The Third International Mathematics and Science Study: Anatomy of this international comparative study in science education

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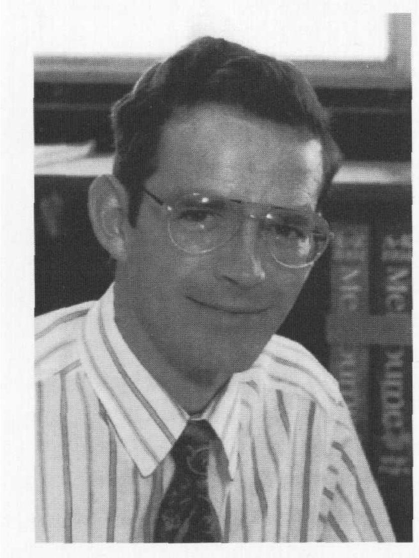
Abstract

The Third International Mathematics and Science Study (TIMSS) was the largest study of its kind ever undertaken in the history of science education. Funded by the International Association for the Evaluation of Educational Achievement (IEA) with contributions from personnel and organisations around the world, TIMSS has evaluated the educational performance in science of approximately 500,000 students from Australia and 46 other countries around the world. In addition to assessing student knowledge and ability in science, TIMSS also included the collection of substantial quantities of information pertaining to more than 800 educational and environmental background variables. Students were asked about their school and home environments, attitudes to science, personal and academic background, career and educational goals; teachers were asked about their academic and professional background, instructional practices, pedagogical beliefs, and attitudes to science; and school principals were asked about school staffing and resources, student populations, curricular and text book policies, and the school community. This article gives a brief description of TIMSS; what it is, its goals, the study design, focus populations, potential to influence science education, and need to use the resultant data to benefit science education.



Dr Russell Jones is a lecturer in science education at the University of Melbourne. With a background in science teaching, at present his major foci of interest are making assessment and evaluation issues meaningful and manageable for science teachers, using IT to teach science, correcting student misconceptions and improving science educational practice. Russell has been involved in several large scale international projects including the Third International Mathematics and Science Study and the International Assessment of Educational Progress, as well as national assessment projects.

Background

Recent years have seen a strong and growing demand for detailed information pertaining to the success of educational systems around the world (Bottani, Duchene & Tuijuman, 1992; Leitz & Keeves, 1994). This demand has come from international authorities such as UNESCO and the OECD, national educational and policy making authorities, state governments and the wider community. The demand has led to an increase in the number and scope of international comparative studies exemplified by the Second International Science Study (Postlethwaite, 1994), the Second International Mathematics Study (Keeves, 1992a), and the International Assessment of Educational Progress II (Lapointe, Mead & Phillips, 1989). These studies serve as empirically based comparative research programs to investigate issues common to many national education systems. The latest such study, and the largest study of its kind in the history of science education, is the Third International Mathematics and Science Study (TIMSS).

International scope of TIMSS

As an international study, TIMSS sought to survey science performance and those factors which might influence science performance of students from countries around the world. Although the exact number of countries participating in TIMSS varied between each of three focus populations, overall the following 47 countries participated in TIMSS.

Argentina	Hungary	Philippines
Australia	Iceland	Portugal
Austria	Indonesia	Romania
Belgium	Iran	Russian Federation
Bulgaria	Ireland	Scotland
Canada	Israel	Singapore
China, PRC	Italy	Slovakia
Colombia	Japan	Slovenia
Cyprus	Korea	South Africa
Czech Republic	Kuwait	Spain
Denmark	Latvia	Sweden
England	Lithuania	Switzerland
France	Mexico	Thailand
Germany	Netherlands	Ukraine
Greece	New Zealand	United States
Hong Kong	Norway	

Some of these countries broke down the assessment of their national performance into different educational systems. For example, Canada separately assessed some Canadian provinces (e.g., Quebec and Ontario) and Belgium separately assessed Belgium Flemish and Belgium French.

