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International perspectives on numeracy learning: PISA and TIMSS

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Jan Lokan is Deputy Head of Measurement at the Australian Council for Educational Research (ACER) in Melbourne. Her undergraduate degree and teacher training were in pure mathematics and she has taught mathematics at both upper secondary and undergraduate levels in Australia, England and Canada. While in Canada she completed a PhD in Educational Measurement at the University of Ottawa. Jan left the classroom to take up a career in educational research, first with the Ottawa Board of Education in Canada and later with ACER. She began her research life developing mathematics assessment materials for the Ontario Ministry of Education and for research projects in Ontario schools. Since joining ACER Jan has undertaken program evaluation studies, test and questionnaire development, and has managed several large-scale surveys and assessment projects. Recent ACER projects she has directed include a major survey of the implementation of curriculum statements and profiles in Australian schools and the Australian component of the Third International Mathematics and Science Study (TIMSS). She was a member of the Expert Group for the recently-developed Australian numeracy benchmarks. Currently Jan is directing the TIMSS-Repeat Video Study of mathematics and science teaching in Australian schools and the national component of the OECD Programme for International Student Assessment (PISA).

This paper examines implications for numeracy education in Australia arising from three international studies.

Although I cannot report any results as yet, I will describe the most recent study first, given that it has aimed to measure aspects of mathematics that would probably come closest to the collective understanding of 'numeracy' held by the people at this conference. I am assuming that this collective understanding will reflect various initiatives to define 'numeracy' in Australia over the past decade or so, particularly the 1997 conference which produced the definition that 'to be numerate is to use mathematics effectively to meet the general demands of life at home, in paid work, and for participation in community and civic life' (AAMT 1997). The study is the Programme for International Student Assessment (PISA), a new international survey of student learning outcomes in three key learning domains, one of them mathematics.

Programme for International Student Assessment (PISA)

PISA is a project of the Organisation for Economic Cooperation and Development (OECD) in Paris. A consortium led by the Australian Council for Educational Research (ACER) won the contract for developing and implementing this project internationally, and, in addition, ACER was also successful in its bid to run the national component. Testing for PISA in Australia took place very recently, from mid July to the end of August 2000, and involved over 6000 students from more than 230 schools. The sample, which came from all states, territories and education sectors, was selected to be nationally representative. The students selected in all countries were aged between 15 years, three months and 16 years, two months. Altogether, students from 31 countries

have participated in the inaugural PISA testing, being all but one of the OECD member countries plus Brazil, Latvia and Russia. Several more countries are likely to do the survey in an extension of PISA next year.

Each student participating in PISA does a two-hour test, containing a mixture of reading, mathematics and science questions, plus a questionnaire to collect information about their background, educational experiences and attitudes. All test and questionnaire items are standard for all countries, with much effort invested in ensuring uniformity of translation and cultural fairness. Countries may add additional material to either the test or the questionnaire as national options if they wish. The year 2000 assessment is the first cycle, with testing planned to occur every three years. Each of the three key areas is the major area once and a minor area twice over the nine-year span. Mathematics will be the major area in 2003.

PISA's definition of 'mathematics'

PISA's definition of mathematics has arisen directly from the framework constructed in the first year of the project (1998) to guide the development of the tests. The framework covers all three domains and was developed by world leaders in the assessment of reading, mathematics and science. One of PISA's main goals is to find out how well prepared the students are for their lives beyond school; the assessment framework therefore has a forward-looking orientation towards life skills rather than a retrospective view at students' curriculum knowledge. In keeping with this focus for PISA, the three domains are referred to as 'reading literacy', 'mathematical literacy' and 'scientific literacy'. PISA is fortunate to have Professor Jan de Lange, of the Freudenthal Institute at the University of Utrecht, as chair of its mathematics expert group.

'Mathematical literacy' is defined as: the capacity to identify, to understand and to engage in mathematics and make well-founded judgements about the role that mathematics plays, as needed for an individual's current and future life as a constructive, concerned and reflective citizen.

In keeping with this orientation, the assessment is broad, focusing on 'students' capacities to analyse, reason and communicate ideas effectively by posing, formulating and solving mathematical problems in a variety of situations' (de Lange 1999, p. 41).

