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The Third International Mathematics and Science Study: Some Implications for New Zealand

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Abstract:

This article discusses issues associated with cross-national studies, and implications for New Zealand of a selection of findings arising from initial exploration of the TIMSS data. These findings indicate some factors identified by TIMSS as amenable to change, and likely to lead to improved teaching and learning in mathematics and science.

The Third International Mathematics and Science Study (TIMSS) is the latest in a series of international studies of educational achievement carried out under the aegis of the International Association for the Evaluation of Educational Achievement (IEA), an independent international cooperative of more than 50 research centres around the world. The main aim of these studies has been the conduct of comparative studies focusing on educational policies and practices in order to enhance learning within and across systems of education.

TIMSS

TIMSS is certainly the most ambitious IEA study to date. More than 50 countries were involved in at least one of the components of the study. Achievement in two subjects, and factors hypothesised to influence achievement in those subjects, are being investigated at three levels of the school system. Throughout the study, quality control and quality assurance measures were of necessity comprehensive and thorough (see Martin & Mullis, 1996). The three target populations were:

- Population 1: Students in the two grades (standards 2 and 3 in New Zealand) containing the majority of 9-year-olds at the time of testing;

- Population 2: Students in the two grades containing the majority of 13-year-olds (forms 2 and 3 in New Zealand) at the time of testing;
- Population 3: All students in their final year of schooling (form 7 students and prospective leavers from form 6 in New Zealand).

All populations 1 and 2 students in countries participating at these levels were taking mathematics and science, and the data gathered related to the broad mathematics and science curricula at those levels. For population 3 the main aim of the study was to obtain measures of mathematics and science literacy in the school leaver population, irrespective of whether students were still in mathematics or science courses. Second International Mathematics Study (SIMS) results had indicated that mean achievement of New Zealand seventh form mathematics students was on a par with that of countries with comparable educational systems at that time (Garden & Irving, 1987, p. 342), so with resources for TIMSS participation already stretched, a decision was made not to participate in the advanced mathematics and physics components of the study.

Culture and Comparison

One thing that soon becomes apparent to those carrying out cross-cultural studies is that the words "mathematics" and "science" do not necessarily mean the same thing to students in different systems. Students (and teachers) tend to relate to these words through their personal experiences in mathematics or science. As with all schooling, mathematics and science as taught and learned in different countries are influenced by the prevailing values, beliefs, and practices as they affect schooling in general, and school subjects in particular.

Occasionally the argument is advanced that international comparisons are therefore not sensible. This would be true if the only information collected was achievement data, and if that information was not interpreted in the light of information about factors known, or hypothesised, to enhance learning. A feature of IEA studies is the extent to which efforts are made to gather information about curricula, students, teachers, and schools, as well as social and economic contextual data with which to illuminate educational outcome data. "Large differences between performance in systems with comparable curricula exist ... and underscore the importance of taking into account the influence of socio-cultural factors which may affect students' and teachers' attitudes and behaviours in highly significant ways" (Robitaille & Garden, 1989, pp. 239-240).

As Stigler & Baranes (1988, p. 260) put it, in a general discussion of culture and mathematics learning:

> But if all mathematics learning is cultural, what is gained by comparing mathematics learning across particular cultures, rather than simply observing the role our own culture plays in learning? The answer is, a great deal.

Stigler & Baranes point out that, for example, widely shared aspects of culture within a society appear natural and universal to people in that society and thus tend to be hidden from their awareness.

For recent studies, an initial brief report designed to facilitate informed interpretation of achievement comparisons, with appropriate press releases, has been distributed. Nevertheless, the ranking list, with little qualification, still receives major attention. On the other hand, the ranking does provide motivation for policy makers to

> ... ponder if there is a discrepancy between what a country thinks its performance should be and what it actually is .... Often there seems to be a pride (is it a false pride?) that the educational system they know is and must be the best in the world. Thus any form of comparison is superfluous; or, seen from another angle, comparison could be dangerous because it could endanger our preconceptions of (or sense of security in) our own social, including educational, system. (Postlethwaite, 1987, pp. 150-152).

People close to educational research and policy making in New Zealand will be familiar with this phenomenon.