Research focus

The quantity of information gathered by a study with the broad scope of TIMSS is enormous with the potential to answer a wide range of useful and informative pedagogical, practical, policy making and research questions. Robitaille, Schmidt, Raizen, McKnight, Britton and Nicol (1993, p. 34) list the following as a sample of the types of information sought by TIMSS.

- International variations in science and mathematics curricula, including variations in goals, intentions and sequences of curricula.
- International variations in the training of teachers of science and mathematics.
- The influence of officially prescribed textbooks on the teaching of science and mathematics.
- The course content that is actually taught in science and mathematics classrooms (i.e., the opportunity to learn).
- The effectiveness of different instructional practices.
- Students' achievement, especially in the areas of non-routine problem solving and the application of science and mathematics in the real world.
- The attitudes and opinions of students and teachers.
- The role of technology in the teaching and learning of science and mathematics, particularly the use of calculators and computers.
- Participation rates in pre-university courses, with particular regard to gender-based differences.
- The effect of tracking, streaming and other practices used to influence or direct students' course selections.

The desire to gather this type of information and the necessity of working within an international arena necessitated the design of a specific conceptual framework for TIMSS. Robitaille and Maxwell (1996) present a detailed discussion of the TIMSS conceptual framework and research questions. A summary of the main points of this work follows. The conceptual framework for TIMSS grew out of earlier International Association for the Evaluation of Educational Achievement (IEA) studies and from relevant literature pertaining to educational indicators. In particular the conceptual framework of TIMSS is linked to the conceptual framework of SIMS (Travers & Westbury, 1989) which was "the first IEA study to highlight the distinction between that which a society would like to have taught, that which is actually taught, and that which students actually learn" (Robitaille & Maxwell, 1996, p. 34), i.e., the intended, the implemented and the attained curricula. Broadly speaking TIMSS was designed to address the following four general research questions:

1. How do countries vary in the intended learning goals for science and mathematics and what characteristics of educational systems, schools and students influence the development of those goals? (i.e., intended curricula)
2. What opportunities are provided for students to learn science and mathematics; how do instructional practices in science and mathematics vary among nations; and what factors influence these variations? (i.e., the implemented curriculum).
3. What science and mathematics concepts, processes, and attitudes have students learned; and what factors are linked to students' opportunity to learn? (i.e., the attained curriculum).
4. How are the intended, the implemented and the attained curricula related with respect to the contexts of education, the arrangements for teaching and learning, and the outcomes of the educational process? (i.e., what are the relationships between curricula and social and educational contexts?)

As Robitaille and Maxwell (1996) point out, each of these general research questions potentially gives rise to an enormous number of specific questions. Many of these specific questions were addressed directly by the items and questions within TIMSS instruments whereas the answers to others will require careful analysis of the TIMSS database

TIMSS curriculum framework

In order to meet the challenge of making meaningful comparisons between countries with extremely varied educational systems and environments it was necessary for TIMSS to develop a common framework suitable for use in all participating countries. The TIMSS framework contained three aspects; subject matter content, performance expectations and perspectives or context (Robitaille et al., 1993). Each aspect contained several major categories:

1. Content: earth sciences; life sciences; physical sciences; science technology; history of science and technology; environmental issues; nature of science; and science and other disciplines.

2. Performance Expectations: understanding; theorising, analysing and solving problems; using tools and routine procedures; investigating the natural world; and communicating.
3. Perspective: attitudes; careers; participation; increasing interest; safety; and habits of mind.

The three aspects and major categories of the mathematics framework were:

1. Content: numbers; measurement; geometry; proportionality; functions, relations and equations; data, probability and statistics; elementary analysis; and validation and structure.
2. Performance Expectations: knowing; using routine procedures; investigating and problem solving; mathematical reasoning; and communicating.
3. Perspective: attitudes; careers; participation; increasing interest; and habits of mind.

