries (about one-seventh). More remarkably, girls in 2015 outperformed boys in 14 countries (more than one-third), compared to no country at all in 1995. In addition, in those countries where girls performed better than boys, the average achievement difference was 28 points.

## Gender Differences in 20 Year Trend Countries

Part of the explanation for the changes in gender differences in student achievement—the decrease in the difference favoring boys and the emergence of the difference favoring girls—may lie in the change in the composition of the TIMSS countries between 1995 and 2015. This idea may be investigated by restricting attention to the 20 year trend countries that participated in both assessments—17 at fourth grade and 16 at eighth grade (see Exhibit 9).

For the 17 TIMSS countries that participated at the fourth grade in both 1995 and 2015, there was little change in gender differences in mathematics achievement over the 20 years. In 1995, 7 of these 20 year trend countries had significant gender differences, with boys having higher mathematics achievement than girls in each case, and an average difference across the participants of 5 scale score points. In 2015, there were significant gender differences in nine of the participants, again favoring boys, although the average gender difference did not increase (5 points in each case). However, in several countries, including Australia, Hong Kong SAR, and Portugal, the achievement gap between boys and girls increased since 1995. In mathematics achievement at fourth grade, therefore, the modest advantage held by boys in some countries was relatively unchanged in 2015. It should be noted that girls did not perform significantly better than boys in fourth grade mathematics in any of the 20 year trend countries.

**Exhibit 9: 20 Year Trends in Gender Differences in Achievement, 1995–2015**

| Fourth Grade | | | | |
|---|---|---|---|---|
| | Mathematics | | Science | |
| | 1995 | 2015 | 1995 | 2015 |
| Countries where boys had higher achievement than girls | 7/17 | 9/17 | 10/17 | 7/17 |
| Countries with no achievement difference between boys and girls | 10/17 | 8/17 | 6/17 | 10/17 |
| Countries where girls had higher achievement than boys | 0 | 0 | 1 | 0 |
| Average difference (boys'-girls' scores, in scale score points) | 5 | 5 | 9 | 3 |
| **Eighth Grade** | | | | |
| | Mathematics | | Science | |
| | 1995 | 2015 | 1995 | 2015 |
| Countries where boys had higher achievement than girls | 4/16 | 3/16 | 15/16 | 3/16 |
| Countries with no achievement difference between boys and girls | 12/16 | 12/16 | 1/16 | 13/16 |
| Countries where girls had higher achievement than boys | 0 | 1 | 0 | 0 |
| Average difference (boys'-girls' scores, in scale score points) | 6 | 2 | 21 | 2 |

In science in 1995, gender differences at the fourth grade were somewhat greater than in mathematics, with 10 of the 17 countries having significant achievement differences, all of them favoring boys, and an average achievement difference across countries of 9 points. However, by 2015 the number of countries with significant gender differences had decreased from 10 to 7 and the size of the difference had decreased from 9 to 3 points. In each of the countries that still showed a difference, boys had higher average science achievement than girls. Countries with the largest decreases in the gender difference included Cyprus, the Czech Republic, Japan, the Netherlands, New Zealand, Norway, and the United States. For science at fourth grade, therefore, there has been a closing of the achievement gap among the 20 year trend countries, to the extent that average gender differences in science and mathematics now are comparable (3 to 5 points). Similar to mathematics, there were no 20 year trend countries in 2015 where fourth grade girls had significantly higher average science achievement than boys.

Among the 16 countries with 20 year trends at eighth grade, gender differences in mathematics achievement were low in 1995 and comparable to those in fourth grade, with significant differences favoring boys in just 4 of the 16 countries and an average achievement difference between boys and girls of just 6 points. By 2015 the average difference had decreased to 2 points, with four of the countries no longer having significant gender differences (Hong Kong SAR, Iran, Japan, and Korea). However, several countries, including Hungary, the Russian Federation, and Sweden, had developed gender differences in favor of boys by 2015. Singapore, which had gender parity in mathematics achievement in 1995, was the only 20 year trend country where girls outperformed boys —by a difference of 9 points.

In contrast to the modest differences between eighth grade boys and girls in mathematics achievement in 1995, the differences in science achievement were much more pronounced. In 15 of the 16 countries, boys had higher average science achievement than girls, with an average score difference of 21 points. However, by 2015 the situation had changed considerably, with the average gender difference falling to just 2 points and only three of the countries having significant differences. Several countries had a reduction in the boy-girl achievement difference of more than 20 points, including England, Hong Kong SAR, Iran, Korea, Lithuania, and New Zealand. Despite this remarkable narrowing of the boy-girl science achievement gap, girls did not have higher science achievement than boys in any of the 20 year trend countries.

It is clear from the foregoing analysis that the change in gender differences in achievement in the 20 year trend countries was due to a convergence over time in the performance of boys and girls in these countries, especially in science and especially at the eighth grade. This may be the result of concerted efforts in countries to make mathematics and science more attractive to girls and to boost their achievement in comparison with boys. Although the elimination of the achievement gap over the past 20 years may well presage an increasing gap in favor of girls in the future, there is little evidence as yet of girls performing better than boys in the 20 year trend countries.

## Girls Outperforming Boys

Exhibit 10 shows the countries in 2015 where girls had higher achievement than boys. In several of these countries, girls seem to have a general advantage in academic achievement over boys. For example, girls outperformed boys in both mathematics and science at fourth grade in Bahrain, Finland, Kuwait, Oman, and Saudi Arabia and at eighth grade in Bahrain, Botswana, Jordan, Oman, and Thailand. These countries face a considerable challenge in bringing boys up to the standard of achievement established by girls.

**Exhibit 10: Countries Where Girls Had Higher Achievement Than Boys in 2015**

| Fourth Grade | | Eighth Grade | |
|---|---|---|---|
| **Mathematics** | **Science** | **Mathematics** | **Science** |
| Bahrain | Bahrain | Bahrain | Bahrain |
| Finland | Bulgaria | Botswana | Botswana |
| Indonesia | Finland | Jordan | Jordan |
| Jordan | Kazakhstan | Malaysia | Kuwait |
| Kuwait | Kuwait | Oman | Lebanon |
| Oman | Morocco | Singapore | Malaysia |
| Saudi Arabia | Oman | Thailand | Malta |
| South Africa | Qatar | | Morocco |
| | Saudi Arabia | | Oman |
| | Sweden | | Qatar |
| | United Arab Emirates | | Thailand |
| | | | Turkey |
| | | | Saudi Arabia |
| | | | United Arab Emirates |

## TIMSS Advanced 2015

TIMSS Advanced assesses achievement at the end of secondary schooling of those select students with advanced preparation in advanced mathematics and physics. In today's technological world, TIMSS Advanced addresses the issue of how many students to educate and to how high a level.

In the 2015 advanced mathematics assessment, the 2 percent of Russian students in intensive study (6 hours-plus per week) and the 4 percent of Lebanese students had the highest achievement (see Exhibit 11). The United States, with 11 percent of its students in TIMSS Advanced, the Russian Federation with 10 percent, and Portugal with 29 percent (nearly three times that of Russia and the United States) had the next highest achievement. France (22%), Slovenia (34%), and Norway (11%) were next with comparable achievement, followed by Sweden (14%) and Italy (25%), each with comparable achievement (Mullis, Martin, Foy, & Hooper, 2016a).

**Exhibit 11: TIMSS Advanced 2015—Countries Participating, Population Coverage, and Average Achievement**

| Country (% of population studying advanced mathematics) | Advanced Mathematics Achievement | Country (% of population studying physics) | Physics Achievement |
|---|---|---|---|
| Russian Federation 6hr+ (2%) | 540 | Slovenia (8%) | 531 |
| Lebanon (4%) | 532 | Russian Federation (5%) | 508 |
| United States (11%) | 485 | Norway (7%) | 507 |
| Russian Federation (10%) | 485 | Portugal (5%) | 467 |
| Portugal (29%) | 482 | Sweden (14%) | 455 |
| France (22%) | 463 | United States (5%) | 437 |
| Slovenia (34%) | 460 | Lebanon (4%) | 410 |
| Norway (11%) | 459 | Italy (18%) | 374 |
| Sweden (14%) | 431 | France (22%) | 373 |
| Italy (25%) | 422 | | |

In the physics assessment, Slovenia with 8 percent of its students assessed had the highest average achievement, followed by the Russian Federation (5%) and Norway (7%) with comparable achievement (see Exhibit 11). Portugal, with 5 percent of its students in TIMSS Advanced, and Sweden with 14 percent had the next highest achievement. The United States, with 5 percent of its students in TIMSS Advanced, had the next highest achievement, followed by Lebanon with 4 percent. Italy, with 18 percent of its students in TIMSS Advanced, and France, with 22 percent, had comparable achievement.

## Trends in TIMSS Advanced

TIMSS Advanced 2015 revealed disappointing trends in advanced mathematics. Of the 6 countries with 20 year trend data, France, Italy, and Sweden had lower average achievement in 2015 than in 1995, while the Russian Federation, Slovenia, and the United States had no significant difference. As a bright spot, Norway and Sweden had upturns between 2008 and 2015. Achievement trends in physics were even more disappointing. Of the 6 countries with 20 year trend data, France, Norway, the Russian Federation, and Sweden experienced substantial decreases in average achievement since 1995, while Slovenia and the United States had no significant change. No country improved over the 20 year period.

## Gender Differences in TIMSS Advanced

TIMSS Advanced 1995 showed that in advanced mathematics and especially in physics there were proportionally more males than females enrolled in the programs or courses assessed, and the males had higher average achievement than the females. Looking at the data for the six countries that also took part in TIMSS Advanced 2015, there has been little change in the gender composition in either subject, but there has been a considerable closing of the achievement gap in physics, perhaps reflecting the developments at fourth and eighth grades.

Although there was some variation, on average across countries 58 percent of the advanced mathematics students in 1995 were male and 42 percent female. By 2015, this 16 percentage point difference had fallen to 7 points (54% males and 47% females). There was little change in the achievement difference, however, with males still outperforming females in average mathematics achievement by about 20 scale score points.

In physics, the gender imbalance in 1995 was more pronounced—64 percent male and 36 percent female—and little changed in 2015 (62% vs. 38%). The gender difference in physics achievement in 1995 also was greater than in advanced mathematics, with males scoring higher than females by 53 points. By 2015 this achievement gap was reduced considerably, to 28 points.

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# CHAPTER 2

# How Is the Curriculum Changing?

In the first part of this report, "How Is the World Doing?" described considerable progress in students' achievement in mathematics and science over the 20 years of TIMSS. The trends are positive, with more countries showing improvements than declines in achievement, especially in the short term between 2011 and 2015 but also in the long term between 1995 and 2015.

But, is the news even better than we think?

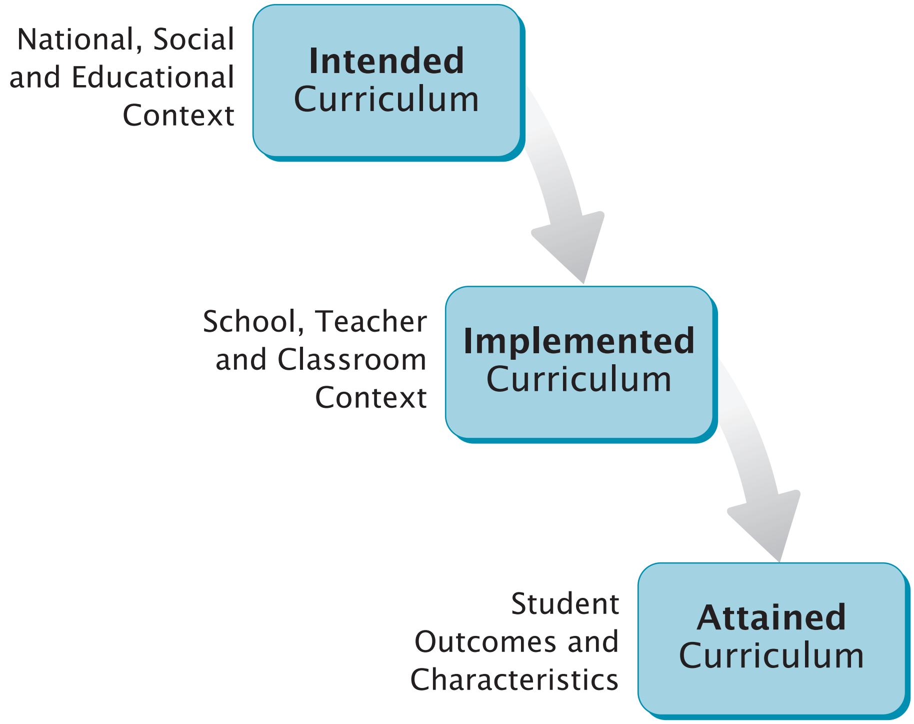
Countries are continually working to improve their mathematics and science curricula, such that the mathematics and science curricula in 2015 covered more content, processes, and procedures than in 1995. As a result, the curriculum reforms of the past two decades may have made K–12 mathematics and science more challenging.

There is concern about achievement stagnating in some countries—but looked at from another perspective, keeping up with the curve is much better than falling behind it. This chapter uses the TIMSS Curriculum Model as a framework for considering countries' updating of their curricula, and in turn the updating of the TIMSS assessments.

## TIMSS Curriculum Model

The TIMSS Curriculum Model has three aspects: the intended curriculum, the implemented curriculum, and the attained curriculum (Mullis & Martin, 2013). These represent, respectively, the mathematics and science that students are expected to learn as defined in countries' curriculum policies and publications and how the educational system is organized to facilitate this learning; what is actually taught in classrooms, the characteristics of those teaching it, and how it is taught; and what students have learned and what they think about learning. In summary, the model considers what is expected, taught, and assessed.

**Exhibit 1: TIMSS Curriculum Model**




Nearly all the TIMSS countries had a national curriculum, except Canada, Germany, and the United States with provincial or state control of education. So in most cases, the intended curriculum is developed at the national level and defines what all students in the country should be able to know and do in mathematics and science. Society expects that the content in the national curriculum will be taught to students. Because the countries' official curricula set the initial standards for students' opportunity to learn mathematics and science, it is very important for the curricula to have challenging content. However, it is clear from the model that raising the challenges in the intended curriculum could make it more difficult for teachers to deliver the curriculum effectively and for students to attain it.

## The TIMSS 2015 Encyclopedia: Education Policies and Curriculum

Beginning in 2007, TIMSS has compiled the TIMSS Encyclopedia with each assessment cycle to document education policies and the curriculum in mathematics and science in each of the participating countries. The TIMSS Encyclopedia consists of chapters prepared by the TIMSS participants that summarize the official mathematics and science curricula in primary and secondary grades, among other topics. To provide standard information across countries when possible, countries also complete a curriculum questionnaire that supplements the chapters.