Conceptual Framework for TIMSS

From earlier IEA studies and other literature, particularly that on educational indicators, a conceptual framework for the study of school achievement had been emerging. This was based on three perceived levels of curriculum – the *intended* curriculum (i.e., what a society intended its students to be taught, as described in official curriculum guides and prescriptions); the *implemented* curriculum (the planned learning experiences students were actually exposed to, or what teachers actually taught); and the *attained* curriculum (what students learned and the attitudes they acquired as a result of exposure to the implemented curriculum). Variables known, or hypothesised, to affect student attitude and achievement outcomes of schooling were drawn from the general social, educational, and personal student contexts influential at each of these levels.

Curriculum Differences

One of the important foundations of TIMSS was a minute examination of the intended mathematics and science curricula of participating countries. This was based on detailed analysis of the content, performance expectations, and affective perspectives of each entry in curriculum statements, teaching guides, and typical textbooks in use in each country. Schmidt et al. (1997a, p. 16; 1997b, p. 16) point out that similarities in intended mathematics and science curricula exist in a context of differences between and within countries, and that "any cross-national comparison of mathematics curricula requires careful interpretation and contextualization."

Fortunately for those who construct achievement tests for international studies, implemented curricula exhibit less variation across countries than intended curricula appear to. In TIMSS, intended curricula at the population 2 level were found to show less variation across countries than did curricula at either the younger or the older population levels. In the Second International Mathematics Study (SIMS) substantial differences in mathematics curricula were evident in pre-university courses, but "At the population A (form 3) level, with the possible exception of the geometry strand, the situation is one characterised more by similarities among systems than by differences" (Robitaille & Garden, 1989, p. 235).

TIMSS tests were intended to measure achievement in mathematics and science that students at given grade levels had had the opportunity to learn at some stage during their schooling – that is, the content was not tied to particular grade levels (as was the case for the analysis of intended curricula). Although the curriculum framework was largely based on intended curricula, the tests reflected the implemented curricula. Given the sometimes considerable differences between intended and implemented curricula (Livingstone, 1986; Robitaille, 1997; Travers & Westbury, 1989, pp. 113-116), seeking explanations for student achievement in terms of statements in official curricula is not likely to be fruitful.

Following extensive item trialing and negotiation with national centres, the TIMSS tests were unanimously approved by National Research Coordinators (see Garden & Orpwood (1996) for a detailed account of test development for TIMSS). A "curriculum matching analysis" (Beaton et al. 1996a, Appendix B) revealed that national differences in mathematics and science intended curricula made little difference to mean scores of achievement as measured by the TIMSS tests, in spite of the fact that the tests covered a wide range of topics and expected behaviours.

TIMSS Tests

In an article suggesting ways of improving mathematics education in New Zealand, following the release of initial TIMSS results, Begg (1997, p. 23) included the following set of questions.

> There is also the question of what did the TIMSS project measure? Was it specific factual knowledge or low level procedures that can be tested with multiple-choice questions which our children are not used to? Was it mathematical thinking skills such as the ability to solve non-routine problems and to argue logically? Related to these questions we might ask "what does our curriculum emphasise?"

Biddulph et al. (1997, pp. 15-20) raised similar doubts in an article written for an audience of school principals. Detailed answers to the questions posed by Begg and by Biddulph et al. are available from an already extensive range of international and national TIMSS publications and from the Internet (at wwwcsteep.bc.edu). In fact TIMSS utilised a variety of item types in measuring achievement.

Test forms consisted of multiple-choice items and free-response (short answer and extended response) items. About two-thirds of the overall test time was allowed for multiple-choice items and one-third for free-response items. Multiple-choice items allow valid, reliable, and economical measurement of a wide range of mathematics and science content and performance expectations (i.e., the kinds of performance students will be expected to demonstrate while engaged with the content) in a relatively short testing time. Few New Zealand students would not have encountered this type of item. Free-response items allow students to demonstrate behaviours such as developing an argument, and explaining phenomena. Items that could be classed as non-routine were included in both the free-response items and the multiple-choice items, but these were few in number because item trialing revealed that very few students in any country, including New Zealand, were able to deal with items of this sort.

It is sometimes claimed that the multiple-choice item-type favours boys, and that free-response item format favours girls. For example, in Ireland, Bolger and Kellaghan (1990) reported that female students produced significantly higher mean scores than males on tests of English, Irish, and mathematics for the free-response format compared

with the multiple-choice format. But on the TIMSS tests neither item type favoured either sex over the other for New Zealand students.