The TIMSS design

TIMSS used a simultaneous cross sectional research design whereby a series of three studies were conducted, each focusing on a different age group or "population". The samples from each age group were all drawn independently, and identical prediction and criterion variables were used for each age sample (Keeves & Adams, 1994). Cross sectional studies of this kind are a useful method to procure information pertaining to educational processes, existing conditions and outcomes of educational systems (Bottani, et al, 1992). Moreover the TIMSS research design incorporated a longitudinal dimension by permitting the comparison of data for the different age samples. This feature overcomes some of the problems associated with true longitudinal studies. A problem with true longitudinal studies is that, by definition, they take a great deal of time. This leads to a further problem because, by the time final data are collected, environmental influences acting during the initial portions of the study are likely to have changed. These changes limit the value of the conclusions that can be drawn from the findings of the study. However, because data for TIMSS were essentially gathered at only one point in time, the confounding effects from environmental influences are considerably reduced compared to true longitudinal studies. Furthermore, this approach more readily allows the effects of particular educational practices, such as the effect of the number of years students spend learning foreign languages (Carroll, 1975) or the effects of educational innovations, to be more readily observed (Keeves & Adams, 1994).

Study organisation

TIMSS was initiated under the auspices of the IEA. Since 1993, the International Study Centre at Boston College has had overall responsibility for the study design, implementation, direction and quality control. Prior to this time the International Coordinating Centre at the University of British Columbia coordinated TIMSS and this Centre continued to cooperate with the International Study Centre on matters relating to test development, translation verification and publication after 1993 (Beaton, 1996).

The International Study Centre liaised directly with a National Research Coordinator, or NRC, within each country. Each NRC was based in a National Research Centre and was responsible for coordinating the nationwide assessment of all schools, teachers and students within each country. To facilitate this process, each NRC liaised with a series of School Coordinators at the school level who, in turn, liaised with the Survey Administrators. The NRCs were trained by personnel under the guidance of the International Study Centre and each NRC trained staff within her/his country in the art of test administration. NRCs were also responsible for coding student responses to the TIMSS instruments (including marking of student responses to the achievement test instruments) and entering the data from their country into computers before passing these data on to the IEA Data Processing Centre for construction of the TIMSS database.

The International Study Centre also coordinated the input of other major contributors to the study. These contributors included substantial support from large research organisations in Australia, Europe and North America.

- The Australian Council for Educational Research was responsible for initial country level scaling, final country level scaling and production of individual student score estimates. This included basic item analysis (test reliability, item difficulty, item discrimination, item fit and preliminary item-by-country interactions), full multidimensional item scaling and the report of final item statistics and distributions of student performance to each country and study centre.[1]
- The IEA Data Processing Centre was located in Hamburg, Germany, and was responsible for production of many operational procedures and the overall construction of the TIMSS database (e.g., school, teacher and student files and univariate statistics for all background questionnaire items).
- Statistics Canada was responsible for sampling and the calculation of school, classroom and student weighting.
- Educational Testing Service (based in the United States) played a significant role in test development.

Focus populations and sampling

TIMSS predominantly focused on students, teachers and school principals from three student populations:

- Population 1 = the two grades with the most 9-year-old students.
- Population 2 = the two grades with the most 13-year-old students.
- Population 3 = the final year of secondary schooling (equivalent to Year 12 in Australia).

Sampling utilised a two-stage design whereby schools were selected in the first stage and classes or students in the second. The sampling for Populations 1 and 2 typically selected 150 schools for participation within each country[2]. Within each school, two classes of students were selected; one from the upper grade and one from the lower. Using intact classes as the unit of sampling, rather than a random sample of students within the grades, offered several powerful advantages. These included the linking of student achievement with teacher characteristics (as well as with school and system characteristics) and additional practical and administrative benefits (Robitaille & Garden, 1996).

Research questions relevant to Population 3 tended to be focused upon the overall achievement of students rather than student achievement in relation to instructional variables. Thus no links were made between teachers and students and the Population 3 sampling design required the random selection of individual students from the Population 3 cohort rather than the selection of entire classes (Robitaille & Garden, 1996). Sampling for Population 3 typically selected 120 schools from each country and, where possible, 40 students from each school; 10 advanced physics students, 10 advanced math students, 10 advanced physics and math students, and 10 other students.