Considering the wide diversity of the TIMSS 2015 countries across such dimensions as population size, gross national income per capita, geography, number of languages spoken, and basic quality of life (e.g., life expectancy), countries' reports about their mathematics and science curricula show more similarities than differences. According to the *TIMSS 2015 Encyclopedia* (Mullis, Martin, Goh, & Cotter, 2016), most of the countries' current mathematics and science curricula:

- Began in preprimary school and were allotted substantial percentages of the available instructional time
- Emphasized integrating technology into mathematics and science learning
- Emphasized problem solving and thinking/reasoning skills as well as inquiry and investigation skills in science
- Specified major content domains (e.g., algebra and geometry in mathematics and biology and physics in science) with subtopics
- Encouraged developing positive attitudes

## Prominence of Mathematics and Science in Countries' Curricula

According to the TIMSS 2015 Encyclopedia, mathematics and science are central areas in countries' curricula, allotted approximately one-fourth to one-third of the available instructional time. Also, curricular guidelines that include mathematics and science are emerging in preprimary programs.

Countries devote considerable energy and resources to updating their mathematics and science curricula. During the 20 years of TIMSS, nearly all countries have implemented curriculum reforms in mathematics and science, ranging from updates to full scale revisions. Many countries initiated curriculum reform in the 1990s or early 2000s, particularly in mathematics, and the reform was based at least partially or even wholly on TIMSS results. For example, the TIMSS 1995 results created concern among mathematics and science educators in New Zealand, such that the Ministry of Education started developing a comprehensive numeracy policy and strategy in late 1998, piloting "Count Me In Too" and initiating the Numeracy Development Projects in 2001. In Hong Kong SAR, TIMSS research directly informed a new mathematics curriculum implemented in 1999. By the mid-2000s, curriculum reform in mathematics and science was widespread across the TIMSS countries. In 2007, approximately 60 percent of the countries at fourth grade were revising their mathematics and science curricula, with higher percentages at the eighth grade (70% for mathematics, 65% for science).

In 2015 at the fourth and eighth grades, about half the countries were revising their mathematics and science curricula, and a number of those were using TIMSS data. For example, in 2015 the Department of Education in Northern Ireland commissioned an analysis of science education in the seven countries that outperformed Northern Ireland in 2011, and found those countries tended to teach science as a separate subject in primary education. The report suggested raising the profile of science within the current integrated subject (The World Around Us). Analyses of TIMSS 2011 trend results in Malaysia indicated that students were falling behind because they lacked the opportunity to develop higher order thinking skills, and experts in Croatia are using information from *Recommendations for Improving Curricula of Mathematics Education Based on the Results of TIMSS 2011* to implement curriculum reform in mathematics.

## Using Technology to Improve Mathematics and Science Learning

The most pervasive change in the mathematics and science curricula across countries in the past two decades is the nearly universal integration of technology into countries' curricula. Most of the TIMSS 2015 countries reported initiatives for integrating Information and Communications Technology (ICT) across the curriculum. Historically speaking, incorporating digital devices into educational settings, including the teaching and learning of mathematics and science, is coming into widespread practice for the first time. These are pioneering efforts, so the most effective strategies and approaches are not necessarily known. Singapore is unique for having worked on technology policies for longer than a decade. Singapore had introduced its fourth Masterplan in 2015, building on the foundation of the first three Masterplans. Incorporating insights from extensive reviews and stakeholder consultations, the fourth Masterplan seeks to optimize the use of ICT in the whole curriculum.

Most large scale efforts to integrate technology and education are relatively recent. For example, from 2011 to 2015, Denmark allocated a budget of 500 million DKK for the increase of ICT use in schools, and the initiative has been extended through the end of 2017. In Israel, a national program of teacher training workshops was initiated in 2011 to create classrooms in which technology serves the development of innovative pedagogy and 21$^{st}$ century skills. In conjunction with the teacher workshops, the Bring your Own Device program was initiated in 2015 to support the implementation of technological devices in classroom activities.

At the fourth grade, 80 percent of the countries reported having a specific policy regarding the use of technology in the mathematics curriculum. Guidelines ranged from general suggestions about integrating ICT into instruction to suggestions involving problem solving, dynamic geometry, and representing data through tables and graphs. Nearly 40 percent of the countries' mathematics curricula mention calculator use, sometimes including restrictions (e.g., not using calculators until a particular grade or not allowing use during testing). In science at the fourth grade, 65 percent of the countries have curriculum guidelines for ICT. Some guidelines specifically apply to science. For example, the Singaporean curriculum explains that ICT in science supports the inquiry process and facilitates student collaboration and self-directed learning. Internet-enabled devices facilitate data collection and analysis in situated learning, and simulation tools enable students to explore and visualize abstract concepts.

At the eighth grade, most of the TIMSS 2015 countries (93% for mathematics and 88% for science) reported curriculum guidelines for incorporating technology into instruction, and the guidelines sometimes made specific recommendations for ICT use in mathematics. Such suggestions included using ICT when doing operations on numbers, exploring functions, and analyzing data (Georgia); data analysis, graphical presentation, symbolic manipulation, and observing patterns (Hong Kong SAR); supporting mathematics applications and problem solving skills (Ireland); and exploring problems, making calculations, and presenting and interpreting data (Sweden). For science, guidelines often mentioned making the subject more engaging through activities such as using simulations or graphing software (Canada); animations, simulations, and critical assessment of Internet-based information (Norway); facilitating collaboration (Singapore); and enhancing investigations and explorations (Slovenia).

In response to the global emphasis on STEM education as well as growing concern about students' college and career readiness, TIMSS Advanced was conducted in 2015 in nine countries (France, Italy, Lebanon, Norway, Portugal, the Russian Federation, Slovenia, Sweden, and the United States) (Mullis, Martin, Foy, & Hooper, 2016). As would be anticipated, these countries had specific policies regarding the use of technology in advanced mathematics and physics programs. In France, the advanced mathematics policy focused on using tools such as calculators equipped with computer algebra systems (CAS) in problem solving to focus students on reasoning and strategy rather than technical calculations. Norway used digital tools for comprehensive computations and visualization, including retrieving, processing, and presenting mathematics information in electronic form, as well as evaluating the suitability, possibilities, and limitations of digital tools.

Fewer TIMSS Advanced countries had specific technology policies for physics, but Sweden's curriculum states that students be given opportunities to collect, simulate, calculate, process, and present data. In the United States, most states include standards requiring students to use technology in laboratory courses and use computers or graphing calculators for simulations, modeling, and data analysis. Most advanced courses in physics require students to have access to the Internet; electronic sensors for collecting, analyzing, and processing data; and software for laboratory experiments.

## Changes in Mathematics and Science Curricula

The Encyclopedia chapters written by the TIMSS 2015 countries provide considerable detail about the mathematics and science curricula at fourth and eighth grades, and the advanced mathematics and physics curricula are described in the *TIMSS Advanced 2015 International Results in Advanced Mathematics and Physics*. There is substantial similarity across the countries' mathematics and science curricula; however, it needs to be emphasized that no two curricula are exactly alike.

### Increased Emphasis on Problem Solving and Inquiry

Despite the growing popularity of problem solving and inquiry, when TIMSS first was administered in 1995 many countries' curricula in the lower grades did not include a focus on reasoning and communicating. The first TIMSS assessments were not designed to report separately on higher order skills. TIMSS began assessing process domains in mathematics and science in TIMSS 2003 as the result of an eight country initiative spearheaded by the United States. In TIMSS 2007, to ensure comparable reporting, the cognitive skills were aligned across mathematics and science—knowing, applying, and reasoning. The science framework also delineates inquiry as an overarching strand.

Most TIMSS 2015 countries specified process skills as a separate dimension cross-cutting the mathematics or science content areas. Some had two sets of process skills (e.g., thinking skills vs. doing skills) and other countries simply integrated skills in the content (e.g., use protractors, design an experiment).

In particular, the TIMSS 2015 countries targeted thinking, problem solving, and communicating skills in fourth and eighth grade mathematics. Examples include: Bahrain—problem solving, reasoning and proving, communication, and linking and representing knowledge; Belgium (Flemish)—understand, apply, develop critical thinking, regulate and reflect on processes; Chinese Taipei—use abstract reasoning, communicate understanding, develop problem solving skills; France—research and reasoning, imagination and the capacity for abstraction, rigor and accuracy; Iran—

problem solving, modeling, making and evaluating hypotheses, reasoning; Singapore—reasoning, communication, connecting, thinking, application, modeling; and Turkey—problem solving, reasoning, communication, and making connections.

About two-thirds of the science curricula at fourth and eighth grades focused on thinking skills as well as inquiry and investigation. For example, Canada's Common Framework of Science Learning Outcomes (K-12) specified developing the skills required for scientific and technological inquiry, solving problems, communicating scientific ideas, working collaboratively, and making informed decisions; Ireland described working scientifically as including observing, predicting, carrying out investigations, recording and analyzing results, sharing and discussing findings, and extending thinking to accommodate new findings; and Singapore has inquiry as the center of a multidimensional science curriculum. Indonesia's new curriculum, introduced in 2013, includes observing, questioning, exploring, associating, and communication. In Australia, the new science curriculum introduced in 2015 appears to emphasize processes more than content. It is organized around three interrelated strands: Science Understanding (biological sciences, chemical sciences, Earth and space sciences, and physical sciences); Science as a Human Endeavor (nature and development of science, use and influence of science); and Science Inquiry Skills (questioning and predicting, planning and conducting, processing and analyzing data, evaluating, communicating).

## Mathematics Content Areas

According to the *TIMSS 2015 Encyclopedia*, countries typically organize their mathematics curricula at both fourth and eighth grades around broad content areas such as Number, Algebra, Geometry, Measurement, and Data.

All TIMSS 2015 countries reported that the mathematics curriculum at the fourth grade included the area of numbers, encompassing understanding and operations with numbers (whole numbers, fractions, and/or decimals). More than half included one or more algebra topics, such as algebraic expressions, simple equations/number sentences, and/or relationships/patterns. Most countries mentioned the areas of geometry and measurement combined or separately. Nearly all the countries mentioned two-dimensional shapes and about two-thirds mentioned three-dimensional shapes as part of geometry. Points, lines/length, and angles as well as area, perimeter, and volume were mentioned by about 85 percent of the countries as part of geometry or measurement.

Data became more prominent as a fourth grade content area in the 20 years of TIMSS. The data content area (often called data handling or processing, but also often called statistics or statistics and probability) was named in almost all of the TIMSS 2015 countries. Within this area, about three-fourths of the countries mentioned reading/interpreting/evaluating tables, bar graphs, pictographs, and pie charts, and nearly half mentioned making or drawing them. Nearly half mentioned introducing the concept of probability or frequencies of outcomes. More than half the countries mentioned students should collect, organize, and display data (often in the context of their daily lives). About a dozen countries mentioned specific statistics (e.g., average).

Nearly all countries organized their eighth grade mathematics topics according to Number, Algebra, Geometry, Measurement, and Data and Probability. Besides operations with rational numbers, exponents, and square roots, countries emphasized algebra topics combined with Number or separately, including expressions, linear equations, and functions. Geometry and Measurement (combined or separate) included properties of geometric shapes, angles and lines, perimeter, area, and volume. Data included reading, interpreting, and creating a variety of data displays; measures of central tendency; and collecting, organizing, and analyzing data. Probability centered on understanding the frequencies of events and how to calculate them.

## Science Content Areas

In science, the content areas are Biology, Chemistry, Physics, and Earth and Space Sciences (sometimes taught in Geography), but the science curriculum was different between the fourth and eighth grades in some countries. The fourth grade science curriculum sometimes was centered on learning about nature or the world around students, and not on the separate science areas.

In fourth grade science, countries' science curriculum included content areas such as: Our Surroundings; Natural Phenomena; Substances Around Us; Man and Living Things and the Environment; Nature; Humans' Health and Safety, World Around Us, Discovering Myself, and separate topics—plants, animals, health, systems, energy, matter, seasons, or oceans. Often the same topics were included across many curricula, but there was considerable variation in organization and presentation.

Nearly all the eighth grade science curricula included Biology (living things) and Physical Science (physics and chemistry), and Earth and Space Science (sometimes taught in Geography). Biology topics included characteristics, systems, and processes of living things. Physical Science included the study of matter (classification and changes) as well as energy, light and sound, electricity and magnetism, and forces and motion. Earth Science included Earth's physical features, processes and cycles, the solar system, and in some instances space exploration. A number of curricula emphasized a study of the environment, including human impact and problems such as pollution and global warming.

### TIMSS Advanced Content Areas

Across the advanced mathematics curricula in the TIMSS Advanced countries, the mathematics topics typically were organized into three or more of the following content areas: Analysis, Algebra, Calculus, Functions, Geometry, Trigonometry, Probability (combinatorics), and Statistics. There was a wide range of approaches to the organization of the physics topics; sometimes they were organized according to areas such as mechanics, waves and optics, electricity and magnetism, forces and motion, or modern physics, but more typically were presented as lengthy lists of the topics to be covered.

## Changes in Content Areas in the TIMSS Assessments

In TIMSS 2003, a systematic collaborative process was instituted to update the mathematics and science assessment frameworks from cycle to cycle. With each new assessment cycle, the TIMSS & PIRLS International Study Center drafts an updated version of the framework based on the previous cycles' experiences. The draft is reviewed by the National Research Coordinators and revised to reflect the countries' concerns. Then the NRCs consult with national experts, and respond to a topic by topic survey about how to best update the content and cognitive domains. The frameworks are revised again based on the survey results, and a final draft is circulated among experts and NRCs for final approval. Based on this comprehensive process, there is relatively good correspondence between the mathematics and science curricular content in the TIMSS countries and the content covered in the TIMSS assessment frameworks.

The process also ensures that the TIMSS mathematics and science frameworks evolve in concert with revisions in countries' curricula. Changes in TIMSS evolve gradually. More than half the items are maintained in common from cycle to cycle to monitor trends in students' achievement, but no items are kept for more than three assessments, so that the entire assessment is being refreshed continually.

Because of this evolution, it is interesting to look at how the assessments have changed over the 20 years of TIMSS. Across the mathematics and science assessments conducted from 1995 to 2015, there has been:

- Consolidation of the content areas between 1995 and 2007
- Reduction in the number of specified topics within the content areas between 2007 and 2015
- Increased alignment from 2007 to 2015 between the countries' intended curricula and the topics assessed by TIMSS

At the fourth grade in mathematics, TIMSS 1995 reported results for six content areas: Whole Numbers; Fractions and Proportionality; Measurement, Estimation, and Number Sense; Data Representation, Analysis, and Probability; Geometry; and Patterns, Relations, and Functions (Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996a). Beginning in 2007, TIMSS reported results for three content areas: Number; Geometric Shapes and Measures; and Data Display (Mullis, Martin, & Foy, 2008). TIMSS 2007 included 35 topics compared to 17 topics in TIMSS 2015. In 2007, on average, countries included 63 percent of the topics in their curricula (22 of 35), and in TIMSS 2015 the average increased to 76 percent (13 of 17), which also may indicate that the curriculum became more similar across countries.