A sub-sample of students (613 standard 3 and 824 form 3 students in New Zealand) took part in a performance assessment component of TIMSS. In this exercise, students were administered hands-on tasks requiring them to demonstrate several behaviours, including problem-solving and communication skills. Preliminary results for this component of the study are reported in Harmon et al. (1997) and Garden (1997).

Intended Curricula

Relative to comparable (especially English-speaking) countries the mean performance of standard 3 students in mathematics and science was low, the mean performance of form 3 students was about average, and the mean measure of mathematics and science literacy of school leavers (from forms 5 and 6) was above average. There are two factors which probably account for the improvement (relative to other countries) with class level. First, as noted in Werry (1987, p. 101) secondary school mathematics teachers, especially those who teach at senior levels, are generally well-qualified to teach at the appropriate level. The same is true for the sciences. The second reason for the trend to better performance with age, relative to that of other countries, lies in the high proportion of New Zealand students who take mathematics and science to at least a fifth form level. In many countries a much higher proportion of students choose to drop mathematics and/or science early in their secondary school careers.

Disappointment with the results achieved through the intended mathematics and science curricula of the 1960s and 1970s led, in the early 1980s, to the advocacy of "problem-solving" as a central pillar for the teaching of mathematics. Official curricula in many countries, including New Zealand, now reflect this trend (Robitaille, 1997). Both mathematics and science curricula around the world advise teachers to "contextualise" the problems to be solved in the "real world" and, partly as a result of the influence of constructivist views of learning, to incorporate the prior experiences of the learners.

In some quarters there is confidence that new official curricula in mathematics and science which were being introduced into New Zealand schools at the time TIMSS data were collected will lead to improved achievement. Elements of these, as well as the former intended curricula, were included in the TIMSS curriculum analysis.

Only minor changes had been made to the subject matter to be taught, but the new curricula were described by their developers as "outcomes-based", and guides to teaching and assessment approaches were included. They were restructured to "give special emphasis to continuity and progression in learning" (O'Rourke, 1992).

The new mathematics and science curriculum statements have sound aims, and have received favourable comment from teachers. However, implementation of them in the manner which is intended demands considerable expertise in subject matter, pedagogy, and assessment. As Howson (1994, p. 33) commented in reviewing the mathematics curriculum guide:

> I can think of no other country in which such demands are made of teachers and I have great doubts then about the ability of even well-intentioned and well-prepared teachers to meet the goals which are set of them in this document.

TIMSS curriculum analysis revealed that, for both the former and the new curricula in mathematics and science, New Zealand teachers were expected to cover more topics each year than were teachers in most other countries. In the former curricula, teaching of the topics tended to be spread over a greater number of years than was common in other countries. It is likely that teaching fewer topics each year, but teaching them to greater depth would be more effective.

Given the current state of mathematics and science teaching at lower class levels in New Zealand, promotion of problem-solving as a prime vehicle for improved achievement causes some misgivings.

> If we cannot address the problems that stem from the diversity of students' mathematical experience, students' limited capacity to express their ideas, and teachers' limited capacity to respond, we should not delude ourselves that school mathematics can be organized by students problematizing the subject. (Smith, 1997, p. 23)

Holton et al. (1996, p. vi), in a study of the benefits of problem solving in the learning of mathematics, state that:

> It seems to be the case that problem solving does not come easily to students. Considerable time needs to be spent enabling them to incorporate various strategies into their "automatic responses". During the time that they are learning these strategies, it is essential that the mathematical content of the problems that they are tackling is content that they have fully mastered. Otherwise their lack of fluency in the content area of the problem will stymie their efforts to problem-solve.

This is especially so if teachers are not well-equipped, in terms of personal experience or resources, to teach the subject.

Teaching Quality

Young-Loveridge (1993, p. 78) interviewed teachers as part of a study investigating the effectiveness of two kinds of intervention procedures designed to improve the number skills of five-year-olds. She reported that "... somewhat disturbing was the number of teachers who admitted feeling quite negative about their own mathematics, and sometimes also about their teaching of mathematics to their young pupils." The importance of teacher knowledge of mathematics in order to ensure that children in the junior school receive the opportunity to learn mathematics as intended, through the procedures and activities described in the official curriculum, is highlighted by Higgins (1994, pp. 118-120).