Some countries also elected to have a subsample of approximately 450 students from a minimum of 50 schools participate in a series of performance assessment tasks. These students were selected from the upper grades of students within Populations 1 and 2 (Robitaille & Garden, 1996).

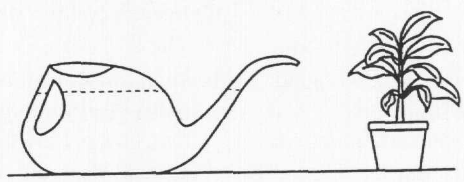
Achievement test items

Four types of test item were used; multiple-choice items, short answer items, extended response items and performance assessment tasks. Short answer and extended response items were often referred to as "free response items". Detailed descriptions of these items are contained within Garden (1996). In summary: multiple-choice items consisted of a typical multiple-choice stem followed by four or five answer choices, with a single best answer and no use of "I don't know" or "none of the above" as answer options; short answer items required students to write a short numerical or textual answer which was marked as either correct or incorrect; extended response items required students to provide detailed solutions and marking included partial credit for partially correct solutions; performance assessment tasks were designed with a "hands on" approach to enable students to demonstrate important scientific skills (for example, correctly designing and conducting a scientific investigation, successfully making, recording and communicating observations, systematically collecting and presenting experimental data, and so on).

Achievement test booklets

Eight test booklets were administered to students from each of Populations 1 and 2, and nine test booklets to students from Population 3. Each student completed one booklet. Test booklets for Population 1 contained a total of 199 items and for Population 2 and Population 3, 286 items

A watering can is almost filled with water as shown.



The watering can is tipped so that the water just begins to drip through the spout.

Draw a line to show where the surface of the water in the can is now.

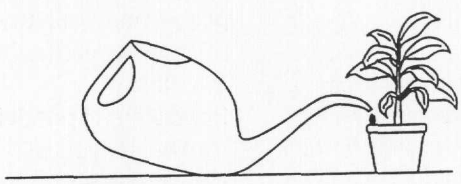
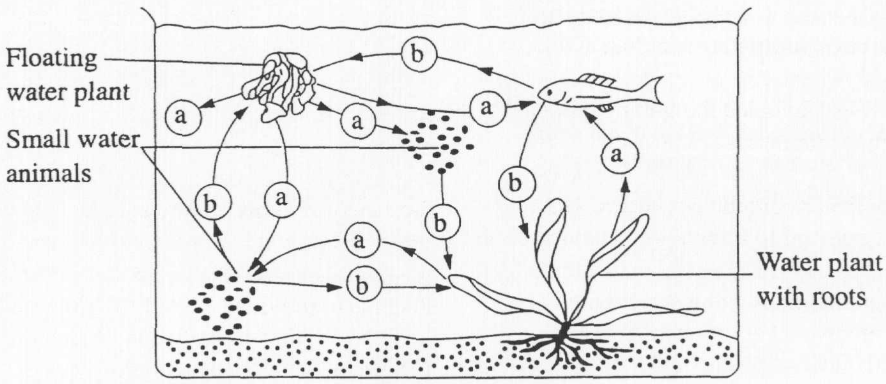


Figure 1. An example of a free response item administered to students in Populations 1 and 2 (TIMSS, 1997a,b)

The diagram below shows an example of interdependence among aquatic organisms. During the day the organisms either use up or give off (a) or (b) as shown by the arrows.



Choose the right answer for (a) and (b) from the alternatives given.