In fourth grade science, TIMSS 1995 reported results for Earth Science; Life Science; Physical Science; and Environmental Issues and the Nature of Science (Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996a). The fourth content area covering the environment and nature of science has been integrated into the other three areas since TIMSS 2003. TIMSS 2007 included 35 topics and TIMSS 2015 included 23 topics (Martin, Mullis, & Foy, 2008). In 2007, on average, countries included 66 percent of the topics in their curricula (23 of 35), and in TIMSS 2015 the average was 70 percent (16 of 23).

At the eighth grade in mathematics, TIMSS 1995 reported results for six content areas: Fractions and Number Sense; Geometry; Algebra; Data Representation; Measurement; and Proportionality (Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996b). By TIMSS 2007, this was consolidated into four content areas: Number; Algebra; Geometry; and Data and Chance. There were fewer topics in TIMSS 2015 than in TIMSS 2007 (39 compared to 20), but a higher degree of agreement with the topics in countries' intended curriculum—85 percent (17 of 20) in 2015 compared to 79 percent (31 of 39) in 2007.

TIMSS 1995 reported eighth grade results for five science content areas: Earth Science; Life Science; Physics; Chemistry; and Environmental Issues and the Nature of Science (Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996b). In TIMSS 2007, the content areas were consolidated to four content areas: Biology; Chemistry; Physics; and Earth Science. TIMSS 2007 had 46 topics, compared to 22 topics in TIMSS 2015. In 2007, on average, countries included 74 percent of the topics in their curricula (34 of 46), and in TIMSS 2015 the average increased to 82 percent (18 of 22 topics).

## Attitudes

About half of the mathematics curricula at fourth and eighth grades mentioned attitudes as part of the process or content areas. In the TIMSS 1995 Curriculum Frameworks, developing positive attitudes was considered a curricular goal together with achievement in the content and cognitive domains (Robitaille, Schmidt, Raizen, McKnight, Britton, & Nicol, 1993). However, in the *TIMSS 2015 Encyclopedia*, attitudes were not given a prominent place in the curricula and the types of attitudes included addressed a variety of aims. For example, Singapore included mathematics beliefs, interest, appreciations, confidence, and perseverance. Norway emphasized a broad range of mathematics applications and utilities. Other countries mentioned appreciating the beauty of mathematics, developing a productive disposition toward mathematics, understanding the role of mathematics as a significant component of human nature, appreciating the practical applications of mathematics in life, and displaying a constructively critical attitude toward mathematics.

In fourth and eighth grade science, some countries addressed students' appreciation of scientific inquiry or science as a discipline or a curiosity and interest in science. Countries also targeted attitudes about the environment and how it should be protected, including Georgia's becoming aware of the environment and caring for the environment; Malaysia's developing a conscientious, dynamic, and progressive society that values nature and the preservation and conservation of the environment; and Canada's developing attitudes that support the responsible acquisition and application of scientific and technological knowledge to the mutual benefit of self, society, and the environment.

## Conclusion

There is ample evidence that curriculum revisions by TIMSS countries from 1995 to 2015 have resulted in mathematics and science curricula that are more multidimensional. Most notably, there is an increasing emphasis on integrating new technologies into teaching and learning. Also, there is rising emphasis on process skills such as problem solving, reasoning, and inquiry. Almost all countries' curricula explicitly include a process dimension, and some have two.

Evidence also shows that the curricula are being pushed down to lower grades. The preprimary curricula in the TIMSS 2015 countries include learning mathematics and sometimes science. At the fourth grade, the mathematics and science curricula are beginning to emphasize data collection, analysis, and graphic presentation. In mathematics, some curricula include statistics and probability, and in science there are shifts from the basic study of the students' environments to curricula anchored in life science, physical science, and earth science. By the eighth grade, the mathematics and science curricula in the TIMSS 2015 countries are challenging to the extent that they include complex topics in algebra, geometry, and probability as well as in biology, chemistry, and physics, and call for an emphasis on solving complicated problems and conducting scientific investigations.

TIMSS assessments have kept pace with changes in mathematics and science curricula. In TIMSS 2015 there was more alignment between the topics assessed by TIMSS and the countries' curricula than in TIMSS 2007. As countries continue to embrace more challenging content, TIMSS assessments have evolved to reflect the increased expectations.

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# CHAPTER 3

# Is Instruction Keeping Pace with Curricular Changes?

In the *TIMSS 2015 Encyclopedia*, countries highlighted their ongoing efforts to design curricula that present challenging content and foster problem solving skills (Mullis, Martin, Goh, & Cotter, 2016). Countries reported allocating considerable amounts of instructional time to mathematics and science. Yet adopting a curriculum with challenging content and mandating instructional time does not automatically raise students' achievement. It takes quality teaching to impart the curriculum to students in meaningful and effective ways. In the parlance of the TIMSS Curriculum Model described in the previous chapter, the curriculum must move beyond the *intentional* phase and actually be *implemented* via effective instruction.

This chapter explores whether progress has been made in various aspects of school instruction and whether instruction has kept pace with advances in the intended curricula. In particular, this chapter focuses on trends in teachers' reports collected via the TIMSS context questionnaires:

- Teaching in a supportive school environment
- Teacher education (degrees and majors)
- Professional development
- Classroom contexts for learning
- Instruction in mathematics and science

The context questionnaire data collected by TIMSS in each assessment cycle is guided by the TIMSS context questionnaire framework, which is based on important research about the factors related to higher educational achievement and the experiences of the participating countries. The *TIMSS 2015 Context Questionnaire Framework* (Hooper, Mullis, & Martin, 2013) addresses how educational systems around the world promote learning in mathematics and science, and reflects a global consensus on important areas for monitoring educational improvement.

This chapter primarily focuses on trends between 2007 and 2015 because 2007 is the first assessment year TIMSS placed an increased emphasis on developing policy relevant background questionnaire scales, as well as the first year that TIMSS published an Encyclopedia. Exhibit 1 shows the countries that participated in both TIMSS 2007 and TIMSS 2015 at the fourth grade and at the eighth grade. The sets of countries are not identical, but 15 countries participated in both assessments at both grades, providing the basis for trend comparison between the grades. When 1995 data are available, trends are provided based on the 13 countries at the fourth grade and 14 countries at the eighth grade that also participated in 1995.

**Exhibit 1: Countries in Both TIMSS 2007 and TIMSS 2015**

| Fourth Grade—22 Countries | Eighth Grade—26 Countries |
|---|---|
| Australia* | Australia* |
| Chinese Taipei | Bahrain |
| Czech Republic* | Chinese Taipei |
| Denmark | Egypt |
| England* | England* |
| Georgia | Georgia |
| Germany | Hong Kong SAR* |
| Hong Kong SAR* | Hungary* |
| Hungary* | Iran* |
| Iran* | Italy |
| Italy | Japan* |
| Japan* | Jordan |
| Lithuania | Korea* |
| Netherlands* | Kuwait |
| New Zealand* | Lebanon |
| Norway (4)* | Lithuania* |
| Russian Federation | Malaysia |
| Singapore* | Malta |
| Slovak Republic | Norway (8)* |
| Slovenia* | Oman |
| Sweden | Russian Federation* |
| United States* | Singapore* |
| | Slovenia* |
| | Sweden* |
| | Thailand |
| | United States* |

* Denotes participation of country in TIMSS 1995—13 countries at fourth grade and 14 countries at eighth grade

*Note: Fifteen countries are in common between fourth grade and eighth grade.*

## Supportive School Environment

A safe and orderly school could arguably be considered a requisite for creating a supportive and productive school environment. Of the school environment variables included in the TIMSS 2011 school effectiveness analysis (Martin, Foy, Mullis, & O'Dwyer, 2013), the Safe and Orderly Schools scale was one of the most important variables—related to achievement over and above the effects of home background in about half the countries. The trend scale for 2007 to 2015 summarizes the extent to which teachers agreed that their schools were safe and orderly, based on their responses to three statements:

- This school is located in a safe neighborhood
- I feel safe at this school
- This school's security policies and practices are sufficient

The trend results in Exhibit 2 indicate a considerable shift between 2007 and 2015 from the middle category of Somewhat Safe and Orderly to the top category of Very Safe and Orderly at both fourth and eighth grades. The percentage of students in Very Safe and Orderly schools rose substantially from 47 to 69 percent (increase of 22 percentage points) at fourth grade and from 39 to 63 percent (increase of 24) at eighth grade.

**Exhibit 2: Trends in Safe and Orderly Schools, 2007–2015**

| Percentages of Students in Schools that Teachers Judged Safe and Orderly | | | |
|---|---|---|---|
| | Very Safe and Orderly | Somewhat Safe and Orderly | Not Safe and Orderly |
| **Fourth Grade** | | | |
| 2007 | 47 | 49 | 4 |
| 2015 | 69 | 28 | 2 |
| **Eighth Grade** | | | |
| 2007 | 39 | 54 | 7 |
| 2015 | 63 | 33 | 3 |

Students were assigned to the **Very Safe and Orderly** category if their Rasch scale scores corresponded to their teachers at least agreeing to "a lot" with two of the three statements and agreeing "a little" with the other statement, on average, and to the **Not Safe and Orderly** category when the scores were no higher than disagreeing "a little" with two of the statements and agreeing "a little" with the other one, on average. All other students were categorized as attending **Somewhat Safe and Orderly** schools.

*Note: Results in this exhibit are based on trend scaling conducted specifically for this report.*

A school's emphasis on academic success, characterized as its expectation of academic excellence, can be a powerful contributor to high academic achievement. The TIMSS Emphasis on Academic Success scale was another important variable in the TIMSS 2011 school effectiveness study—related to achievement over and above the effects of home background in about one-third of the countries. For comparability between TIMSS 2007 and TIMSS 2015, a variant of the Emphasis on Academic Success scale was created based on five aspects of academic success:

- Teachers' understanding of the school's curricular goals
- Teachers' degree of success in implementing the school's curriculum
- Teachers' expectations for student achievement
- Parental support for student achievement
- Students' desire to do well in school

Exhibit 3 presents the trend results for 2007 to 2015. There was a sizeable increase at both grades in the percentage of students in the "high" category of emphasis, accompanied by a commensurate decrease in the percentage of students in the "medium" category, which was the lowest category reported for this school characteristic. At the fourth grade, the decrease in the percentage of students in the "medium" category was from 40 percent in 2007 to 28 percent in 2015 (12 percentage points), and at the eighth grade the decrease was from 53 to 35 percent (18 points), indicating considerably fewer students in schools with only a moderate press for academic achievement. At the other end of the continuum, however, despite small gains between 2007 and 2015 only 7 percent of the students in 2015 at both fourth and eighth grades were in schools placing a "very high" emphasis on academic success.

**Exhibit 3: Trends in School Emphasis on Academic Success, 2007–2015**

| Percentages of Students in Schools Where Teachers Reported Emphasized Academic Success | | | |
|---|---|---|---|
| | Very High Emphasis | High Emphasis | Medium Emphasis |
| **Fourth Grade** | | | |
| 2007 | 5 | 55 | 40 |
| 2015 | 7 | 65 | 28 |
| **Eighth Grade** | | | |
| 2007 | 4 | 43 | 53 |
| 2015 | 7 | 58 | 35 |

Students were assigned to the **Very High** category if their Rasch scale scores corresponded to their teachers at least responding "very high" to three of the statements and "high" to the other two statements, on average, and to the **Medium** category when the scores were no higher than responding "medium" with three statements and "high" with the other two, on average. All other students were categorized as attending schools with a **High** emphasis on academic success.

*Note: Results in this exhibit are based on trend scaling conducted specifically for this report.*

Although resource availability may be different from the previous two indicators of a positive school climate, the extent and quality of school resources can be important to a supportive school environment and effective instruction. TIMSS routinely asks school principals to what degree shortages or inadequacies in school resources affect instruction. The trend analysis is based on a scale summarizing responses about four basic resources that can have an impact on instruction:

- Instructional materials (e.g., textbooks)
- School buildings and grounds
- Heating/cooling and lighting systems
- Instructional space

Exhibit 4 presents the trend results for the Adequacy of School Resources scale, which contrast with the gains in the school climate variables. At the fourth grade, there was little change between 2007 and 2015 in reports about how much resource shortages affected instruction. Moreover, at the eighth grade, there was a shift toward the Affected a Lot category, such that instruction for 15 percent of the students was "affected a lot" in 2015 compared to only 6 percent in 2007.

**Exhibit 4: Trends in Adequacy of School Resources for Instruction, 2007–2015**

| | Percentages of Students in Schools Where Instruction Was Affected by Resource Shortages | | |
|---|---|---|---|
| | Not Affected | Affected Somewhat | Affected a Lot |
| **Fourth Grade** | | | |
| 2007 | 53 | 43 | 4 |
| 2015 | 50 | 45 | 6 |
| **Eighth Grade** | | | |
| 2007 | 46 | 48 | 6 |
| 2015 | 44 | 42 | 15 |

Students were assigned to the **Not Affected** category if their Rasch scale scores corresponded to their principals at least responding "not at all" to two of the resources and "a little" to the other two, on average, and to the **Affected A Lot** category if the scores were no higher than responding "a lot" to two resources and "some" to the other two, on average. All other students were categorized as **Affected Somewhat**.

*Note: Results in this exhibit are based on trend scaling conducted specifically for this report.*

## Teacher Education

Ensuring a well qualified teacher in every classroom begins with educating teachers, and a global movement to improve teacher preparation has occurred over the 20 years of TIMSS. According to the *TIMSS 2015 Encyclopedia,* countries are working harder than ever to provide future teachers with a good undergraduate education in pedagogy, as well as mathematics and science content. About half the countries have raised the requirements for becoming a primary school teacher and some for teaching mathematics or science at the eighth grade.

Most notably, countries have increased the number of years of education it takes to become a teacher. According to the *TIMSS 2015 Encyclopedia*, requirements for teaching at the fourth grade and for teaching at the eighth grade were very similar. Nearly all countries required at least a four year university degree to teach at fourth grade and at eighth grade, with about 15 percent requiring five year programs or master's degrees. In 1995, according to the TIMSS mathematics and science international reports for the primary school years, only a three year program at a teacher training institution was required in about half of the countries for certification as a third grade or fourth grade teacher (Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996a; Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996a). The 1995 requirements for teaching at the eighth grade typically were higher than for the fourth grade, but according to the TIMSS 1995 international reports for the middle school years, graduating from a three year teacher training institution was a possible path for certification as a seventh grade or eighth grade teacher in about one-fourth of the countries (Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996b; Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996b).

