1 Introduction

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TIMSS represents the continuation of a series of studies conducted by the International Association for the Evaluation of Educational Achievement (IEA). Since its inception in 1959, the IEA has conducted more than 15 studies of cross-national achievement in curricular areas such as mathematics, science, language, civics, and reading. IEA conducted its First International Mathematics Study (FIMS) in 1964, and the Second International Mathematics Study (SIMS) in 1980-82. The First and Second International Science Studies (FISS and SISS) were conducted in 1970-71 and 1983-84, respectively. Since the subjects of mathematics and science are related in many respects, the third studies were conducted together as an integrated effort.[1] The number of participating countries, the number of grades tested, and testing in both mathematics and science resulted in TIMSS becoming the largest, most complex IEA study to date and the largest international study of educational achievement ever undertaken.

Traditionally, IEA studies have systematically worked toward gaining a deeper insight into how various factors contribute to the overall outcomes of schooling. Particular emphasis has been placed on refining our understanding of students' opportunity to learn as that opportunity becomes defined and implemented by curricular and instructional practices. In an effort to extend what had been learned from previous studies and provide contextual and explanatory information, TIMSS was expanded beyond the already substantial task of measuring achievement in two subject areas to include a thorough investigation of curriculum and how it is delivered in classrooms around the world.

Continuing the approach of previous IEA studies, TIMSS defined three conceptual levels of curriculum. The intended curriculum is composed of the mathematics and science instructional and learning goals as defined at the system level. The implemented curriculum is the mathematics and science curriculum as interpreted by teachers and made available to students. The attained curriculum is the mathematics and science content that students have learned and their attitudes towards these subjects. To aid in interpretation and comparison of results, TIMSS also collected extensive information about the social and cultural contexts for learning, many of which are related to variations among education systems.

[1] In the time elapsed since SIMS and SISS, curriculum and testing methods have evolved considerably. The resulting changes in items and methods as well as differences in the populations tested make comparisons of TIMSS results with those of previous studies very difficult.

To gather information about the intended curriculum, mathematics and science specialists in each participating country worked section by section through curriculum guides, textbooks, and other curricular material to categorize them in accordance with detailed specifications drawn from the TIMSS mathematics and science curriculum frameworks (Robitaille et al., 1993). Initial results from this component of TIMSS can be found in two companion volumes: *Many Visions, Many Aims: A Cross-National Investigation of Curricular Intentions in School Mathematics* (Schmidt, McKnight, Valverde, Houang, and Wiley, 1997) and *Many Visions, Many Aims: A Cross-National Investigation of Curricular Intentions in School Science* (Schmidt, Raizen, Britton, Bianchi, and Wolfe, 1997).

To measure student achievement, TIMSS tested more than half a million students in mathematics and science at five grade levels involving the following three populations:

- Population 1. Students enrolled in the two adjacent grades that contained the largest proportion of 9-year-old students at the time of testing (third- and fourth-grade students in most countries).
- Population 2. Students enrolled in the two adjacent grades that contained the largest proportion of 13-year-old students at the time of testing (seventh- and eighth-grade students in most countries).
- Population 3. Students in their final year of secondary education. As an additional option, countries could test two subgroups of these students: students having taken advanced mathematics, and students having taken physics.

All countries that participated in TIMSS were to test students in Population 2. Many TIMSS countries also tested the mathematics and science achievement of students in Population 1 and of students in Population 3. Subsets of students in the fourth and eighth grades also had the opportunity to participate in a “hands-on” performance assessment. Together with the achievement tests, TIMSS administered a broad array of background questionnaires. The data collected from students, teachers, and school principals, as well as the system-level information collected from the participating countries, provide an abundance of information for further study and research. TIMSS data make it possible to examine differences in current levels of performance in relation to a wide range of variables associated with the classroom, school, and national contexts within which education takes place. The results of the assessments of Population 1 and Population 2 students have been published in:

> *Mathematics Achievement in the Primary School Years: IEA’s Third International Mathematics and Science Study* (Mullis, Martin, Beaton, Gonzalez, Kelly, and Smith, 1997)

Science Achievement in the Primary School Years: IEA's Third International Mathematics and Science Study (Martin, Mullis, Beaton, Gonzalez, Smith, and Kelly, 1997)

Mathematics Achievement in the Middle School Years: IEA's Third International Mathematics and Science Study (Beaton, Mullis, Martin, Gonzalez, Kelly and Smith, 1996)

Science Achievement in the Middle School Years: IEA's Third International Mathematics and Science Study (Beaton, Martin, Mullis, Gonzalez, Smith, and Kelly, 1996)

Performance Assessment in IEA's Third International Mathematics and Science Study (Harmon, Smith, Martin, Kelly, Beaton, Mullis, Gonzalez, and Orpwood, 1997)

These reports have been widely disseminated and are available on the Internet (http://www.csteep.bc.edu/timss). The entire TIMSS international database containing the achievement and background data underlying these reports also has been released and is available at the TIMSS website.