The PISA assessment tasks have three main aspects: content, processes and the situations in which mathematics is used. *Content* is defined in broad concepts underlying mathematical thinking, for example 'change and growth', 'space and shape', 'uncertainty' and 'dependency relationships'. These broad concepts allow wide coverage of more familiar areas such as number, estimation, probability, functions, and so on. *Processes* are embodied in mathematical competencies such as:

- mathematical thinking;
- mathematical argumentation;
- mathematical modelling;
- problem posing and solving;
- representation;
- manipulation of symbols;
- understanding and correct use of terminology;
- knowing about and appropriate use of aids and tools; and
- communication.

These competencies can be grouped into three classes:

- Class 1 – reproduction, definitions and computations;
- Class 2 – connections and integration for problem solving;
- Class 3 – mathematisation, mathematical thinking, generalisation and insight.

An important aspect of mathematical literacy in PISA is use of mathematics in a variety of *situations*, from personal life and school life to sports, work and the broader community.

Some sample items will be shown to illustrate their innovative nature, broadness of coverage and range of skills required to answer them successfully.

PISA and numeracy

A book that is a decade old now, but still very relevant to discussions of numeracy education, presents the following points (among others) about numeracy skills:

An appropriate curriculum to develop numeracy in all students would focus on developing: the attitude

that mathematics is relevant to me personally and to my community; the learning skills (listening, reading, talking and writing) and fundamental mathematical concepts needed to access personally new mathematical ideas; and the confidence and competence to make sense of mathematical and scientific arguments in decision-making situations (Willis 1990, p. 22);

and

In order for a mathematics curriculum to build real numeracy, it needs to develop:

- the ability to make sensible choices about which method to use;
- the ability to recognize major problem types and how to deal with them efficiently;
- confidence in one's ability to carry out the procedure properly; and
- sufficient general problem-solving skills so that students can get the problem into a state where their algorithmic and procedural knowledge is of some use. (Stacey 1990, p. 76).

In its overall aims, variety of applied situations for tasks and innovative problems posed, PISA has readily recognised overlap with many of the aspects of numeracy listed here.

Third International Mathematics and Science Study (TIMSS)

Another recent international survey was the Third International Mathematics and Science Study (TIMSS), more conventional than PISA in its coverage but nevertheless able to offer useful insights into Australian students' numeracy skills in relation to those of students from many other countries.

TIMSS was different from PISA in that it attempted to identify curriculum areas and topics that were common across many countries, and to assess knowledge and skills in those areas. Thus the TIMSS mathematics items reflected traditional strands such as Number, Geometry, Algebra, Data representation and analysis etc, and featured processes such as recall of basic knowledge, routine operations, complex operations and problem solving/investigating.

The TIMSS testing was carried out in 1994–95 at three schooling levels: mid-primary (Years 3 to 5); lower secondary (Years 7 to 9) and upper secondary (Year 12). Our students in the national random samples selected for TIMSS acquitted themselves relatively well. At mid-primary level, Australia outperformed half of the countries and fewer than a quarter outperformed us. At lower secondary level, we outperformed almost half of the countries and only a fifth achieved better results than we did. At upper secondary, in the specialist advanced mathematics and physics tests, Australia was

among the highest achieving countries, though we did less well in the more general TIMSS mathematics and science literacy tests. Of some concern to our federal education minister was that the countries outperforming us at primary and lower secondary levels included our Asian trading partners of Singapore, Japan, Korea and Hong Kong (these countries did not participate in the Year 12 testing).

Analysis of the Australian TIMSS results within strands and processes have enabled us to see where our strengths and weaknesses lie in an international context. For example, at mid-primary level our students achieved relatively best in geometry and in measurement, estimation and number sense, but relatively weakest in understanding and use of whole numbers. At lower secondary level they performed relatively best in algebra and data representation/analysis/probability, and relatively weakest in geometry and fractions and number sense.