In addition to requiring lengthier teacher education programs (e.g., three years to four years, bachelor's to master's degree) some countries reported tightening the admissions criteria for teacher education programs by requiring a minimum grade point average (GPA), testing candidates, or requiring interviews. Also, some countries have initiated new qualifying examinations for certification or mandated a probationary period that includes an induction program or monitoring by an experienced teacher. The requirements are especially demanding to teach advanced science, technology, engineering, and mathematics (STEM) subjects. In 2015, nine countries (France, Italy, Lebanon, Norway, Portugal, the Russian Federation, Slovenia, Sweden, and the United States) participated in the TIMSS Advanced assessments of mathematics and physics for students studying at advanced levels in their final year of secondary school. All these countries required teachers of advanced mathematics and physics to have at least a university degree, including substantial coursework in their subject area or demonstrated expertise, and some required advanced degrees and/or passing an examination (Mullis, Martin, Foy, & Hooper, 2016b).

Consistent with countries' new, more rigorous teacher certification policies, the fourth and eighth grade mathematics and science teachers in TIMSS 2015 reported that they were better educated than their counterparts in TIMSS 2007. In TIMSS 2015, at the fourth grade 85 percent of the students had teachers with a bachelor's degree or higher and 31 percent had teachers with an advanced degree. In TIMSS 2007, 78 percent of the students had teachers with at least a bachelor's degree and 26 percent had teachers with an advanced degree. In TIMSS 2015 at the eighth grade, 93 percent of students had teachers with a bachelor's degree and 30 percent had teachers with an advanced degree, compared to TIMSS 2007 when 90 percent of the students had teachers with at least a bachelor's and 25 percent had teachers with an advanced degree.

At the fourth grade, there was little change in teachers' majors between 2007 and 2015. Nearly 80 percent of the students had teachers who majored in primary education in both assessments. At the eighth grade in TIMSS 2015, 88 percent of students had mathematics teachers who majored in mathematics, mathematics education, or both, compared to 85 percent in 2007. In science in TIMSS 2015, 92 percent of eighth grade students had teachers who majored in science, science education, or both, compared to 90 percent in 2007.

## Teacher Professional Development

The TIMSS trend results indicate teachers are remaining in the profession just as many years as they were 20 years ago. From 1995 to 2015, teachers' average number of years of experience at the fourth grade was 17 to 18 years, and at the eighth grade it was 15 to 16 years.

Given mathematics and science teachers' long service, it is important to keep them up to date with innovations in their fields, current research about effective pedagogy, and advances in technology. Some recent research shows that while teachers make the most progress in improving students' achievement in the first three to five years in the classroom, teachers continue to improve their effectiveness for at least 12 years and maybe even for 30 years (Papay & Kraft, 2015; Ladd & Sorenson, 2015).

In the *TIMSS 2015 Encyclopedia*, a number of countries seem to concur with the value of ongoing teacher professional development and describe increased efforts to support teaching as a profession and to help teachers be successful in their classrooms. Some examples include:

- Australia established an institute in 2010 to provide national leadership in promoting excellence in the professions of teaching and school leadership. Among other initiatives, the institute developed the Australian Professional Standards for Teachers (implemented in 2011) covering three domains—

Professional Knowledge, Professional Practice, and Professional Engagement—over four career stages, including Graduate, Proficient, Highly Accomplished, and Lead.

- Belgium (Flemish) brought important changes in teacher training under one coherent framework, where teacher profiles enumerate competencies in terms of knowledge, skills and attitudes, and continuing education courses that allow teachers to acquire the necessary qualifications for particular aspects of the profiles.
- England set the Teachers' Standards, and all trainee teachers must pass a statutory 12 month induction program to attain Qualified Teacher Status.
- In Finland, the Ministry of Education and Culture funded a new development program in 2014 to train 50,000 teachers in a two year period.
- Hong Kong SAR established the Committee on Professional Development of Teachers and Principals to advise the government's Education Bureau on policies and measures related to the professional development of teachers and principals at different career stages. In 2015, the Education Bureau announced the provision of 810 professional development programs to cater to the needs of approximately 60,000 principals and teachers.
- In Northern Ireland, the performance of all teachers is reviewed annually in accordance with the Performance Review and Staff Development Scheme, which identifies development needs and ensures that the corresponding professional development opportunities are made available.

Despite national efforts, teachers reported little change in the amount of professional development they received on a regular basis in key instructional areas. In TIMSS 2007 and TIMSS 2015, the mathematics and science teachers were asked if they had participated in professional development in the past two years in the areas of content, pedagogy, and Information and Communications Technology (ICT).

Exhibit 5 presents the trends. At the fourth grade in 2007, 37 percent of teachers responded that they had professional development in content (mathematics or science) and 39 percent in pedagogy (mathematics or science), with fewer (28%) reporting professional development in ICT. In 2015, the gap between professional development in teaching mathematics and science and professional development in ICT (35% and 36%, compared to 30%) was reduced somewhat, perhaps reflecting an increased emphasis on integrating technology into the curricula described in the previous chapter.

**Exhibit 5: Trends in Teacher Professional Development, 2007–2015**

| | Percentages of Students Whose Teachers Reported Professional Development in the Past Two Years | | |
|---|---|---|---|
| | Content | Pedagogy | ICT |
| **Fourth Grade** | | | |
| 2007 | 37 | 39 | 28 |
| 2015 | 35 | 36 | 30 |
| **Eighth Grade** | | | |
| 2007 | 60 | 61 | 49 |
| 2015 | 56 | 61 | 50 |

Although the set of eighth grade countries differs somewhat from the set of fourth grade countries (see Exhibit 1), it is interesting to note that in both 2007 and 2015 professional development looks more prevalent at eighth grade than at fourth grade. Also, at the eighth grade, there was little change between the 2007 and 2015 participation rates for the three areas of professional development, except for a modest decrease in the percentage of students whose teachers reported professional development in mathematics or science content.

## Classroom Contexts for Learning

Considerable variation exists from classroom to classroom in the resources available to support teaching and learning. The class may be large or small, instructional time may be generous or limited, and teachers may or may not have access to a wide variety of instructional materials and technology. A recent comprehensive study of TIMSS and PISA international assessment data indicated that differences in expenditures and class size play a limited role in explaining cross-country achievement differences, but that teacher quality and instructional time matter (Woessmann, 2016).

Despite a lack of consistent findings from research relating reductions in class size to students' higher achievement, there is a widely held belief that smaller classes would be more manageable for teachers. The TIMSS trend data indicate a modest decrease in class sizes between 1995 and 2015. At fourth grade, on average, mathematics and science teachers reported average class sizes of 28 students in 1995, and 24 students in 2007 and 2015. Eighth grade teachers reported a slight decline, from 30 students in 1995 to 29 students in 2007 to 28 students in 2015.

Considering the increasingly larger scope of mathematics and science curricula since the launch of TIMSS in 1995, it is interesting to see if more time has been allotted for instruction in these subjects. Of course, providing more instructional time does not necessarily improve students' learning. It depends on how effectively and efficiently the time is used.

Exhibit 6 presents trends in instructional time in mathematics and science across TIMSS 1995, TIMSS 2007, and TIMSS 2015. The data for "yearly hours" is based on teachers' reports of weekly hours of mathematics or science instruction divided by principals' reports of the number of school days per week (hours per day) and multiplying that by principals' reports about the number of school days per year. This measure of instructional time accounts for differences in weekly and yearly instructional time across countries, but the first component of teachers' reports of weekly hours of mathematics or science instruction also is provided. Also, the data for eighth grade science are probably underestimates, since they are based only on the countries that teach science as an integrated subject. Countries that teach science as separate subjects (e.g., biology, chemistry, physics) spend about twice as much time on science instruction, but it is complicated to combine the two sets of data, and especially so across assessment cycles.

**Exhibit 6: Trends in Instructional Time**

| | Mathematics | | Science | |
|---|---|---|---|---|
| | Yearly Hours | Weekly Hours | Yearly Hours | Weekly Hours |
| **Fourth Grade** | | | | |
| 1995 | 165 | 4 hrs. 1 min. | 73 | 1 hr. 45 min. |
| 2007 | 141 | 3 hrs. 49 min. | 64 | 1 hr. 41 min. |
| 2015 | 151 | 4 hrs. 3 min. | 69 | 1 hr. 49 min. |
| **Eighth Grade*** | | | | |
| 1995 | 127 | 3 hrs. 20 min. | 101 | 2 hrs. 38 min. |
| 2007 | 121 | 3 hrs. 14 min. | 107 | 2 hrs. 49 min. |
| 2015 | 130 | 3 hrs. 34 min. | 116 | 3 hrs. 4 min. |

*Note: Results for 1995 are based on the countries in common with the countries in both 2007 and 2015 (12 of 22 countries at fourth grade, and 14 of 26 countries at eighth grade).*

* At eighth grade, the science results are based only on the countries where science is taught as an integrated subject (17 of 26 countries for 2007 and 2015; 7 of 14 countries for 1995). Countries that teach biology, chemistry, physics, and Earth science separately spend approximately twice as much time on science instruction (Martin, Mullis, Foy, & Stanco, 2012).

Looking at the results for mathematics, students have more instructional time at fourth grade than eighth grade. At both grades the amounts of time have basically remained relatively stable over the 20 years of TIMSS, despite a dip in 2007. According to fourth grade teachers' reports, students have about twice as much instruction in mathematics as science, with about four hours per week for mathematics and two hours per week for science, and this also seems to have remained relatively stable. At the eighth grade, for science instruction in countries that teach science as an integrated subject, there was an increase in yearly instructional time between 1995 and 2007, due primarily to an increase in yearly total school time. Teachers reported a small but steady increase in weekly instructional time, resulting in an increase of 26 minutes per week between 1995 and 2015.

## Instructional Strategies

TIMSS produces an indicator of the percentage of students taught the topics assessed by TIMSS. That indicator shows an increase between 2007 and 2015 in the coverage of these mathematics and topics covered in classrooms internationally. At the fourth grade, the average percentage of students taught the TIMSS topics increased from 68 to 74 percent in mathematics and from 59 to 62 percent in science. At the eighth grade, the average percentage of students taught the TIMSS topics showed little change in mathematics from 2007 to 2015—75 to 74 percent—but increased in science from 66 to 72 percent.

Regarding instructional approaches, nearly all countries reported in the *TIMSS 2015 Encyclopedia* that they were placing an emphasis on using computers and other digital technology to enhance instruction and make it more efficient. In both TIMSS 2007 and TIMSS 2015, data were collected about the availability of computers in students' homes and for use in their mathematics and science lessons.

Exhibit 7 contains the trend results between TIMSS 2007 and TIMSS 2015 in students' access to computers. There was a substantial increase in the percentages of fourth grade and eighth grade students with computers in their homes, reaching the point in 2015 where 93 percent at both fourth and eighth grades had computers at home.

**Exhibit 7: Trends in Computer Access, 2007–2015**

| | Percentages of Students | | |
|---|---|---|---|
| | Computer in the Home | Computer Available for Mathematics Lessons* | Computer Available for Science Lessons* |
| **Fourth Grade** | | | |
| 2007 | 82 | 54 | 56 |
| 2015 | 93 | 48 | 55 |
| **Eighth Grade** | | | |
| 2007 | 80 | 42 | 49 |
| 2015 | 93 | 32 | 43 |

* Due to an improvement in the data processing procedures in 2015, the percentages of computer availability in 2007 may be slight underestimates.

In contrast, teachers reported that the availability of computers for use in mathematics and science lessons did not increase. In 2007, computer availability at the fourth grade was similar for mathematics and science lessons, but availability was higher for science lessons in 2015. At the eighth grade, higher percentages of students had computers available for their science lessons than mathematics lessons in both 2007 and 2015.

Exhibits 8 and 9 present trends between TIMSS 2007 and TIMSS 2015 in the activities that teachers used computers for in mathematics and science lessons. In mathematics lessons at fourth grade, there was essentially no change in the percentages of students whose teachers asked them to use computers for mathematics practice or for looking up information. In science, teachers reported some increased computer use, particularly for practicing science, doing science, and studying simulations of natural phenomena as recommended in the curricula. At the eighth grade, mathematics teachers reported decreased use of computers and science teachers reported little or no change.

**Exhibit 8: Trends in Computer Use in Mathematics Lessons, 2007–2015**

| | Percentages of Students Whose Teachers Ask Them to Use the Computer for Various Activities | | |
|---|---|---|---|
| | Practice Skills and Procedures | Look Up Ideas and Information | Process and Analyze Data |
| **Fourth Grade** | | | |
| 2007 | 44 | 34 | Not asked |
| 2015 | 43 | 34 | Not asked |
| **Eighth Grade** | | | |
| 2007 | 27 | 27 | 25 |
| 2015 | 23 | 22 | 19 |

**Exhibit 9: Trends in Computer Use in Science Lessons, 2007–2015**

| | Percentages of Students Whose Teachers Ask Them to Use the Computer for Various Activities | | | | |
|---|---|---|---|---|---|
| | Practice Skills and Procedures | Look Up Ideas and Information | Do Scientific Procedures or Experiments | Study Simulations of Natural Phenomena | Process and Analyze Data |
| **Fourth Grade** | | | | | |
| 2007 | 30 | 50 | 22 | 28 | Not asked |
| 2015 | 35 | 48 | 29 | 32 | Not asked |
| **Eighth Grade** | | | | | |
| 2007 | 28 | 41 | 26 | 28 | 30 |
| 2015 | 29 | 37 | 27 | 28 | 29 |

In mathematics at the eighth grade, there was a decrease in all three computer activities and in science there was little change.

To end this chapter on an encouraging note, the following exhibits present findings from two new scales in the TIMSS 2015 International Reports—namely, that teachers generally feel rewarded by their careers and students generally appreciate the quality of their instruction (Martin, Mullis, Foy, & Hooper, 2016; Mullis, Martin, Foy, & Hooper, 2016a).

To measure teachers' degree of job satisfaction, TIMSS asked mathematics and science teachers at the fourth and eighth grades how they felt about the following statements:

- I am content with my profession as a teacher
- I am satisfied with being a teacher at this school
- I find my work full of meaning and purpose
- I am enthusiastic about my job
- My work inspires me
- I am proud of the work I do
- I am going to continue teaching for as long as I can

Exhibit 10 contains the TIMSS 2015 results for the Teachers' Job Satisfaction scale. About half the students at fourth and eighth grades had teachers who were "very" satisfied with their careers, and most of the rest were satisfied. Taken together, more than 90 percent of the students had mathematics and science teachers who feel good about their work.