The most recent TIMSS report, *Mathematics and Science Achievement in the Final Year of Secondary School: IEA's Third International Mathematics and Science Study* (Mullis, Martin, Beaton, Gonzalez, Kelly, and Smith, 1998), focuses on the mathematics and science literacy of all students in their final year of upper secondary school, and on the advanced mathematics and physics achievement of final-year students having taken courses in those subjects. This population, Population 3, was the most challenging to assess, largely because of the diversity of upper secondary systems and the complex sample design and test design required.

This technical report, the third in a series of technical reports documenting the TIMSS procedures and analyses, describes the implementation and analysis of the assessment of students in their final year of secondary school in 24 countries (see Figure 1.1). Previous volumes in the series documented the design and development of the study (Martin and Kelly, 1996) and the implementation and analysis of the assessment of students in Populations 1 and 2 (Martin and Kelly, 1997).

1.1 PARTICIPATING COUNTRIES AND STUDENTS

Figure 1.1 shows the countries that participated in the assessment of students in their final year of secondary school in mathematics and science literacy, advanced mathematics, and physics. Each participating country designated a national center to conduct the activities of the study and a National Research Coordinator (NRC) to assume responsibility for the successful completion of these tasks.[2] For the sake of comparability, all testing was conducted at the end of the school year. Most countries tested the mathematics and science achievement of their students at the end of the 1994-95 school year, most often in May and June of 1995. The three countries on a Southern Hemi-

[2] The Acknowledgments section lists the National Research Coordinators.

sphere school schedule (Australia, New Zealand, and South Africa) tested from August to December 1995, which was late in the school year in the Southern Hemisphere. Students in Australia were tested in September to October; students in New Zealand were tested in August; and students in South Africa were tested in August to December 1995. Three countries tested their final-year students (or a subset of them) at the end of the 1995-96 school year. Iceland tested its final-year students in 1996; Germany tested its gymnasium students in 1996; and Lithuania tested the students in vocational schools in 1996. In Germany and Lithuania, all other students included in the TIMSS assessment were tested in 1995.

Table 1.1 Countries Participating in Testing of Students in Their Final Year of Secondary School

Mathematics and Science Literacy	Advanced Mathematics	Physics
• Australia	• Australia	• Australia
• Austria	• Austria	• Austria
• Canada	• Canada	• Canada
• Cyprus	• Cyprus	• Cyprus
• Czech Republic	• Czech Republic	• Czech Republic
• Denmark	• Denmark	• Denmark
• France	• France	• France
• Germany	• Germany	• Germany
• Hungary	• Greece	• Greece
• Iceland	• Israel	• Israel
• Israel	• Italy	• Italy
• Italy	• Lithuania	• Latvia
• Lithuania	• Russian Federation	• Norway
• Netherlands	• Slovenia	• Russian Federation
• New Zealand	• Sweden	• Slovenia
• Norway	• Switzerland	• Sweden
• Russian Federation	• United States	• Switzerland
• Slovenia		• United States
• South Africa		
• Sweden		
• Switzerland		
• United States		

As can be imagined, testing students in their final year of secondary school was a special challenge for TIMSS. The 24 countries participating in this component of the testing vary greatly with respect to the nature of their upper secondary education systems. Some countries provide comprehensive education to students in their final years of school, while in other countries students might attend more specialized academic, vocational, or technical schools. Some countries fall between these extremes, their students being enrolled in academic, vocational, technical, or general programs of study within the same schools. Across countries the definitions of academic, vocational, and technical programs also vary, as do the kinds of education and training students in these programs receive.

The differences across countries in how education systems are organized, how students proceed through the upper secondary system, and when students leave school posed a challenge in defining the target populations to be tested in each country and interpreting the results. In order to make valid comparisons of students' performance across countries, it is critical that there be an understanding of which students were tested in each country, that is, how the target population was defined. It also is important to know how each upper secondary education system is structured and how the tested students fit into the system as a whole. In order to provide a context for interpreting the achievement results presented in this report, TIMSS summarized the structure of the upper secondary system for each country, specified the grades and tracks (programs of study) in which students were tested for TIMSS, and provided this information in the international report (Mullis et al., 1998).