Lack of confidence in teaching mathematics and, especially, science probably accounts for considerable variation in the time devoted to teaching these subjects by some primary school teachers who responded to TIMSS questionnaires. This was especially true in science, with little or no time devoted to the subject in some standards 2 and 3 classrooms.

One of the reasons New Zealand students have performed well in tests of reading skills relative to their counterparts in other countries, but much less satisfactorily in mathematics and science, is likely to have a great deal to do with the amounts of time devoted to teaching the subjects. "Internationally, New Zealand standard 3 teachers allocated more instructional time to both language/English (11.94 hours) and reading (5.11 hours) [per week] than all countries (mean number of hours 7.60 and 3.27, respectively)" (Wagemaker, 1993, p. 101). Comparative times for mathematics and science instruction as revealed by TIMSS were 3.53 hours and 1.36 respectively. Mean classroom time for mathematics at this level in New Zealand was about average for TIMSS countries (although less than that in other English speaking countries), but time for science was well below average, less than half that in ten other countries (Chamberlain, 1997, p. 192).

It is also more than possible that, in the past, the very process of selection for colleges of education has favoured applicants whose interests and accomplishments have been in the arts (including the performing arts), over those applicants for whom the sciences have been the major interest.

> Teaching is a caring profession and teachers' selection has often been influenced by applicants' interest in social aspects of life and on communication skills rather than by academic concerns and success in subjects such as mathematics or science. Pre-service education in the past has reinforced this by devoting much more time to the teaching and learning of reading and writing than it has to subjects such as mathematics.
> (Begg, 1997, p. 24).

Teaching Resources

Indications from TIMSS of a need for teaching resources followed similar conclusions from earlier research into implementation of the mathematics and science curricula. "The availability, review and development of resources to implement the new curricula are key concerns of teachers" (Gilmore, 1994, p. 133). In a needs assessment study to identify problems and their solutions in the implementation of the new mathematics curriculum, Knight & Meyer (1996, p. 38) had as their first recommendation, "That immediate provision be made to schools of finance to purchase currently available teaching resources." The second recommendation called for a range of nationally produced resources to be made available "as soon as possible".

It is also clear from TIMSS data that there is a need for teacher education and resources in the field of educational measurement. Many teachers, especially at form 2 level, appear to be over-dependent on notably unreliable bases for assessment. This can only lead to lack of accurate feedback to teachers about the effectiveness of their teaching programmes, and to the student misperceptions about their learning which were also evident in the TIMSS data. Assessment suggestions in the new curriculum statements in mathematics and science tend to emphasise novel methods which, in some cases, are difficult to implement in the classroom, and should form only part of the arsenal of methods teachers should draw from in selecting the right measurement tool for given assessment situations.

New Zealand primary school teachers are considerably less likely than teachers in other countries to make use of textbooks in teaching mathematics or science, and detailed teacher guides to assist teachers to

implement the new curricula as intended are not provided. At the same time, large numbers of teachers lack confidence in teaching mathematics, and even more lack confidence in teaching science. In TIMSS, higher student achievement tended to be associated with higher qualifications; and with more time spent on planning, professional development, and professional reading. Many teachers reported spending little time engaged in the latter two activities, perhaps because of lack of access to them.

Resources which interpret the general intentions of the new curricula, as thus far produced, have had limited success (see Kerslake & Murrow, 1996), although they are better than nothing. Many teachers want, and need, very specific topic-by-topic advice about teaching the subject. There has been a tendency, in centrally-produced teacher materials, for the science and mathematics competence of a great number of (especially) primary teachers to be seriously overestimated, and thus for the resources to miss their intended target group.

Organisational Issues

Organisation of schooling and length of compulsory schooling varied considerably between TIMSS countries. Robitaille (1997) presents details of the education systems of participating countries, and of curricula and current issues in mathematics and science education for each country. One aspect of organisation in which New Zealand differed from other countries was in the arrangements for school entry. At age nine years, New Zealand children have had at least one more year of schooling, and in some cases two years more schooling, than children of nearly all other participating countries. In spite of this their mean achievement in mathematics and science was below average, prompting questions about what opportunities they have had to learn in these subjects.

There are many possible reasons why one school, or school type, might be considered superior to another. Schools do vary in effectiveness, as illustrated by results of a study at secondary level "... at least 5 percent of total variance in Maths, 5.5 percent for Science, and 9 percent for English, is systematically related to the characteristics of schools as against the inter-individual variability within the population sampled" (Harker & Nash, 1996, p. 167). But when characteristics of their intakes are taken into account, this effectiveness varies within school-type a great deal more than between school-type. So far as achievement, when measured by the TIMSS tests, is concerned, no significant difference in mean scores was found between students in New Zealand rural schools and those in urban schools.