**Exhibit 10: Teachers' Job Satisfaction in 2015**

| | Percentages of Students | | |
|---|---|---|---|
| | Very Satisfied | Satisfied | Less Than Satisfied |
| **Fourth Grade** | | | |
| Mathematics | 52 | 42 | 6 |
| Science | 52 | 42 | 6 |
| **Eighth Grade** | | | |
| Mathematics | 50 | 43 | 7 |
| Science | 49 | 42 | 9 |

Students were assigned to the **Very Satisfied** category if their Rasch scale scores corresponded to their teachers at least responding "very often" to four of the seven statements and "often" to the other three statements, on average, and to the **Less than Satisfied** category when the scores were no higher than responding "sometimes" to four of the statements and "often" to the other three, on average. All other students were categorized as having **Satisfied** teachers.

TIMSS 2015 also asked students about how engaging they found their mathematics and science lessons. Students at fourth and eighth grades were asked how much they agreed with the following 10 statements, separately for their mathematics lessons and their science lessons:

- I know what my teacher expects me to do
- My teacher is easy to understand
- I am interested in what my teacher says
- My teacher gives me interesting things to do
- My teacher has clear answers to my questions
- My teacher is good at explaining the subject
- My teacher lets me show what I have learned
- My teacher does a variety of things to help us learn
- My teacher tells me how to do better when I make a mistake
- My teacher listens to what I have to say

Exhibit 11 presents the results for the scales Students' Views on Engaging Teaching in their mathematics and science lessons. Fourth grade students were especially positive about the teaching in their mathematics and science lessons, with 68 to 69 percent reporting that their mathematics and science lessons were "very" engaging, and another 25 to 27 percent that the lessons were engaging.

**Exhibit 11: Students' Views on Engaging Teaching in 2015**

| | Percentages of Students | | |
|---|---|---|---|
| | Very Engaging Teaching | Engaging Teaching | Less Than Engaging Teaching |
| **Fourth Grade** | | | |
| Mathematics Lessons | 68 | 26 | 5 |
| Science Lessons | 69 | 25 | 6 |
| **Eighth Grade** | | | |
| Mathematics Lessons | 43 | 41 | 17 |
| Science Lessons* | 47 | 36 | 17 |

Students were assigned to the **Very Engaging Teaching** category if their Rasch scale scores corresponded to at least agreeing "a lot" with 5 of the 10 statements and agreeing "a little" with the other 5, on average, and to the **Less than Engaging Teaching** category when the scores were no higher than disagreeing "a little" with 5 of the statements and agreeing "a little" with other 5, on average. All other students were categorized as having **Engaging Teaching**.

* The results are for the 29 countries where science is taught as an integrated subject. The results were similar across biology, chemistry, physics, and Earth science for the 10 countries that teach these subjects separately.

## Conclusion

Together with the increases in student mathematics and science achievement, TIMSS shows there has been solid progress in a number of instructional areas shown to be related to fostering higher student achievement in mathematics and science. First, teachers reported improved school environments in which to conduct classroom instruction. In particular, there has been a substantial increase in the percentage of students in safe schools at fourth and eighth grades, from less than half in 2007 to almost two-thirds in 2015. Also, there has been a considerable increase in the percentage of students in schools with a high emphasis on academic success accompanied by a decrease in schools with only medium emphasis (16% to 18% fewer). These are impressive improvements for the global education community, although non-trivial percentages of students remain in schools that are less than safe or that do not particularly emphasize academic success.

There also are indications that the TIMSS countries are bringing more highly educated teachers into classrooms than they were 20 years ago. Countries have increased the requirements for becoming a teacher since 1995, especially at the fourth grade. In 2015, at both the fourth and eighth grades, most mathematics and science teachers were required to graduate from a four year university program or even earn a master's degree. More recently, countries also have tightened requirements for entering teacher education programs (e.g., minimum GPA, interviews) and for becoming certified (e.g., examinations, teaching demonstrations, induction procedures). Correspondingly, a greater percentage of students in 2015 than 2007 had mathematics and science teachers who were university graduates and had advanced degrees.

Countries also reported national efforts to facilitate the professionalism of teaching and help teachers be more effective in their classrooms, including establishing various types of career ladders and programs to provide continuing teacher development. Teachers at both fourth and eighth grades reported about the same degree of participation in professional development in TIMSS 2015 as they did in TIMSS 2007.

The average size of mathematics and science classes became smaller between 1995 and 2015, from 28 to 24 students at the fourth grade and from 30 to 28 students at the eighth grade, while the amount of mathematics and science instructional time remained relatively stable, except for an increase for science at the eighth grade. Generally, there was more availability of computers for use in science lessons than mathematics lessons in 2007, and this did not change in 2015. Also, the percentages of students using computers in their lessons remained about the same.

There were gains in curriculum coverage between TIMSS 2007 and TIMSS 2015. Greater percentages of students were being taught the mathematics and science topics assessed by TIMSS—topics agreed upon as important to mathematics and science learning.

Finally, in TIMSS 2015 both teachers and students, respectively, were highly positive about delivering and receiving mathematics and science instruction. More than 90 percent of the fourth and eighth grade students had mathematics and science teachers who reported being very satisfied or satisfied with their careers. From the students' perspective, more than 90 percent of the fourth grade students and 80 percent of the eighth grade students agreed that their teachers provided very engaging or engaging instruction.

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# CHAPTER 4

# Trends in the Distribution of TIMSS International Achievement

Even the most casual followers of TIMSS assessments are familiar with national averages. The league tables, in which countries are ordered by average assessment scores, receive a lot of attention. The tables make it easy to compare one country's achievement to that of another country or to all countries participating in TIMSS. Averages are a measure of central tendency, indicating what the typical student knows in mathematics or science. This chapter is about another important characteristic of educational systems—one that also is measured by TIMSS—the distribution of achievement within countries. Statistics on the dispersion of test scores within countries can indicate whether a rising or falling national average is due to changes across the full spectrum of achievement scores or driven primarily by changes at one point in the distribution.

Another term for the spread of test scores is "test score variance." As a topic in policy discussions, test score variance often arises in the context of educational equity. In a purely statistical sense, contemporary policies that seek to close achievement gaps attempt to reduce test score differences between higher and lower scoring groups. To accomplish this goal, boosting the learning of low achieving students has widespread political appeal. As Hanushek and Woessmann (2015) explain, "Differences in the shape of the distribution are themselves the subject of policy concerns because, on equity grounds, no country wants to neglect the least skilled people in the economy" (p. 198). Countries also want to maximize the performance of high achieving students and deepen the pool of talented mathematicians and scientists of the future. Such efforts may boost test score performance at the upper end of the distribution and inadvertently widen the gap between high and low achievers.

The analysis below investigates the spread of achievement within countries and its relationship to changes in national TIMSS scores in mathematics and science. Let's begin by considering standard deviation (or SD), a common measure of spread. In a national population of test takers, about two-thirds will score within the range of scores bounded by one SD above and below the national average. Countries with smaller standard deviations have scores more tightly clustered around the average; larger standard deviations show that scores are more spread out. In addition to describing the distribution of test scores, SDs contain practical value as well. Students with test scores one standard deviation above or below average, for example, will exhibit real, noticeable differences in mathematics or science learning compared to the average student.

## How Has the Spread of Achievement Changed Since 1995?

Different countries participate in each TIMSS cycle. Exhibit 1 shows the changes in national average and standard deviation for 22 countries in fourth grade and 25 countries in eighth grade. These countries will serve as the chapter's primary analytical sample. All of the countries participated in TIMSS 2015. For most of the countries, 1995 serves as the baseline year, allowing for the calculation of a 20 year trend in test scores. Later baselines are included for countries that joined TIMSS in 1999 (which was given in eighth grade only) or in 2003. Thus, the requirement for inclusion in the analysis is a trend of 12 years or more, beginning in 1995, 1999, or 2003 and ending in 2015.

**Exhibit 1: Change in TIMSS International Averages of Achievement and Standard Deviations, 1995–2015***

| Subject-Grade | Baseline TIMSS Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Baseline Year SD | 2015 SD | Change in SD |
|---|---|---|---|---|---|---|
| Mathematics Fourth Grade (n=22) | 515 | 542 | +27 | 81 | 75 | −6 |
| Science Fourth Grade (n=22) | 510 | 530 | +20 | 83 | 72 | −10 |
| Mathematics Eighth Grade (n=25) | 498 | 502 | +5 | 82 | 83 | +1 |
| Science Eighth Grade (n=25) | 500 | 505 | +4 | 85 | 85 | 0 |

* Baseline year may be 1999 or 2003

*Note: Because of rounding some results may appear inconsistent.*

Exhibit 1 displays TIMSS international averages and SDs in the baseline year and 2015. Changes in the international average and SD from baseline to 2015 are shaded for emphasis. Gains were registered in all four subject-grade combinations, but the gains in fourth grade stand out. Fourth grade students registered an increase of 27 scale score points in mathematics (from 515 to 542) and 20 points in science (from 510 to 530). The gains by eighth grade students were smaller, only 5 scale score points in mathematics and 4 scale score points in science. Fourth grade students also registered larger changes in standard deviations, as the SD for mathematics shrank by 6 scale score points (from 81 to 75) and science's SD contracted by 10 points (from 83 to 72). The spread of achievement narrowed at fourth grade but not at eighth.[1]

Exhibit 2 presents changes at two points in the distribution of achievement, the 10$^{th}$ and 90$^{th}$ percentiles. The 10$^{th}$ percentile reflects the performance of low achieving students; it is the score below which the bottom 10 percent of a nation's students fall. The 90$^{th}$ percentile serves the same purpose for identifying high achievers, demarcating the threshold for being in the top 10 percent of students.

**Exhibit 2: Change in TIMSS International Average Achievement at 10$^{th}$ and 90$^{th}$ Percentiles, 1995–2015***

| Subject-Grade | Baseline 10$^{th}$ Percentile | 2015 10$^{th}$ Percentile | Change in 10$^{th}$ Percentile | Baseline 90$^{th}$ Percentile | 2015 90$^{th}$ Percentile | Change in 90$^{th}$ Percentile |
|---|---|---|---|---|---|---|
| **Mathematics Fourth Grade (n=22)** | 409 | 443 | +34 | 615 | 635 | +21 |
| **Science Fourth Grade (n=22)** | 403 | 435 | +32 | 611 | 618 | +8 |
| **Mathematics Eighth Grade (n=25)** | 391 | 393 | +2 | 600 | 607 | +7 |
| **Science Eighth Grade (n=25)** | 390 | 391 | +1 | 606 | 610 | +4 |

* Baselinße year may be 1999 or 2003

*Note: Because of rounding some results may appear inconsistent.*

Examining trends at both of these points in the distribution reveals some intriguing information about the contraction in SD occurring in fourth grade. For both mathematics and science, the two tails of the distribution experienced gains, but the gains among 10$^{th}$ percentile students were larger. In fourth grade mathematics, the 10$^{th}$ percentile students notched an average gain of 34 scale score points. The 90$^{th}$ percentile students registered a gain of 21 points. The 90$^{th}$–10$^{th}$ gap closed by 15 points. In fourth grade science, the 10$^{th}$ percentile students gained 32 scale score points, while an 8 point gain was attained at the 90$^{th}$ percentile. The gap contracted by 26 points. In the eighth

1 A pooled standard error for testing the statistical significance of the SD changes was not calculated. However, in fourth grade mathematics, the mean and median standard errors of SD at baseline are 1.9. In fourth grade science, the median standard error of SD at baseline is 2.0 and the mean is 2.2. Thus, the changes in SD at fourth grade are three to five times the standard error of SD at baseline.

grade, differences in scale score gains between the 10th and 90th percentiles were small, especially in science. Both ends of the distribution registered modest increases, and the gap between them remained virtually unchanged.

## Fourth Grade Mathematics

Let's examine the fourth grade scores more closely, beginning with mathematics. Exhibit 3 displays data for fourth grade mathematics, with the participants ordered by change in TIMSS average achievement. Portugal leads the group, posting a 99 point scale score gain. Note that its gain at the 10th percentile (123 points) is appreciably larger than at the 90th percentile (78 points). The scores of Portuguese low achievers increased more than those of high achievers. England, Slovenia, Hong Kong SAR, and Cyprus round out the top gainers in mathematics, and all of them registered larger gains at the 10th percentile compared to the 90th percentile.

**Exhibit 3: Fourth Grade Mathematics—Change in TIMSS Average Achievement, 10th Percentile, and 90th Percentile (Ordered by Change in TIMSS), 1995–2015**

| Country | Baseline TIMSS Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Change in 10th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|
| Portugal | 442 | 541 | 99 | 123 | 78 |
| England | 484 | 546 | 62 | 76 | 47 |
| Slovenia | 462 | 520 | 58 | 76 | 40 |
| Hong Kong SAR | 557 | 615 | 58 | 71 | 49 |
| Cyprus | 475 | 523 | 48 | 63 | 32 |
| Iran, Islamic Rep. of | 387 | 431 | 44 | 15 | 56 |
| Chinese Taipei | 564 | 597 | 33 | 21 | 44 |
| Russian Federation | 532 | 564 | 32 | 40 | 25 |
| Singapore | 590 | 618 | 27 | 37 | 20 |
| Korea, Rep. of | 581 | 608 | 27 | 24 | 31 |
| Japan | 567 | 593 | 26 | 34 | 19 |
| Ireland | 523 | 547 | 24 | 41 | 10 |
| Australia | 495 | 517 | 23 | 31 | 19 |
| New Zealand | 469 | 491 | 21 | 31 | 18 |
| United States | 518 | 539 | 21 | 23 | 22 |
| Norway | 476 | 493 | 17 | 25 | 13 |
| Hungary | 521 | 529 | 8 | 4 | 5 |
| Italy | 503 | 507 | 4 | 19 | –8 |

**Exhibit 3: Fourth Grade Mathematics—Change in TIMSS Average Achievement, 10th Percentile, and 90th Percentile (Ordered by Change in TIMSS), 1995–2015 (Continued)**

| Country | Baseline TIMSS Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Change in 10th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|
| Lithuania | 534 | 536 | 2 | 10 | 0 |
| Belgium (Flemish) | 551 | 546 | –5 | –7 | –2 |
| Czech Republic | 541 | 528 | –12 | 5 | –30 |
| Netherlands | 549 | 530 | –19 | –7 | –32 |

* Baseline score is from 2003 for Chinese Taipei, Russian Federation, Italy, Lithuania, and Belgium (Flemish).

*Note: Because of rounding some results may appear inconsistent.*

More gains at the 10th percentile is the dominant pattern. Only Iran, Chinese Taipei, Korea, and Hungary display larger gains at the 90th percentile than the 10th percentile. Iran particularly stands out, second only to Portugal in gains at the top of the distribution. Iran's 56 point scale score gain at the 90th percentile dwarfs the 15 point gain registered at the 10th percentile. Belgium (Flemish) also outperformed at the 90th percentile, but it was by declining less (–2) than at the 10th percentile (–7).