Understandably, it was difficult for some countries to test all of the final-year students, particularly those in on-site occupational training. This, combined with the fact that by the final year of secondary school not all students are attending school, meant that countries differ with respect to the age-eligible cohort that was tested. To give some indication of the proportion of the entire school-leaving age cohort that was covered by the testing in each country, TIMSS developed its own index – the TIMSS Coverage Index or TCI.

1.2 THE TESTS FOR FINAL-YEAR STUDENTS

Three tests were developed for the TIMSS assessment of students in the final year of secondary school: the mathematics and science literacy test; the advanced mathematics test; and the physics test. The tests were developed through an international consensus involving input from experts in mathematics, science, and measurement. The TIMSS Subject Matter Advisory Committee, including distinguished scholars from 10 countries, ensured that the mathematics and science literacy tests represented current conceptions of literacy in those areas, and that the advanced mathematics and physics tests reflected current thinking and priorities in the fields of mathematics and physics education. The items underwent an iterative development and review process, with multiple pilot tests. Every effort was made to ensure that the items exhibited no bias towards or against particular countries. Item specifications were checked against data from the curriculum analysis. Items were rated for suitability by subject matter specialists in the participating countries, and a thorough statistical item analysis of data collected in the pilot testing was conducted. The final forms of the test were endorsed by the NRCs of the participating countries.[3]

[3] For a full discussion of the TIMSS test development effort, see Garden and Orpwood (1996), Robitaille and Garden (1996), and Orpwood and Garden (1998).

The mathematics and science literacy test was designed to test students' general knowledge and understanding of mathematical and scientific principles. The mathematics items cover number sense, including fractions, percentages, and proportionality. Algebraic sense, measurement, and estimation are also covered, as are data representation and analysis. Reasoning and social utility are emphasized in several items. A general criterion in selecting the items was that they should involve the types of mathematics questions that could arise in real-life situations and that they be contextualized accordingly. Similarly, the science items selected for use in the TIMSS literacy test were organized according to three areas of science – earth science, life science, and physical science – and included a reasoning and social utility component. The emphasis was on measuring how well students can use their knowledge in addressing real-world problems having a science component. The test was designed to enable reporting for mathematics literacy and science literacy separately as well as overall.

In order to examine how well students understand advanced mathematics concepts and can apply knowledge to solve problems, the advanced mathematics test was developed for students in their final year of secondary school having taken advanced mathematics. This test enabled reporting of achievement overall and in three content areas: numbers and equations; calculus; and geometry. In addition to items representing these three areas, the test also included items related to probability and statistics and to validation and structure, but because there were few such items, achievement in these areas was not reported separately.

The physics test was developed for students in their final year of secondary school who had taken physics, in order to examine how well they understand and can apply physics principles and concepts. It enabled reporting of physics achievement overall and in five content areas: mechanics; electricity and magnetism; heat; wave phenomena; and modern physics – particle physics, quantum physics and astrophysics, and relativity.

1.3 MANAGEMENT AND OPERATIONS

Like all previous IEA studies, TIMSS was essentially a cooperative venture among independent research centers around the world. While country representatives came together to plan the study and to agree on instruments and procedures, participants were each responsible for conducting TIMSS in their own country in accordance with the international standards. Each national center provided its own funding and contributed to the support of the international coordination of the study. A study of the scope and magnitude of TIMSS offers a tremendous operational and logistical challenge. In order to yield comparable data, the achievement survey must be replicated in each participating country in a timely and consistent manner. This was the responsibility of the NRC in each country. Among the major tasks of the NRCs in this regard were the following:

- Meeting with other NRCs and international project staff to plan the study and develop instruments and procedures

- Defining the school populations from which the TIMSS samples were to be drawn, selecting the sample of schools using an approved random sampling procedure, contacting the school principals and securing their agreement to participate in the study, and selecting the classes to be tested, again using an approved random sampling procedure

- Translating and adapting all of the tests, questionnaires, and administration manuals into the language of instruction of the country (and sometimes more than one language) prior to data collection

- Assembling, printing, and packaging the test booklets and questionnaires, and shipping the survey materials to the participating schools

- Ensuring that the tests and questionnaires were administered in participating schools, either by teachers in the school or by an external team of test administrators, and that the completed test protocols were returned to the TIMSS national center

- Conducting a quality assurance exercise in conjunction with the test administration, whereby some testing sessions were attended by an independent observer to confirm that all specified procedures were followed