A. (a) is oxygen and (b) is carbon dioxide.

B. (a) is oxygen and (b) is carbohydrate.

C. (a) is nitrogen and (b) is carbon dioxide.

D. (a) is carbon dioxide and (b) is oxygen.

E. (a) is carbon dioxide and (b) is carbohydrate.

Figure 2. An example of a multiple-choice item administered to students in Population 2 (TIMSS, 1997b)

and 206 items respectively. All booklets contained extended response, short answer and multiple-choice items in approximately equal proportions. Within each population, booklets were generally of equal difficulty (Adams & Gonzalez, 1996). In general students were permitted ample time to complete their test booklets (Population 1 students were allowed 64 minutes, Population 2 students 90 minutes and Population 3 students 90 minutes). The eight booklets within Populations 1 and 2 contained both science and mathematics items, whereas the nine booklets in Population 3 comprised two mathematics and science literacy booklets, three physics booklets, three advanced mathematics booklets, and one physics and advanced mathematics booklet. A sub-sample of students from Populations 1 and 2 in some countries (such as Australia) also participated in the administration of a series of performance assessments. Figures 1 through 3 show examples of typical science items administered during TIMSS.

An idea of the amount of emphasis placed on each science content area and performance category can be obtained through an examination of the number of testing minutes allocated to each of these areas and categories for each population. This information is summarised in Table 1.

Student, teacher and school principal questionnaires

In addition to assessing the current state of science performance of students from each of the three focus populations, TIMSS also gathered extensive information about schools, facilities, curricula, educational strategies, staffing, pedagogical beliefs, problems, student populations, and student background. This information was obtained through the administration of three questionnaires; one each to school principals, teachers and students.

School Principal Questionnaires

Containing questions requiring 243 responses from school principals, this questionnaire solicited information from school principals about their schools, teachers and students. Among the many questions asked, specific

CONTAINERS

At this station you should have:

Three containers (or cups) marked A, B, C
Three thermometers
A clock or watch
A container with very hot water. BE CAREFUL NOT TO SPILL HOT WATER
Pieces of card to use as a fan if you wish
A roll of paper to wipe up spills
A measuring cup

Read ALL directions carefully.

> Your task:
>
> Find out which of the containers will keep a hot drink warm for the longest time.

This is what you should do:

- Place a thermometer in each of the containers BEFORE the hot water is poured in. Your teacher will pour the hot water when you are ready. BE CAREFUL. THE WATER IS VERY HOT.

- Measure the temperature on each thermometer as soon as the hot water is poured in.
- Write these measurements and the time in the table on the opposite page.

- Now you will take measurements over a total of 10 minutes.
  - ➢ Decide how often to read each thermometer.
  - ➢ Write your measurements in the table on the opposite page.

1. Table of Measurements:

Time	Temperature of Container A	Temperature of Container B	Temperature of Container C

1. Look at the table. Which container keeps a hot drink warm for the longest time?

2. Why do you think this container was best for keeping a hot drink warm?

Figure 3. An example of a performance assessment task administered to students in Population 1 (Harmon et al, 1997)

Table 1. The Number of Testing Minutes Allocated to each Science Content Area by performance Category for each Population (adapted from Adams & Gonzalez, 1996).

Pop'n	Science Category	Understanding	Theorising, Analysing & Solving Problems	Using Tools, Routine Procedure & Sci. Processes	Investigating the Natural World	Total
1	Earth Science					
	earth features	6	5	0	1	12
	other content	5	3	1	0	9
	Life Science					
	human biology	12	2	0	0	14
	other content	31	1	1	0	33
	Physical Science	19	13	3	1	36
	Environment	9	0	0	0	9
	Other content	2	0	1	1	4
	Total	84	24	6	3	117
2	Earth Science					
	earth features	10	5	1	-	16
	other content	6	9	2	-	17
	Life Science					
	human biology	12	3	-	5	20
	other content	32	7	1	1	41
	Physics					
	energy types, etc.	5	10	-	-	15
	light	7	7	-	-	14
	other content	16	13	1	2	32
	Chemistry	16	9	1	-	26
	Environment	5	5	-	-	10
	Other Content	3	3	2	2	10
	Total	112	71	8	10	201
3	Physics					
	forces & motions	3	30	12	5	50
	electricity & magnetism	12	39	3	-	54
	thermal & wave phenomena	12	12	3	-	27
	particle physics & relativity	12	15	-	5	32
	energy	12	27	6	3	48
	Total	51	123	24	13	211
	Science Literacy					
	earth science	1	8	-	-	9
	life science	12	2	2	1	17
	physical science	8		-	-	19
	Total	21	21	2	1	45
	Reasoning & Social Utility	4	7	5	-	16