The bottom five systems in the table all lost ground at the 90th percentile. The performance of 90th percentile students in the Czech Republic declined by 30 points despite a 5 point gain among 10th percentile students. The Netherlands experienced a 7 point loss at the 10th percentile and a 32 point loss, the largest of these TIMSS participants, among its high achieving students at the 90th percentile.

## Fourth Grade Science

Exhibit 4 displays country level data for fourth grade science. Most countries closed the gap between their lowest and highest achieving students in science, even more so than in mathematics. The five countries with the biggest TIMSS gains over time—Slovenia, Singapore, Portugal, Hong Kong SAR, and the Russian Federation—all registered larger gains at the 10th percentile than the 90th percentile. Iran again bucked the general trend with a 48 point gain at the 90th percentile and 19 point gain at the 10th percentile. Lithuania also was an exception, gaining 20 points at both the 90th percentile and 10th percentiles. Belgium (Flemish) essentially did not change at the 90th percentile, but scores at the 10th percentile slipped by 18 points.

**Exhibit 4: Fourth Grade Science—Change in TIMSS Average Achievement, 10th Percentile, and 90th Percentile (Ordered by Change in TIMSS), 1995–2015***

| Country | Baseline TIMSS Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Change in 10th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|
| Slovenia | 464 | 543 | 78 | 91 | 63 |
| Singapore | 523 | 590 | 67 | 83 | 49 |
| Portugal | 452 | 508 | 56 | 101 | 20 |
| Hong Kong SAR | 508 | 557 | 49 | 58 | 42 |
| Russian Federation | 526 | 567 | 41 | 61 | 23 |
| Iran, Islamic Rep. of | 380 | 421 | 41 | 19 | 48 |
| Hungary | 508 | 542 | 34 | 33 | 30 |
| Cyprus | 450 | 481 | 31 | 38 | 21 |
| Lithuania | 512 | 530 | 18 | 20 | 20 |
| Japan | 553 | 569 | 16 | 25 | 7 |
| Ireland | 515 | 529 | 14 | 34 | –5 |
| Korea | 576 | 589 | 14 | 16 | 10 |
| England | 528 | 536 | 8 | 43 | –24 |
| United States | 542 | 546 | 4 | 20 | –10 |
| Chinese Taipei | 551 | 555 | 4 | 1 | 1 |
| Czech Republic | 532 | 534 | 3 | 15 | –14 |
| Australia | 521 | 524 | 2 | 27 | –19 |
| New Zealand | 505 | 506 | 0 | 22 | –19 |
| Italy | 516 | 516 | 1 | 24 | –23 |
| Belgium (Flemish) | 518 | 512 | –7 | –18 | 1 |
| Norway | 504 | 493 | –11 | 12 | –36 |
| Netherlands | 530 | 517 | –13 | –13 | –17 |

* Baseline score is from 2003 for Chinese Taipei, Russian Federation, Italy, Lithuania, and Belgium (Flemish).

*Note: Because of rounding some results may appear inconsistent.*

Closing achievement gaps is not always benign for the top of the distribution. In several countries, narrowing the performance gap between high and low achievers was primarily due to falling scores at the 90th percentile. England managed a modest, 8 point scale score gain in its national average from 1995 to 2015. But beneath the surface, the country's dispersion of scores dramatically contracted. England's 90th–10th gap shrank by 67 points, with 10th percentile scores increasing by 43 points and scores at the 90th percentile falling by 24 points. Joining England, the United States, Czech Republic, Australia, New Zealand, Italy, and Norway closed the performance gap between the 90th and 10th percentiles, at least in part, because the scores of high achievers fell. Norway managed a 12 point gain at the 10th percentile but lost 36 points at the 90th percentile. Achievement for the Netherlands fell at both the 10th percentile (–13) and 90th percentile (–17), resulting in an overall decline in its national average of 13 points.

## Are There Ceiling or Floor Effects?

Could the pattern revealed in Exhibits 3 and 4 be driven by ceiling or floor effects? Ceiling and floor effects refer to statistical anomalies influencing the direction of test score changes. The position of initial scores creates the problem. High scorers may suffer test score losses because their initial test scores are bumping up against the top (or "ceiling") of a scale. Floor effects refer to the opposite circumstance. Participants with exceptionally low scores may exhibit gains simply because there is no other direction for the score to go but up. As applied to the data in Exhibits 3 and 4, then, one might suspect that the larger gains at the 10th percentile compared to the 90th percentile could be the result of statistical artifacts.

It's doubtful that ceiling or floor effects are at work here.[2] In practice, the TIMSS scale runs from about 300 to 700, providing a lot of room for change both above and below even the broadest distribution of baseline scores. Several nations with high initial TIMSS scores (and very high baselines at the 90th percentile) managed nevertheless to make gains at the top end of the distribution. Hong Kong and Singapore both established high baseline scores in 1995 and still notched gains of more than 40 scale score points at the 90th percentile. Moreover, recall that the contraction in the 90th–10th percentile gap observed in both subjects in fourth grade is not evident in either subject in eighth grade, and yet the four scales were constructed following basically the same protocols.

## Is Inequality Related to Average Performance?

Freeman, Viarengo, and Machin (2010) analyzed TIMSS scores from 1999 and 2007 and discovered "a striking inverse relation between the within-country dispersion of scores and the average level of scores by country…*Lower inequality in test scores is associated with higher average scores* [italics original]." The authors called this a "virtuous equity-efficiency tradeoff," contradicting the notion that the pursuit of equity and efficiency is a zero sum game, with one attained at the expense of the other.[3]

Exhibit 5 presents data on the subject. The relationships of TIMSS national averages and SDs were modeled by calculating correlation coefficients. The first two

2 Note that floor effects may be in play with the short term trend data presented in Exhibits 6 to 9.

3 The premise of seeing equality and efficiency in opposition is that equality is an organizing principle of democratic societies and efficiency a fundamental principle of markets. See Okun (1975).

columns report cross-sectional relationships—correlation of national average and SD in the baseline year and 2015 national average with 2015 SD. The final column, which is shaded for emphasis, reports a longitudinal relationship (correlation of change in national average with change in national SD). Several of the cross-sectional correlation coefficients are statistically significant (and negative), confirming that higher scoring countries are indeed less likely to exhibit within-nation inequality.

**Exhibit 5: Cross-Sectional (Baseline and 2015) Relationships of National Averages with SDs and Longitudinal Relationships of Change in National Averages and SDs (Correlation Coefficients)**

| Subject-Grade | Baseline Average with SD | 2015 Average with SD | Change in Average with Change in SD |
|---|---|---|---|
| Mathematics Fourth Grade | −0.51* | −0.45* | −0.21 |
| Science Fourth Grade | −0.32 | −0.40* | −0.05 |
| Mathematics Eighth Grade | −0.16 | −0.15 | −0.04 |
| Science Eighth Grade | −0.29* | −0.73* | −0.30 |

* p<.05

*Note: Because of rounding some results may appear inconsistent.*

The evidence is not as strong when the relationship is modeled longitudinally. The dispersion of within-country achievement scores narrows as countries gain academically, but not to the extent necessary to reach statistical significance. Despite that, the data do not refute the hypothesis of a "virtuous trade-off," and as Exhibits 3 and 4 illustrate, many countries have raised their TIMSS national averages while also narrowing the achievement gap between low and high achieving students. Some have even managed to do so while registering gains among 90$^{th}$ percentile students. The lesson is that equality and efficiency can go hand in hand.

## Recent Trend, 2011–2015

The preceding analysis focused on countries with a long track record of TIMSS participation. Several countries have joined TIMSS in recent years, including a number of developing countries with different demographic characteristics and quite different school systems than the long-time participants. The analysis now turns to the most recent interval in TIMSS, 2011 to 2015, to see if the trends detected above have continued with this newer contingent of countries.

Exhibit 6 displays the 2011 to 2015 data for 41 countries in fourth grade and 32 countries in eighth grade. Consistent with Exhibit 1 showing long term trends, the changes in TIMSS international average and SD are shaded for emphasis. Across all four subject-grade combinations, countries made solid gains: 8 scale score points in fourth grade mathematics and science, 9 points in eighth grade mathematics, and 6 points in eighth grade science. Standard deviations changed very little, if at all.

**Exhibit 6: Change in TIMSS International Averages in Achievement and Standard Deviations, 2011–2015**

| Subject-Grade | TIMSS 2011 Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | 2011 SD | 2015 SD | Change in SD |
|---|---|---|---|---|---|---|
| Mathematics Fourth Grade (n=41) | 502 | 510 | +8 | 80 | 79 | –1 |
| Science Fourth Grade (n=41) | 498 | 506 | +8 | 83 | 81 | –2 |
| Mathematics Eighth Grade (n=32) | 480 | 489 | +9 | 88 | 86 | –2 |
| Science Eighth Grade (n=32) | 490 | 496 | +6 | 87 | 88 | +0 |

*Note: Because of rounding some results may appear inconsistent.*

Exhibit 7 presents changes at the 10$^{th}$ and 90$^{th}$ percentiles for short term trend. At the fourth grade, in mathematics gains at the 10$^{th}$ and 90$^{th}$ percentiles are equal, and in science the difference is relatively small (5 points). At the eighth grade, there were small differences in gains between the 10$^{th}$ and 90$^{th}$ percentiles in both mathematics (4 points) and science (1 point).

The impression is that all boats are rising about the same. This pattern differs from long term trend where gains at the fourth grade were larger at the 10$^{th}$ than 90$^{th}$ percentiles.

**Exhibit 7: Change in TIMSS International Average Achievement at 10th and 90th Percentiles, 2011–2015**

| Subject-Grade | 2011 10th Percentile | 2015 10th Percentile | Change in 10th Percentile | 2011 90th Percentile | 2015 90th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|---|
| **Mathematics Fourth Grade (n=41)** | 397 | 406 | +9 | 601 | 610 | +9 |
| **Science Fourth Grade (n=41)** | 389 | 400 | +11 | 601 | 607 | +6 |
| **Mathematics Eighth Grade (n=32)** | 364 | 376 | +12 | 591 | 599 | +8 |
| **Science Eighth Grade (n=32)** | 373 | 379 | +6 | 598 | 605 | +7 |

*Note: Because of rounding some results may appear inconsistent.*

To give an indication of the results across countries, Exhibit 8 displays the 2011 to 2015 data for eighth grade mathematics. Countries are ordered by gain in TIMSS score. Many of the countries with the largest gains are low scoring nations. The top five—Bahrain, Kazakhstan, Oman, Qatar, and Malaysia—all made gains at both ends of the achievement distribution. With the exception of Kazakhstan, these five countries made larger gains at the 10th percentile than at the 90th percentile. Georgia stands out as a country making much larger gains at the 10th percentile (42 points) than at the 90th percentile (7 points). That result is in stark contrast to the United Arab Emirates, which is notable for registering a strong gain at the 90th percentile (23 points) while the 10th percentile scores declined by 4 points.

Countries at the bottom of the table experienced falling national averages. For these countries, declines tended to be larger at the 90th percentile than at the 10th percentile. Chinese Taipei, for example, lost 20 scale score points at the 90th percentile while registering 10th percentile scores that were unchanged.

**Exhibit 8: Eighth Grade Mathematics, Change in TIMSS Average Achievement, 10th Percentile, and 90th Percentile (Ordered by Change in TIMSS), 2011–2015**

| Country | TIMSS 2011 Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Change in 10th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|
| Bahrain | 409 | 454 | 45 | 72 | 19 |
| Kazakhstan | 487 | 528 | 41 | 22 | 58 |
| Oman | 366 | 403 | 37 | 54 | 22 |
| Qatar | 410 | 437 | 28 | 40 | 20 |
| Malaysia | 440 | 465 | 25 | 34 | 20 |
| Georgia | 431 | 453 | 22 | 42 | 7 |
| Iran, Islamic Republic of | 415 | 436 | 21 | 20 | 23 |
| Japan | 570 | 586 | 17 | 12 | 25 |
| Sweden | 484 | 501 | 16 | 11 | 21 |
| Morocco | 371 | 384 | 13 | 20 | 8 |
| Norway | 475 | 487 | 12 | 9 | 12 |
| Slovenia | 505 | 516 | 12 | 13 | 9 |
| England | 507 | 518 | 11 | 21 | 8 |
| Chile | 416 | 427 | 11 | 9 | 9 |
| Lithuania | 502 | 512 | 10 | 10 | 7 |
| Singapore | 611 | 621 | 10 | 11 | 3 |
| Hungary | 505 | 514 | 10 | 5 | 18 |
| United Arab Emirates | 456 | 465 | 9 | –4 | 23 |
| United States | 509 | 518 | 9 | –1 | 17 |
| Hong Kong SAR | 586 | 594 | 9 | 19 | 2 |
| Turkey | 452 | 458 | 5 | 13 | –5 |
| New Zealand | 488 | 493 | 5 | 2 | 8 |
| Thailand | 427 | 431 | 4 | 4 | 12 |
| Australia | 505 | 505 | 0 | 0 | –8 |
| Russian Federation | 539 | 538 | –1 | –2 | 0 |
| Italy | 498 | 494 | –4 | –4 | –2 |
| Israel | 516 | 511 | –5 | –10 | 1 |
| Lebanon | 449 | 442 | –7 | –7 | –7 |
| Korea, Republic of | 613 | 606 | –7 | –1 | –13 |
| Chinese Taipei | 609 | 599 | –10 | 0 | –20 |
| Jordan | 406 | 386 | –20 | –8 | –22 |
| Saudi Arabia | 394 | 368 | –26 | –13 | –35 |

*Note: Because of rounding some results may appear inconsistent.*

Exhibit 9 shows national scores for eighth grade science. The patterns are similar to those in mathematics. The countries tended to make strong gains at both ends of the distribution, but with a tilt toward larger gains at the top of the table at the 10th percentile. However, in science the countries that lost ground from 2011 to 2015 tended to experience larger declines at the 10th percentile than at the 90th percentile. In both mathematics and science, Sweden reversed several years of declining TIMSS scores, chiefly by making strong gains with its high achieving students.