Forbes et al. (1990, p. 156) reported in a study of form 3 mathematics achievement conducted in a representative sample of schools in the Central region of New Zealand, that "There is no particular evidence in this study to support the view that females taking mathematics are better to do so in single sex schools, at least in terms of their later performance in first year university mathematics."

For form 3, differences in mean TIMSS scores between students in single sex and students in coeducational schools (favouring students in single sex schools) were accompanied by matching differences in mean measures of socio-economic status. No advantage for mathematics or science achievement in either single-sex schools or coeducational schools to either girls or boys was evident from the data. This result supports a similar finding by Harker & Nash (1997, p. 5). These results contradict a commonly held belief, but LePore and Warren (1997, pp. 485-511) discuss apparent short-comings of earlier (USA) studies which purported to show an academic advantage for girls in single-sex schooling.

Composite classes are much more common in New Zealand than in other countries. Veenman (1995, p. 319), from a "best-evidence synthesis" of mostly United States studies, covering cognitive and non-cognitive outcomes of schooling, concluded that "there is no empirical evidence for the assumption that student learning may suffer in multigrade and multi-age classrooms." However, Mason & Burns (1996, p. 307) in a critique of Veenman's finding, argued that Veenman had ignored two key factors, and concluded that "... multi-grade classes have at least a small negative effect on achievement."

Both Veenman, and Mason & Burns, call for further research in this area. Given the high proportion of students being taught in composite classes in New Zealand, there is certainly a case for New Zealand research in this area. In smaller schools composite classes are unavoidable, but where schools are sufficiently large so that there is a choice, New Zealand school managers should have access to information about whether the conditions applying in their schools favour composite or single grade classes.

School climate was not measured directly in TIMSS, but indicators in this domain included students' responses as to whether or not they had encountered various "occurrences" at school. These revealed that New Zealand students were among the most likely of all of those in

participating countries to be bullied, or to be stolen from. These data supported Lind & Maxwell (1996, pp. 10-12), who also reported high levels of bullying. The fact that principals indicated that little time was spent dealing with bullying and theft may indicate that much of this behaviour goes unreported to teachers. School milieus in which bullying and theft are common occurrences are likely to be associated with student underachievement in all academic areas, but even if this were not the case, there are problems here that clearly need confronting.

Conclusion

This article has touched on only a handful of the variables examined in TIMSS, but among these few are some "malleable" variables that are both highly influential in ensuring that students are given the maximum possible opportunity to achieve in mathematics and science, and variables in which changes can be made. For students to have maximum opportunity, their teachers must at least know the subject matter, be competent in the associated pedagogical skills, and have access to the necessary resource materials for students and for teacher guidance. The curricula they experience must be appropriate to their abilities, and to that of their teachers, and they must feel secure in their school environment.

As this is being written, a number of plans with the potential to effect improvements are being considered. The Minister of Education has announced that recommendations of a Task Force set up to address problems in the teaching of mathematics and science identified by TIMSS would be acted on. This is satisfying for those Ministry researchers, principals, and teachers who participated in the study, and for the members of the Advisory Committee who advised on its administration in New Zealand. It is particularly pleasing that the recommendations cover a reasonably broad front.

> ... complex enterprises generate complex problems requiring equally complex solutions. Schooling is such an enterprise. Therefore solutions to problems of schooling must, inevitably, be complex .... The longing for simplicity in the face of essential complexity is likely to produce deceptive explanations that lead to ineffective solutions. (McKnight et al., 1987, p. 5)

Nevertheless, several more issues raised by the data remain to be considered. It will be important that those developing policies and resources work with the researchers so that the TIMSS data are accurately interpreted and understood. The necessarily skeletal nature of reports may otherwise result in initiatives being shaped by the preconceptions of the developers, rather than by the findings from TIMSS and other relevant research. Policy makers, and mathematics and science educators, have to demonstrate the will to test their beliefs open-mindedly against evidence provided by TIMSS (and other substantial research). Where the evidence conflicts with whatever beliefs are current and popular in education, they need to have the courage to challenge these beliefs.

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