examples of information obtained included (but were not limited to) the type of community where the school was located; the grade levels taught in the school; the number of students attending the school; information regarding school staff including the number of years of teaching experience, full-time/part-time status, and the number of hours timetabled for science; computer availability for teachers and students; the extent to which instruction is affected by shortages of resources such as library resources pertinent to science, computer hardware and software, audio-visual material, instructional space, school buildings, instructional materials and a limited budget for educational supplies; problems at school such as tardiness, absenteeism, classroom disturbance, cheating, vandalism, theft, intimidation and injury, and tobacco, alcohol and drug abuse; and school admission policy.

Teacher questionnaires

Containing questions requiring 468 responses, these questionnaires solicited information from teachers about themselves, their students, their teaching methods, topics taught, opportunities for students to learn and their pedagogical approach. Among the many questions asked, specific examples of information obtained included (but were not limited to) demographic information; educational background; number of years teaching experience; what year levels teachers typically teach and what year levels they currently teach in science; what are typical teaching duties and how much time is devoted to each; educational activities outside school day; background beliefs about science learning and teaching; use of texts and other teaching aids; identification of problems which may limit the effects of science teaching; calculator use and availability; planning of science lessons; lesson structure, content and activities; curricular structure and content; content, use, frequency and quality of homework; assessment practice and uses; student opportunity to learn specific content areas; and the teacher's pedagogical approach.

Student questionnaire

Containing questions requiring 148 responses these questionnaires solicited information from students about themselves, their families, their educational and recreational activities, school and home environments, motivation, enjoyment of science, classroom activities, and thoughts about science. Among the many questions asked, specific examples of information obtained included (but were not limited to) educational and other activities before and after school; availability of educational resources in the home and school environments; the school environment; perceived reasons for success in science; motivation to do well in science; classroom activities; homework; calculator and computer use; and the practical applicability of science to solve global problems.

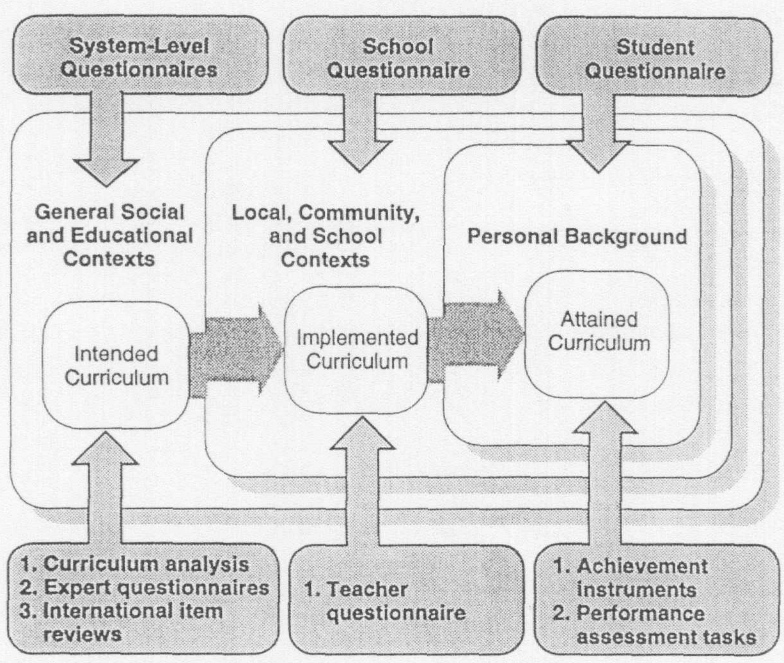


Figure 4. Relationship od TIMSS data collection instruments to the TIMSS conceptual framework (Robitaille & Garden, 1996)

TIMSS data collection instruments and the conceptual framework

In addition to the test booklets and questionnaires described above, TIMSS also relied on other sources of information to inform its research questions. These included curriculum analyses, international item reviews, and expert and system-level questionnaires. The relationship between all of the TIMSS data collection instruments and the TIMSS conceptual framework is summarised in Figure 4.