**Exhibit 9: Eighth Grade Science, Change in TIMSS Average Achievement, 10th Percentile, and 90th Percentile (Ordered by Change in TIMSS), 2011–2015**

| Country | TIMSS 2011 Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Change in 10th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|
| Malaysia | 426 | 471 | 44 | 52 | 33 |
| Kazakhstan | 490 | 533 | 43 | 32 | 56 |
| Qatar | 419 | 457 | 38 | 52 | 27 |
| Oman | 420 | 455 | 35 | 54 | 19 |
| Georgia | 420 | 443 | 23 | 32 | 22 |
| Morocco | 376 | 393 | 17 | 18 | 16 |
| Bahrain | 452 | 466 | 13 | 12 | 18 |
| Japan | 558 | 571 | 13 | 14 | 14 |
| Sweden | 509 | 522 | 13 | 8 | 19 |
| United Arab Emirates | 465 | 477 | 12 | –3 | 22 |
| Hong Kong SAR | 535 | 546 | 11 | 19 | 9 |
| Turkey | 483 | 493 | 10 | 18 | 1 |
| Slovenia | 543 | 551 | 8 | 7 | 10 |
| Lithuania | 514 | 522 | 8 | 7 | 10 |
| Singapore | 590 | 597 | 7 | 22 | –9 |
| Chinese Taipei | 564 | 569 | 6 | 4 | 3 |
| United States | 525 | 530 | 5 | 6 | 6 |
| Thailand | 451 | 456 | 5 | 6 | 8 |
| Hungary | 522 | 527 | 5 | 4 | 12 |
| England | 533 | 537 | 4 | 10 | 1 |
| Russian Federation | 542 | 544 | 2 | 1 | 2 |
| New Zealand | 512 | 513 | 1 | –6 | 4 |
| Italy | 501 | 499 | –2 | –3 | –2 |
| Korea, Republic of | 560 | 556 | –5 | –5 | –3 |

**Exhibit 9: Eighth Grade Science, Change in TIMSS Average Achievement, 10th Percentile, and 90th Percentile (Ordered by Change in TIMSS), 2011–2015 (Continued)**

| Country | TIMSS 2011 Average Achievement | TIMSS 2015 Average Achievement | Change in TIMSS Average Achievement | Change in 10th Percentile | Change in 90th Percentile |
|---|---|---|---|---|---|
| Norway | 494 | 489 | –5 | –9 | –1 |
| Australia | 519 | 512 | –7 | –8 | –14 |
| Chile | 461 | 454 | –7 | –19 | 1 |
| Lebanon | 406 | 398 | –8 | –13 | –2 |
| Israel | 516 | 507 | –9 | –23 | 5 |
| Iran, Islamic Republic of | 474 | 456 | –18 | –16 | –19 |
| Jordan | 449 | 426 | –23 | –15 | –21 |
| Saudi Arabia | 436 | 396 | –40 | –59 | –20 |

*Note: Because of rounding some results may appear inconsistent.*

## Conclusion and Policy Implications

TIMSS has assessed international achievement in mathematics and science from 1995 to 2015 in both fourth and eighth grades. Of the countries with 2015 scores, 22 have participated in TIMSS long enough to establish a trend of at least 12 years in fourth grade scores. Twenty-five countries have done the same at eighth grade. Over time, in both mathematics and science, these countries have made larger gains with fourth grade students than with eighth grade students. The fourth grade gains have been propelled by larger gains at the 10th percentile than at the 90th percentile. Fourth grade low achievers have made greater strides in mathematics and science than high achievers. In eighth grade, gains are less impressive than at fourth grade but more evenly distributed across the continuum of achievement.

The most recent TIMSS cycle, 2011 to 2015, shows gains in all four subject-grade combinations and fairly evenly distributed at both the 10th and 90th percentiles. Whether this is the beginning of a new trend remains to be seen as many of the countries in the more recent trend analysis were not part of the analysis going back to 1995.

The data above support three implications for research and policy:

First, among the countries in the long term analysis, losses and gains at the 10th percentile are strongly associated across mathematics and science in both the fourth and eighth grades (r= 0.75 in fourth grade and r=0.76 in eighth). In other words, countries that raised the performance of low achievers in one subject were likely to have raised the performance of low achievers in the other. And countries where low achievers' achievement declined in one subject were likely to have witnessed low achievers' falling test scores in the other subject.

Correlations are not proof of causality. Perhaps the correlations are merely reflecting the fact that mathematics and science learning are closely related; however, the observed pattern also mirrors how countries typically deliver specialized educational services in the elementary grades. Children who are identified as needing help rarely receive interventions tailored to specific subject areas (outside of reading). As the European Commission Working Group on Mathematics, Science, and Technology (2013) observed, "Specific national support policies for low achievers in science subjects do not exist in any European country. Instead, support is covered by a general framework of measures for students with learning difficulties, irrespective of the subject. These include differentiated teaching, one-to-one tuition, peer assisted learning, tutoring and ability grouping" (p. 6).

It is unknown if this omnibus approach is more effective than interventions targeted to specific weaknesses by subject area. A plausible hypothesis is that interventions serving low achievers will be more effective if they address specific subjects, content areas, or topics in which students are struggling. That hypothesis should be tested in high quality experiments designed to assess causal effects.

A second implication involves monitoring achievement. As the TIMSS data demonstrate, a country's overall academic progress—as measured by changes in average achievement—may mask variation at different points in the distribution. League tables draw an inordinate amount of attention to national means, but educational authorities would be remiss if they also did not monitor how well low and high achievers are doing.

The third implication concerns high achievers. Efforts to close achievement gaps are popular among contemporary policy makers. Unfortunately, gaps between low and high achieving students will shrink if low achievers' scores are static and the scores of high achievers decline. Although enhancing equality, that is hardly an ideal scenario. TIMSS scores identify many countries that have been able to boost achievement across the continuum of achievement and, with achievement rising just a bit more among low achievers, have reduced achievement gaps as well.[4]

4 Policymakers who are concerned about high achievers in advanced mathematics and science at the high school level should take note of the Chapter 1 discussion of the disappointing TIMSS Advanced 2015 results.

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# CHAPTER 5

# What Do Students Think About Mathematics?

The first TIMSS results revealed a paradox involving two unsurprising findings. In countries all over the world, students who said they enjoyed learning mathematics scored much higher than students who said they did not. Students who said they usually do well at mathematics also outperformed those who said they struggle with the subject.

The surprise emerges when data are aggregated to the national level. The relationships reverse. High scoring countries have large percentages of students who do not like mathematics, while students in lower scoring nations express enjoyment with the subject. The top scoring countries, when compared to lower scoring countries, also report larger percentages of students saying they do not do well in mathematics.

The same contradictory results have appeared in every TIMSS cycle since then—in 1999, 2003, 2007, 2011, and in the most recent results, from 2015. The paradox appears at both fourth and eighth grades, and not just in mathematics but in the TIMSS science results as well.

What's going on? This chapter will investigate the paradox, examine how student attitudes toward mathematics have changed over the past two decades, review explanations that previous researchers have offered, and discuss implications for policy. To keep the analysis focused—and hopefully interesting—only two questions from the TIMSS student questionnaires receive attention. That is not to suggest that these two questions can serve as a proxy for student attitudes in general or that they possess some mysterious power to peer into students' psyches. They have been asked in a consistent manner from 1995 to 2015 and are therefore well-suited to investigate trends for that period. Analysts of future trends will want to use the TIMSS indexes that were introduced in 2011, as they provide more comprehensive measures of both student enjoyment and confidence.

## Students Enjoy Learning Mathematics

Let's examine the 2015 results and document the relationship of liking mathematics and mathematics achievement. The student questionnaire presents the statement, "I enjoy learning mathematics" and provides four possible responses, two that are positive—"agree a little" and "agree a lot" and two that are negative—"disagree a little" and "disagree a lot." Exhibit 1 displays the 2015 international averages for the four response options and TIMSS average mathematics achievement for the four categories. The data are the averages for the 49 countries that participated at the fourth grade and the 39 countries at the eighth grade.

**Exhibit 1: International Average Percentage of Student Responses to the Statement "I enjoy learning mathematics" (and Associated Average Achievement in Mathematics), TIMSS 2015**

| | Agree a Lot | Agree a Little | Disagree a Little | Disagree a Lot |
|---|---|---|---|---|
| **Fourth Grade** | 57 (513) | 28 (505) | 9 (507) | 6 (476) |
| **Eighth Grade** | 34 (504) | 37 (484) | 17 (468) | 12 (443) |

The results in Exhibit 1 indicate that students enjoy learning mathematics. An overwhelming majority, 85 percent of fourth grade students and 71 percent of eighth grade students, express positive sentiments about the subject. And, as one would expect, students who enjoy learning mathematics are better at it than students who do not care for the subject. The TIMSS achievement difference between fourth grade students who enjoy learning mathematics a lot (513) and those who do not enjoy it a lot (476) is about 37 points. At eighth grade, the difference is 61 points.

How has enjoyment varied over time? Exhibit 2 displays the percentage of fourth and eighth grade students who reported disliking mathematics in each TIMSS assessment from 1995 to 2015. For the data in Exhibit 2, the two negative categories have been combined. One benefit from collapsing two questionnaire categories differing in degree but not in direction is dampening potential cultural bias in response styles. Chen, Lee, and Stevenson (1995), for example, found Asian students more likely to select response categories near the middle of an ordinal scale compared to students from the United States, where they were more likely to select extreme responses.

**Exhibit 2: International Average Percentage of Students Disliking Mathematics, TIMSS 1995 to TIMSS 2015**

| | 1995 | 1999 | 2003 | 2007 | 2011 | 2015 |
|---|---|---|---|---|---|---|
| **Fourth Grade** | 15 | -- | 22 | 19 | 16 | 15 |
| **Eighth Grade** | 34 | 33 | 35 | 33 | 29 | 29 |

*Note: Percentage of students responding "disagree a little" or "disagree a lot" with the statement "I enjoy learning mathematics." The 1995 question was "Do you think that you enjoy learning mathematics?" Beginning in 1999, it was "I enjoy learning mathematics." TIMSS 1999 was administered only in eighth grade.*

The main reason for focusing on negative attitudes toward mathematics is because popular discussions—especially when it comes to policy—are concerned with precisely that aspect of the topic. Media are filled with stories on why students hate mathematics and what should be done about it. Conventional wisdom is that mathematics is unpopular. But also note that changes in smaller, negative frequencies can appear more significant than they are. Here's an illustration. To the casual observer, a change from 20 to 25 percent in negative sentiments toward mathematics probably seems larger than a change from 80 to 75 percent in positive sentiments, even though the two statistics have a sum of 100 percent and are reflecting the exact same change.

Exhibits 1 and 2 indicate that the popular stories are off base. Most of the world's children enjoy learning mathematics. For 20 years, they have consistently enjoyed learning mathematics. Nevertheless, a consistent segment of students expresses disdain for the subject. In fourth grade, dislike for learning mathematics has ranged from 15 to 22 percent. It peaked in 2003 at 22 percent and has declined since then, back to the lowest 1995 figure of 15 percent.

Older students do not like learning mathematics as much as younger ones. Compared to fourth grade students, approximately twice the percentage of eighth grade students say they dislike learning mathematics. The 2-to-1 ratio is relatively stable from 1995 to 2015, with the percentage for disliking mathematics at eighth grade ranging from 29 to 34 percent. Again, as was the case with fourth grade, disdain for learning mathematics registered at the lowest level in 2015 (29%, a tie with 2011).

## The Enjoyment–Achievement Paradox

The roster of countries participating in TIMSS changes from year to year. Let's use 1995 and 2015 to illustrate the paradox that emerges when student attitudes and achievement are modeled at the national level. The 17 countries in Exhibit 3 participated in the TIMSS fourth grade mathematics assessment in both 1995 and 2015. The averages for this subset of TIMSS participants are displayed in the bottom row of the table.

**Exhibit 3: Fourth Grade Countries Participating in Both 1995 and 2015—TIMSS Percentage of Students Disliking Mathematics and Average Mathematics Achievement**

| Country | 1995 | | 2015 | |
|---|---|---|---|---|
| | Dislike Percentage | TIMSS Average Achievement | Dislike Percentage | TIMSS Average Achievement |
| Australia | 17 | 495 | 21 | 517 |
| Cyprus | 5 | 475 | 15 | 523 |
| Czech Republic | 22 | 541 | 23 | 528 |
| England | 16 | 484 | 12 | 546 |
| Hong Kong SAR | 17 | 557 | 19 | 615 |
| Hungary | 23 | 521 | 19 | 529 |
| Iran, Islamic Rep. of | 5 | 387 | 6 | 431 |
| Ireland | 18 | 523 | 17 | 547 |
| Japan | 28 | 567 | 25 | 593 |
| Korea, Rep. of | 26 | 581 | 25 | 608 |
| Netherlands | 32 | 549 | 18 | 530 |
| New Zealand | 18 | 469 | 17 | 491 |
| Norway | 14 | 476 | 11 | 493 |
| Portugal | 4 | 442 | 7 | 541 |
| Singapore | 8 | 590 | 15 | 618 |
| Slovenia | 10 | 462 | 21 | 520 |
| United States | 15 | 518 | 19 | 539 |
| **Average** | 16 | 508 | 17 | 539 |

*Note: Percentage of students responding "disagree a little" or "disagree a lot" with the statement "I enjoy learning mathematics."*

The top of the achievement distribution is interesting. Japan and Korea, two of the highest achieving countries across the two decades, exhibit high levels of discontent studying the subject, with a steady proportion of fourth grade students (about one-fifth) expressing negative sentiments. The Netherlands (549) achieved well above the international average in 1995, despite a very high percentage of students not enjoying the subject (32%). By 2015, fourth grade students in the Netherlands enjoyed the subject more—discontent declined to 18 percent—but the country's mathematics achievement fell to 530. The Czech Republic achieved near the top in 1995 (541). Although its mathematics achievement slipped to 528 in 2015, the percentage of fourth grade students not enjoying the subject remained about the same. Singapore's 1995 mathematics achievement of 590 led all TIMSS participants at the fourth grade. Only 8 percent of Singaporean fourth grade students said they did not enjoy learning mathematics that year. Singapore's 2015 mathematics achievement rose to 618, again leading all TIMSS countries, but its share of unhappy mathematics students had also increased—to 15 percent.

Contentment with studying mathematics is pervasive on the other end of the achievement distribution. In 1995, Cyprus (5%), Iran (5%), and Portugal (4%) reported small percentages of students saying they do not enjoy learning mathematics. They also registered national TIMSS achievement significantly below the international average. In 2015, Cyprus and Portugal had notched strong 20 year gains in mathematics achievement, climbing above the international average, but levels of discontent among fourth grade students also climbed, from 5 to 15 percent in Cyprus, and from 4 to 7 percent in Portugal.

Across the countries in Exhibit 3, the correlation coefficient for the percentage of students disliking mathematics and TIMSS mathematics achievement in 1995 is 0.64. In 2015, the correlation coefficient is 0.50.[1] Both are statistically significant ($p < 0.05$). High scoring countries tend to have high levels of students who do not enjoy learning mathematics, while low scoring countries have larger proportions saying that they enjoy learning the subject. There are exceptions. As noted above, Singapore is a high scoring TIMSS participant with relatively low percentages of students who dislike learning mathematics.