- Recruiting and training individuals to score the free-response questions in the achievement tests, and implementing the plan for scoring the student responses, including the plan for assessing the reliability of the scoring procedure

- Recruiting and training data entry personnel for keying the responses of students, teachers, and principals into computerized data files, and conducting the data entry operation using the software provided

- Checking the accuracy and integrity of the data files prior to shipping them to the IEA Data Processing Center in Hamburg

In addition to their role in implementing the TIMSS data collection procedures, NRCs were responsible for conducting analyses of their national data and for reporting on the results of TIMSS in their own countries.`

The TIMSS International Study Director was responsible for the overall direction and coordination of the project. The TIMSS International Study Center, located at Boston College in the United States, was responsible for supervising all aspects of the design and implementation of the study at the international level. This included the following:

- Planning, conducting, and coordinating all international TIMSS activities, including meetings of the International Steering Committee, NRCs, and advisory committees

- Developing and field testing the data collection instruments

- Developing sampling procedures for efficiently selecting representative samples of students in each country, and monitoring sampling operations to ensure that they conformed to TIMSS requirements

- Designing and documenting operational procedures to ensure efficient collection of all TIMSS data

- Designing and implementing a quality assurance program encompassing all aspects of the TIMSS data collection, including monitoring of test administration sessions in participating countries

- Supervising the checking and cleaning of the data from the participating countries, the construction of the TIMSS international database, the computation of sampling weights, and the scaling of the achievement data

- Analyzing the international data and writing and disseminating the international reports

The International Study Center was supported in its work by the following advisory committees:[4]

- The International Steering Committee, which advised on policy issues and on the general direction of the study

- The Subject Matter Advisory Committee, which advised on all matters relating to mathematics and science subject matter, particularly the content of the achievement tests

- The Technical Advisory Committee, which advised on all technical issues related to the study, including study design, sampling design, achievement test construction and scaling, questionnaire design, database construction, data analysis, and reporting

- The Performance Assessment Committee, which developed the TIMSS performance assessment and advised on the analysis and reporting of the performance assessment data

- The Free-Response Item Coding Committee, which developed the coding rubrics for the free-response items

- The Quality Assurance Committee, which helped to develop the TIMSS quality assurance program

- The Advisory Committee on Curriculum Analysis, which advised the International Study Director on matters related to the curriculum analysis

[4] See the Acknowledgments section for membership of TIMSS committees.

Several important TIMSS functions, including test and questionnaire development, translation checking, sampling consultations, data processing, and data analysis, were conducted by centers around the world under the direction of the TIMSS International Study Center. In particular, the following centers have played important roles in the TIMSS project.

- The IEA Data Processing Center (DPC), located in Hamburg, Germany, was responsible for checking and processing all TIMSS data and for constructing the international database. The DPC played a major role in developing and documenting the TIMSS field operations procedures

- Statistics Canada, located in Ottawa, Canada, was responsible for advising NRCs on their sampling plans, for monitoring progress in all aspects of sampling, and for the computation of sampling weights

- The Australian Council for Educational Research (ACER), located in Melbourne, Australia, participated in the development of the achievement tests, conducted psychometric analyses of field trial data, and was responsible for the development of scaling software and for scaling the achievement test data

- The International Coordinating Center (ICC) in Vancouver, Canada, was responsible for the international project coordination prior to the establishment of the International Study Center in August 1993. Since then, the ICC has provided support to the International Study Center, particularly in managing translation verification in the achievement test development process, and has published several monographs in the TIMSS monograph series

- As Sampling Referee, Keith Rust of Westat, United States, worked with Statistics Canada and the NRCs to ensure that sampling plans met the TIMSS standards, and advised the International Study Director on all matters relating to sampling

1.4 SUMMARY OF THIS REPORT

The variation across countries regarding the nature of upper secondary education systems, including what constitutes the in-school population, what programs of study students follow, and when students finish secondary school, posed many challenges in sampling schools and students. In Chapter 2 of this report, Jean Dumais describes the implementation of the TIMSS sample design for Population 3: how students were stratified according to their academic preparation, how schools and students were sampled, how TIMSS quantified the coverage of the school-leaving age cohort with the TIMSS Coverage Index (TCI), the response rates for each country, and how TIMSS documented the extent to which the sampling guidelines were followed in each country.