The reversal of the latter two areas between mid-primary level and lower secondary level provides food for thought. For both areas, the change may reflect differing curriculum emphasis. This certainly seems likely for geometry, which receives a lot of emphasis at primary level in the Space strand of our curricula. For number sense the situation seems less clear. Among the fractions items are some requiring conceptual understanding, others requiring manipulation, and still others requiring a combination of these aspects. In the main, our students showed reasonable levels of conceptual understanding of fractions, but very poor ability to manipulate even straightforward fractions. (Those who support use of calculators may think that this is not something to be concerned about, but I throw my hat into the ring to say that easy computations, such as dividing 14 by 2, should be able to be done by 13-year-olds without the aid of a calculator.)

TIMSS and Australia's numeracy benchmarks

Further analyses were undertaken to see if there were mathematics questions in TIMSS that constituted good or reasonable matches to Australia's numeracy benchmark statements for Years 3, 5 and 7. Many of these were identified, and useful information derived about Australian and other countries' achievement on them. Illustrative examples will be shown as part of the conference presentation.

Repeat of TIMSS (TIMSS-R)

A repeat of TIMSS, using questions that had been kept secure from the first study together with some new material, was carried out in 1998–99, but only at lower secondary level. Results from that testing are due for

release in December this year. I have mentioned TIMSS-R because I now want to describe the exciting video study that Australia is taking part in as an extension of TIMSS-R.

An objective of TIMSS is to identify classroom practices that enhance mathematics and science learning, which has been attempted mostly through having the TIMSS students' teachers complete specially developed questionnaires. But the TIMSS researchers knew that written questionnaires for this purpose are a poor substitute for watching what teachers do, and so some of them set up a pilot study in the USA, Japan and Germany in which many mathematics classrooms were videotaped. Analyses of the tapes revealed significant, and in some cases, striking, differences in teaching styles across these three countries (Stigler & Hiebert 1997).

Encouraged by the pilot study results, the researchers, led by Professor Jim Stigler from UCLA, set up a study in science as well as mathematics teaching in a wider group of countries. Australia was fortunate to receive some financial support from the US National Center for Education Statistics (NCES), supplemented by funds from the Commonwealth, State and Territory Governments, to enable us to be a participant in this extension of TIMSS-R.

The video study

So far, the video study in Australia has involved selecting a national random sample of 100 secondary schools, and then selecting a Year 8 mathematics teacher at random from all such teachers in the school to have a lesson filmed at an unannounced time. A daunting prospect for teachers, I would say, and we did have some schools pull out of the study for this reason (in most circumstances it was not permitted to substitute an alternative teacher). In those cases we approached schools that had been selected as replacement schools when the sampling was done.

There were standard videotaping procedures for the study, and specially trained videographers were sent to schools all around the country to film the selected lessons. The filming was intentionally spread over several months, to get away from any lock-step teaching of similar content at similar times of the year (not a problem in Australia, but a problem in Japan, for example). Altogether in Australia 88 randomly-selected mathematics classes were filmed, and also 88 science classes occurring on the same or the next day in the same schools as the mathematics classes. The teachers whose lessons were filmed each completed a questionnaire about the goals of the lesson and where it fitted in a teaching sequence, and the students in the filmed classes completed a short questionnaire and a mathematics or science test. The data collection was completed in June 2000.

Processing the video study data

How does one go about studying teaching practices from videotaped lessons? This is a very complex undertaking, as anyone who is or has been a teacher will realise. A basic unit of time needs to be decided, beginning and ending of lessons need to be specified, transitions between activities need to be recognised and documented, and the activities themselves have to be described. A coding scheme has to be devised that can capture all of these things (and much more), and has to be specified precisely enough that people coding the lessons can do so in a highly reliable way. Some extracts of the coding scheme developed for the TIMSS-R video study will be included in the presentation, and will be illustrated by short lesson excerpts where the teaching appears likely to enhance students' numeracy development (provided that the teachers grant permission for these to be shown).

Conclusion

In the short time available, a presentation such as this can only skim the surface of some examples of large-scale studies that have already provided useful information about Australian students' numeracy learning. The potential of the PISA survey is greater than that of the TIMSS projects because of the closer match of PISA's framework and assessment tasks to Australian conceptions of what constitutes 'numeracy'. The TIMSS-R video study offers the additional potential of being able to identify teaching practices that seem more likely than others to enhance students' numeracy learning.

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