Eighth grade exhibits a pattern similar to fourth grade (see Exhibit 4). Sixteen countries participated in both 1995 and 2015.

**Exhibit 4: Eighth Grade Countries Participating in Both 1995 and 2015—TIMSS Percentage of Students Disliking Mathematics and Average Mathematics Achievement**

| Country | 1995 | | 2015 | |
|---|---|---|---|---|
| | Dislike Percentage | TIMSS Average Achievement | Dislike Percentage | TIMSS Average Achievement |
| Australia | 35 | 509 | 35 | 505 |
| England | 20 | 498 | 31 | 518 |
| Hong Kong SAR | 35 | 569 | 34 | 594 |
| Hungary | 61 | 527 | 50 | 514 |
| Iran, Islamic Rep. of | 18 | 418 | 19 | 436 |
| Ireland | 32 | 519 | 37 | 523 |
| Japan | 54 | 581 | 48 | 586 |
| Korea, Rep. of | 59 | 581 | 47 | 606 |
| Lithuania | 55 | 472 | 28 | 512 |
| New Zealand | 26 | 501 | 33 | 493 |
| Norway | 24 | 498 | 30 | 487 |

1 The correlation coefficient of the percentage disliking mathematics and TIMSS achievement for all 1995 countries is 0.62, and for all 2015 participants, 0.59, compared to the results reported for the smaller, long term trend sample of countries in Exhibit 3.

**Exhibit 4: Eighth Grade Countries Participating in Both 1995 and 2015—TIMSS Percentage of Students Disliking Mathematics and Average Mathematics Achievement (Continued)**

| Country | 1995 | | 2015 | |
|---|---|---|---|---|
| | Dislike Percentage | TIMSS Average Achievement | Dislike Percentage | TIMSS Average Achievement |
| Russian Federation | 46 | 524 | 26 | 538 |
| Singapore | 22 | 609 | 21 | 621 |
| Slovenia | 51 | 494 | 62 | 516 |
| Sweden | 26 | 540 | 37 | 501 |
| United States | 30 | 492 | 34 | 518 |
| **Average** | 37 | 521 | 36 | 529 |

*Note: Percentage of students responding "disagree a little" or "disagree a lot" with the statement "I enjoy learning mathematics."*

Again, Japan and Korea are high scoring countries with a lot of students (more than 40%) saying they do not enjoy learning mathematics. In 1995, Hungary and Sweden were among the countries with high mathematics achievement but low contentment. As with fourth grade, Singapore bucks the trend. Singapore led all nations in 1995 (609) and 2015 (621) and had below average percentages of students disliking mathematics.

Negative feelings toward learning mathematics are clearly more prevalent in eighth grade than in fourth. Is TIMSS capturing a phenomenon related to age or maturation? It is plausible that dislike of mathematics increases as students proceed through schooling and TIMSS is taking snapshots of that development at two points in time. Of the countries in Exhibits 3 and 4, 13 participated in both fourth and eighth grade TIMSS in 1995 and 2015. The "enjoyment gap" between fourth and eighth grade students—that is, the difference between the two grades in the percentage of students saying they dislike mathematics—was 17 percentage points in 1995 and 19 points in 2015. Compared to fourth grade students, eighth grade students have consistently expressed greater dislike for learning mathematics, and the negative sentiments at eighth grade may be on the rise.

## Students Say They Usually Do Well in Mathematics

TIMSS asks students to respond to the statement, "I usually do well in mathematics." The item has a similar structure to the item on enjoying mathematics, with four response options: agree a lot, agree a little, disagree a little, and disagree a lot. Exhibit 5 displays the percentages and associated average achievement for the four categories. Here TIMSS mathematics achievement is more dispersed than it was with the enjoyment item. Among fourth grade students, 73 scale score points separate the categories representing the most confident (524) and least confident (451) mathematics students. At eighth grade, the gap is a whopping 91 points (519 vs. 427).

**Exhibit 5: International Average Percentage of Student Responses to the Statement "I usually do well in mathematics" (and Associated Average Achievement in Mathematics), TIMSS 2015**

| | Agree a Lot | Agree a Little | Disagree a Little | Disagree a Lot |
|---|---|---|---|---|
| **Fourth Grade** | 51 (524) | 36 (499) | 9 (474) | 4 (451) |
| **Eighth Grade** | 32 (519) | 41 (483) | 19 (455) | 8 (427) |

Students are quite confident in mathematics, with 87 percent of fourth grade students and 72 percent of eighth grade students giving positive responses to the questionnaire item. Exhibit 6 shows the percentage of negative responses to the question—students disagreeing a little or a lot with the "I usually do well in mathematics" statement. Consistency is the rule from 1995 to 2015, with the percentage of students reporting that they do not usually do well changing very little over the two decades for either grade. Eighth grade students are about twice as likely to respond negatively. As was true with the data on enjoying mathematics, eighth grade students have more negative perceptions than their fourth grade counterparts.

**Exhibit 6: International Average Percentage of Students Not Confident in Mathematics, TIMSS 1995–2015**

| | 1995 | 1999 | 2003 | 2007 | 2011 | 2015 |
|---|---|---|---|---|---|---|
| **Fourth Grade** | 12 | -- | 17 | 14 | 13 | 13 |
| **Eighth Grade** | 26 | 28 | 26 | 24 | 27 | 28 |

*Note: Percentage of students responding "disagree a little" or "disagree a lot" with the statement "I usually do well in mathematics." TIMSS 1999 was administered only in eighth grade.*

## The Confidence–Achievement Paradox

Exhibit 7 provides a closer look at 16 countries that participated in TIMSS at the fourth grade in both 1995 and 2015. Culture appears to be playing a role in the levels of confidence expressed by students of different nations. In a paper on the topic, Leung (2002) highlighted the lack of confidence East Asian eighth grade students expressed on the 1999 TIMSS, and speculated that it "may be due to the stress in the cultures of these countries on the virtue of humility or modesty" (p. 106). He also speculated that "the competitive examinations system coupled with the high expectations for student achievement in these countries have left a large number of students classified as failures in their system."

**Exhibit 7: Fourth Grade Countries Participating in Both 1995 and 2015—TIMSS Percentage of Students Not Confident in Mathematics and Average Mathematics Achievement**

| Country | 1995 | | 2015 | |
|---|---|---|---|---|
| | Not Confident Percentage | TIMSS Average Achievement | Not Confident Percentage | TIMSS Average Achievement |
| Australia | 10 | 495 | 15 | 517 |
| Cyprus | 3 | 475 | 8 | 523 |
| Czech Republic | 21 | 541 | 15 | 528 |
| England | 11 | 484 | 11 | 546 |
| Hong Kong SAR | 30 | 557 | 22 | 615 |
| Hungary | 16 | 521 | 14 | 529 |
| Iran, Islamic Rep. of | 5 | 387 | 6 | 431 |
| Ireland | 7 | 523 | 9 | 547 |
| Japan | 26 | 567 | 47 | 593 |
| Netherlands | 16 | 549 | 14 | 530 |
| New Zealand | 11 | 469 | 13 | 491 |
| Norway | 10 | 476 | 8 | 493 |
| Portugal | 16 | 442 | 10 | 541 |
| Singapore | 23 | 590 | 25 | 618 |
| Slovenia | 10 | 462 | 14 | 520 |
| United States | 9 | 518 | 13 | 539 |
| **Average** | 14 | 503 | 15 | 535 |

*Note: Data from Korea were not reported on this item in 1995. Percentage of students responding "disagree a little" or "disagree a lot" with the statement "I usually do well in mathematics."*

Indeed, the three East Asian countries in Exhibit 7—Hong Kong, Japan, and Singapore—register high TIMSS achievement along with low levels of confidence. In 2015, Japan stands out with nearly half (47%) of fourth grade students saying that they do not usually do well in mathematics—Singapore with 25 percent and Hong Kong with 22 percent. Korea, not shown in the table because of the absence of 1995 data, had 31 percent of fourth grade students expressing a lack of confidence in 2015. England, Ireland, Portugal, and the United States did not score as high as the East Asian nations, but they attained above average mathematics achievement while also exhibiting much lower percentages of students lacking confidence in the subject— England (11%), Ireland (9%), Portugal (10%), and the United States (13%).

Based on the data in Exhibit 7, the correlation coefficient for lack of confidence and TIMSS mathematics achievement was 0.71 in 1995 and 0.67 in 2015. Both are statistically significant ($p<0.05$). Higher achieving countries on the TIMSS mathematics assessment have larger numbers of students who feel they do not usually do well in the subject. Lower achieving countries report more confidence. Dropping the three East Asian countries lowers the correlation coefficients to 0.49 in 1995 and 0.46 in 2015. Neither correlation coefficient is statistically significant.

Exhibit 8 displays the percentage of eighth grade students disagreeing with the statement "I usually do well in mathematics." Despite their superior performance, Hong Kong, Korea, and Japan are again standouts for having large numbers of students lacking confidence in mathematics. Hong Kong's proportion of unconfident eighth grade students declined from 1995 to 2015 (from 62% to 39%), as did Korea's (from 62% to 52%). But Japan's percentage of unconfident students increased dramatically, from 55 percent in 1995 to 73 percent in 2015.

Correlation coefficients for the eighth grade relationship between TIMSS mathematics achievement and lack of confidence are 0.68 in 1995 and 0.66 in 2015, comparable to the associations at fourth grade. Dropping Hong Kong, Japan, Korea, and Singapore lowers the correlations to 0.23 for 1995 and 0.33 for 2015. Those statistics of association are not statistically significant ($p<.05$).

**Exhibit 8: Eighth Grade Countries Participating in Both 1995 and 2015— TIMSS Percentage of Students Not Confident in Mathematics and Average Mathematics Achievement**

| Country | 1995 | | 2015 | |
|---|---|---|---|---|
| | Not Confident Percentage | TIMSS Average Achievement | Not Confident Percentage | TIMSS Average Achievement |
| Australia | 18 | 509 | 25 | 505 |
| England | 7 | 498 | 18 | 518 |
| Hong Kong SAR | 62 | 569 | 39 | 594 |
| Hungary | 28 | 527 | 36 | 514 |
| Iran, Islamic Rep. of | 9 | 418 | 25 | 436 |
| Ireland | 21 | 519 | 26 | 523 |
| Japan | 55 | 581 | 73 | 586 |
| Korea, Rep. of | 62 | 581 | 52 | 606 |
| Lithuania | 51 | 472 | 29 | 512 |
| New Zealand | 15 | 501 | 25 | 493 |
| Norway | 21 | 498 | 20 | 487 |
| Russian Federation | 39 | 524 | 37 | 538 |
| Singapore | 43 | 609 | 36 | 621 |
| Slovenia | 26 | 494 | 36 | 516 |
| Sweden | 25 | 540 | 27 | 501 |
| United States | 14 | 492 | 19 | 518 |
| **Average** | 31 | 521 | 33 | 529 |

## Implications for Research

The analysis above investigated two paradoxes in TIMSS mathematics. Both pertain to counterintuitive findings about the relationship between student attitudes and average achievement in mathematics. High achieving countries tend to report large percentages of students who do not enjoy learning mathematics and do not believe they usually do well in the subject. Conversely, students in low achieving nations are more likely to say they enjoy learning mathematics and to express confidence in their mathematics performance. The paradoxes have persisted over the TIMSS 20 year history.

This chapter takes no stand on the causes of the paradoxes. Only correlational data have been presented, which serve descriptive purposes well but are unable to confirm or reject causal hypotheses. That said, research has generated explanations with the potential to solve these riddles.

## Culture

As demonstrated above, the paradoxes are particularly evident in East Asian nations. Analysts have suspected that East Asian TIMSS participants may share cultural values—for example, a hesitancy to declare that one "usually does well" at any school subject—influencing the students' responses. And, indeed, removing those countries when calculating correlation coefficients reduces that measure of association. Analyses of TIMSS 1995 results by Kifer (2002) and Wilkins (2004), using data modeled at the country level, concluded that both Asian and Eastern European countries were especially prone to the conundrum of high achievement accompanied by low self-concept in mathematics and science.

## Economic Development

In a study of gender differences in attitudes toward mathematics at the eighth grade, Maria Charles and colleagues (2014) reported an inverse relationship between students' attitudes toward mathematics and national economic development. The authors used TIMSS data from 2003 to 2011 to model attitudes toward mathematics and the Human Development Index (HDI) to represent national economic development. They found attitudes toward mathematics significantly more negative in high HDI countries. A decrease of 0.1 point in the HDI (about the difference between the Czech Republic and the United States) is associated with a 79 percent increase in the odds of students saying they enjoy learning mathematics.

## Frog Pond Effects

Sociologists have been interested in "frog pond" effects for many years. The term refers to the tendency of individuals to base self-evaluations on local comparison groups. It harkens to the age-old question of whether one is better being a big fish in a little pond or a little fish in a big pond. James A. Davis's 1966 study "The Campus as Frog Pond" found the career choices of college seniors influenced by the academic standing of fellow students: the higher achieving the campus as a whole, the lower students' evaluations of their own ability. Two decades later, Herbert Marsh (1987) applied the same logic to an investigation of high school students and found that students at low achieving schools judged themselves more positively compared to students of equal ability attending high achieving schools. When gifted students transfer from non-selective to selective schools, their academic self-concept often declines.

As applied to TIMSS, the question is whether nations also can serve as frog ponds. In high achieving countries, students' attitudes toward mathematics may be depressed by comparisons to high achieving peers. The opposite would occur in low achieving countries.

## Adolescence and the Curriculum

The deterioration of attitudes toward mathematics from fourth to eighth grade may arise from the collision of two forces: children maturing into adolescents and the mathematics curriculum getting much more difficult. Adolescence is a stage of life in which likes and dislikes crystallize and young people forge self-identities based on their interests and talents. At about the same time, the mathematics curriculum shifts from arithmetic to more abstract topics. The combination of these two developments may drive both disdain for studying mathematics and insecurity about mathematics performance.

## Conclusion: Implications for Policy

The data above support three implications for policymakers to consider:

First, local context matters. Do not expect results of a policy in one country to be duplicated in another. Think about it. All of the top candidates that researchers support as potential causes of the paradoxes described above involve the influence of local context. Culture, economic development, the characteristics of immediate peer groups, and the difficulty of curriculum topics manifest within countries, sometimes even with regions of countries.

Second, the level of analysis matters. Surveys of "enjoying mathematics" may be measuring different constructs at the individual, class, school, regional, and national levels. Data on attitudes are collected from individuals and then aggregated to group levels. Policy crafted in response to research findings at one level of analysis may not produce the same outcomes at another level of analysis.

Third, decouple enjoyment and confidence from achievement when considering policies. Boosting enjoyment and confidence may be reasonable policy goals in their own right. That said, do not expect that attaining them will automatically produce higher achievement.

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