To ensure the availability of comparable, high-quality data for analysis, TIMSS took a set of rigorous quality control steps to create the international database. TIMSS prepared manuals and software for countries to use in entering their data so that the information would be in a standardized international format before it was forwarded to the IEA Data Processing Center (DPC) in Hamburg for creation of the international database. Upon arrival at the Center, the data from each country underwent an exhaustive cleaning process. That process involved several iterative steps and procedures designed to identify, document, and correct deviations from the international instruments, file structures, and coding schemes. The process also emphasized consistency of information within national data sets and appropriate linking among the many student, teacher, and school data files. Following the data cleaning and file restructuring by the DPC, Statistics Canada computed the sampling weights and the Australian Council for Educational Research computed the item statistics and scale scores. These additional data were merged into the database by the DPC. Throughout, the International Study Center reviewed the data and managed the data flow. In Chapter 3, Heiko Sibberns, Dirk Hastedt, Michael Bruneforth, Knut Schwippert, and Eugenio Gonzalez describe the TIMSS data management, including procedures for cleaning and verifying the data and the links across files, restructuring of the national data files to the standard international format, the various data reports produced throughout the cleaning process, and the computer systems used to undertake the data cleaning and construction of the database.

Within countries, TIMSS used a two-stage sample design for Populations 3. The first stage involved selecting 120 public and private schools within each country. Within each school, the basic approach required countries to use random procedures to select 40 students. The actual number of schools and students selected depended in part on the structure of the education system – tracked or untracked – and on where the student subpopulations were in the system. The complex sampling approach required the use of sampling weights to account for the differential probabilities of selection and to adjust for non-response in order to ensure the computation of proper survey estimates. Statistics Canada was responsible for computing the sampling weights for the TIMSS countries. In Chapter 4, Jean Dumais and Pierre Foy describe the derivation of school and student weights.

Because the statistics presented in the TIMSS reports are estimates of national performance based on samples of students, rather than the values that could be calculated if every student in every country had answered every question, it is important to have measures of the degree of uncertainty of the estimates. The complex sampling approach that TIMSS used had implications for estimating sampling variability. Because of the effects of cluster selection and the effects of certain adjustments to the sampling weights, standard procedures for estimating the variability of sample statistics generally underestimate the true variability of the statistics. To avoid this problem, TIMSS used the jackknife procedure to estimate the standard errors associated with each statistic presented in the international reports. In Chapter 5, Eugenio Gonzalez and Pierre Foy describe the jackknife technique and its application to the TIMSS data in estimating the variability of the sample statistics.

Prior to scaling, the TIMSS cognitive data were thoroughly checked by the IEA Data Processing Center, the International Study Center, and the national centers. The national centers were contacted regularly and given multiple opportunities to review the data for their countries. In conjunction with the Australian Council for Educational Research, the International Study Center conducted a review of item statistics for each of the mathematics and science literacy, advanced mathematics, and physics items in each of the countries to identify poorly performing items. In Chapter 6, Ina Mullis and Michael Martin describe the procedures used to ensure that the cognitive data included in the scaling and the international database are comparable across countries.

The complexity of the TIMSS test design and the desire to compare countries' performance on a common scale led TIMSS to use item response theory to summarize the achievement results. TIMSS reported scale scores for mathematics literacy; science literacy; advanced mathematics; three advanced mathematics content areas; physics; and five physics content areas. These scales were based on a variant of the Rasch item response model. The model, developed by Adams, Wilson, and Wang (1997), includes refinements that enable reliable scores to be produced even though individual students responded to relatively small subsets of the total item pools. This approach was preferred for developing comparable estimates of performance for all students, since students answered different test items depending on which of the test booklets they received. In Chapter 7, Greg Macaskill, Ray Adams, and Margaret Wu describe the scaling methodology and procedures used to produce the TIMSS achievement scores, including the estimation of international item parameters and the derivation and use of plausible values to provide estimates of performance.

TIMSS reported achievement from a number of perspectives. Mean achievement and percentiles of distribution were reported by country for mathematics and science literacy, advanced mathematics, and physics, and significant differences between countries (adjusted for multiple comparisons) were also reported. To show whether or not countries may have achieved higher performance because they tested fewer students and, in particular, a more elite group of students, TIMSS showed the relationship between the TIMSS Coverage Index and achievement for mathematics and science literacy, advanced mathematics, and physics. TIMSS also reported achievement for the school-leaving age cohort, regardless of the coverage of this cohort by the sample; achievement was reported for the top 25 percent of students in mathematics and science literacy, and the top 10 percent and 5 percent of students in both advanced mathematics and physics. TIMSS also compared countries' achievement on the final-year mathematics and science literacy test with achievement on the Population 2 mathematics and science tests, in relationship to the international averages. In Chapter 8, Eugenio Gonzalez describes the analyses undertaken to report the achievement scale scores in these various ways in the international reports.

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