Questions remaining to be answered

TIMSS has gathered a wealth of information from students, teachers and principals from dozens of countries across the world. These data are incredibly rich in terms of their potential to inform educational decision making, to identify both successful and unsuccessful educational practices and to benefit science education. However this will only be achieved if the rich databases created by TIMSS are successfully mined. Although TIMSS is the most recent international study, there have been other earlier international comparative studies. One of the problems encountered by educators (both practitioners and policy makers) wishing to use the results of these earlier studies was the significant time lag between when data were initially gathered and when research based on the data was eventually published. For example, data collection for the Second International Science Study occurred in 1983-84 (Keeves, 1992b) yet, according to Postlethwaite (1994), the three major publications resulting from this study (Keeves, 1992a; Rosier & Keeves, 1991; and Postlethwaite & Wiley, 1992) were not published until 1991 and 1992. Furthermore, the bulk of the scientific articles based on these data were not published until 1992 (see, for example, Banks & Rosier, 1992; Holbrook, 1992; Jacobson, Doran & Schneider, 1992; Leimu, 1992; Meng, 1992; Menis, Connelly, Crocker & Kass, 1992; Parent & Wood, 1992; Pelgrum & Plomp, 1992; Soydhurum, 1992; Tamir, 1992; Vari, 1992; Wolf, 1992). A similar time lag was experienced between the collection of data for the Second International Mathematics Study in 1980 and the publication of the subsequent significant reports between 1989 and 1993 (Postlethwaite, 1994). Obviously educational practice and policy are best served if practice and decision making are based upon prompt analysis of data and rapid dissemination of research results. Although this may not have been possible with other, earlier, large scale international studies, a feature of TIMSS is the rapid availability of the databases created by the study. The IEA have made the international database available. Furthermore each participating country has been given its own country specific database by the IEA and most countries, including Australia, have made this database available to those interested in mining this rich resource with the aim of improving science education. The international database is available from The International Study Centre[3] and country specific databases are generally available by contacting the appropriate NRC[4].

Another constraint which has placed limitations on the extent to which data resulting from earlier large scale comparative studies have been researched is the limited time and resources which the data gathering organisations are able to bring to bear on the research of their databases. The IEA have already produced a series of reports based on the TIMSS data (see, for example, TIMSS 1996, 1997c) and many individual countries have produced or are in the process of producing reports based on country specific performance (see, for example, Lokan, Ford & Greenwood (1996, 1997) which summarise some of the findings from Populations 1 and 2 within Australia). Yet practical space and resourcing limitations cause these reports to be largely in the nature of summaries of country performance. The answers to many important educational questions remain buried within the extensive databases. These answers will only be unearthed through the efforts of other science educators with an interest in establishing optimal educational practices for science education. Such educators should be encouraged to obtain copies of the databases from the IEA and/or their own country's NRC and pursue the plethora of research questions whose answers promise so many benefits to science education. Within Australia this seems especially valuable at a time when educational policy makers prepare to make significant changes to Australia's educational policy with regard to science; for example, as the nation moves closer towards adoption of a national curriculum (Fairbrother, Dillon & Gill, 1995).

Notes

1. In this regard the Australian Council for Educational Research fulfilled a dual role as both a major contributor to the international running of the study and also as the National Research Centre responsible for the nationwide study within Australia.
2. The precise number of participating schools and students varied from country to country. For example, Australia far exceeded the typical number of participating schools and students with 179 schools and 11,500 students from 542 classes participating in Population 1, and 180 schools and 14,000 students from 547 classes participating in Population 2 (Lokan, Ford & Greenwood, 1996; 1997).
3. Contact TIMSS International Study Centre, Campion Hall, Boston College, MA 02167, USA.
4. For example, for the Australian database contact ACER, Private Bag 55, Camberwell, Vic 3124, Australia.

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