Factors Affecting Mathematics Achievement in Primary and Secondary schools: Results from TIMSS

Sue Fullarton
Australian Council for Educational Research
<fullarton@acer.edu.au>

Stephen Lamb
Australian Council for Educational Research
<lamb@acer.edu.au>

A previous paper has shown that in the Third International Mathematics and Science Study (TIMSS) teacher effects contribute little to student achievement in mathematics, but that classroom differences are important. The present study used data from TIMSS to examine classroom and school differences in maths achievement at secondary school level to find out which classroom and school variables affect achievement. It found that the pooling of student resources associated with grouping has a large effect on mathematics achievement at primary level, while at secondary level policies regarding pupil management such as grouping according to ability have the greatest effect on mathematics achievement.

Introduction

The Third International Mathematics and Science Study (TIMSS) provides a rich data set for investigating the effects of student, classroom, and school-level variables on student achievement in mathematics. A previous paper (Lamb & Fullarton, 2000) has shown that while student background variables are important for achievement in mathematics, classroom and school variables also contribute substantially.

Schools don't Matter ... or do they?

The early literature on school effectiveness placed an emphasis on the ability and social backgrounds of students in identifying the factors that shape academic performance, and suggested that schools had little direct effect on student achievement. Coleman, Campbell, Hobson, Portland, Mood, Weinfeld & York (1966), for example, in a major study of US schools seemed to cast doubt on the possibility of improving school achievement through reforms to schools. They found that differences in school achievement reflected variations in family background, and the family backgrounds of student peers, concluding that "schools bring little influence to bear on a child's achievement that is independent of his background and general social context" (Coleman et al., 1966, p.325). A later analysis of the same data set by Jencks and his colleagues reached the same conclusion, "our research suggests ... that the character of a school's output depends largely on a single input, namely the characteristics of the entering children. Everything else—the school budget, its policies, the characteristics of the teachers—is either secondary or completely irrelevant" (Jencks, Smith, Acland, Bane, Cohen, Gintis, Heyns, & Michelson, 1972, p. 256). However, the methodology employed in this early work did not take account of the hierarchical nature of the data, and was not able to separate out school, student and classroom factors. The importance of recognising this structure was noted by Raudenbush & Willms (1991):

> An irony in the history of quantitative studies of schooling has been the failure of researchers' analytic models to reflect adequately the social organisation of life in classrooms and schools. The experiences that children share within school settings and the effects of these experiences on their development might be seen as the basic material of educational research; yet until recently, few studies have explicitly taken into account of the effects of particular classrooms and schools in which students and teachers share membership. (p. xi).

More recent school effectiveness research has used multi-level modelling techniques to account for the clustering effects of different types of data. The results of such studies show, according to the meta-analysis of school effectiveness research undertaken by Bosker &

Witziers (1996), that school effects account for approximately eight to ten per cent of the variation in student achievement, and that the effects are greater for mathematics than for language. It has also been found that classrooms as well as schools are important and that teacher and classroom variables account for more variance than school variables (Scheerens, 1993; Scheerens, Vermeulen, & Pelgrum, 1989). But several studies also show that there are substantial variations between schools (Mortimore, Sammons, Stoll, Lewis, & Ecob, 1988; Nuttall, Goldstein, Prosser, & Rasbash, 1989; Smith & Tomlinson, 1989; Lamb, 1997) .

Other studies have shown that contextual variables such as student body composition and organisational policies play an important role in mathematics achievement. Teacher background attributes such as gender, number of years teaching and educational qualifications have been shown to be important factors in student achievement (Anderson, Ryan, & Shapiro, 1989; Larkin & Keeves, 1984), as have a variety of school effects such as school size (Lee & Smith, 1997) and mean student social composition.

These studies suggest that classrooms and schools matter, as well as student background. A range of studies has examined different effects, however few have been able to utilise the range of contextual variables available in the TIMSS data set. This paper uses the TIMSS data to investigate the interrelationships among different factors at the student, classroom and school levels.

Variables Explored

The main aim of this analysis of the TIMSS data was to explore the relationships between student achievement in mathematics and factors at the student, classroom and school levels for both the primary and secondary school populations. Table 1 provides details of the variables that were used in the analysis.

Student Background Variables

The sex of each student was recorded, as well as the number of people living in the student's household and the number of books in the home. This latter measure is an indication of the cultural background of the student. A variable representing socioeconomic status (SES) was computed as a weighted composite comprising the higher of mother's or father's occupational status, the higher of mother's and father's level of education (secondary students only), and the number of possessions in the home[1]. Ethnicity was measured as a weighted composite variable based on student's birthplace, the birthplaces of their parents and the primary language spoken at home.

Student Mediating Variables

Students completed a word knowledge test (Thorndike, 1973) as a measure of their prior verbal ability. This test presents the student with a number of word pairs and requires the student to decide whether the words in each pair are (near) synonyms or (near) antonyms. The test was used in both the First and Second International Science Studies, and the importance of language skills has been shown to be important for achievement in mathematics. A composite variable was derived to represent the student's enjoyment of mathematics. This variable consisted of positive responses to five attitude prompts; 'I usually do well in mathematics', 'I like mathematics', 'I enjoy learning mathematics', 'Mathematics is boring', and 'Mathematics is an easy subject'. A further variable was computed for secondary students only to represent student's perceptions of the importance of mathematics. This variable was

[1] Number of possessions was measured by asking students which of the following possessions were in their homes: calculator, computer, dictionary, separate desk/table for study, personal bookshelves and books, separate wardrobe, dishwasher, cd or video player in their own room.

comprised of responses to the items 'Mathematics is important to everyone's life', 'I would like a job involving mathematics', 'I need to do well in mathematics to get the job I want', 'I need to do well in mathematics to please my parent(s)', 'I need to do well in mathematics to get into the university/post-school course I prefer', and 'I need to do well in mathematics to please myself'. These items were not given to primary students.

Classroom and Grade-level Variables

A number of classroom variables were collected or derived for this analysis. This included the student's year level and the stream or level of the class if setting was a practice used in the school to organise mathematics classes. Mean word knowledge scores and socioeconomic status were derived at the class level. Teacher background attributes—gender, age, number of years teaching and educational qualifications—were also controlled for. Scales representing teacher attitudes and beliefs about mathematics and teaching were developed using factor analysis. These scales are described in greater detail in a forthcoming TIMSS publication, and are summarised in Table 1. There were 6 subscales derived for primary teachers and five for secondary teachers.

Table 1
Student, Classroom and School Variables

	Population 1	Population 2
STUDENT LEVEL		
Student background variables:		
Sex	Student's gender	Student's gender
Books	Number of books in student's home	Number of books in student's home
Family size	Number of people living in student's home	Number of people living in student's home
Ethnicity	A composite of student's birthplace, birthplace of parents and language spoken at home	A composite of student's birthplace, birthplace of parents and language spoken at home
Socioeconomic status	A composite variable representing family wealth	A composite variable representing family wealth
Student mediating variables:		
Word knowledge	Verbal ability as measured by the word knowledge test	Verbal ability as measured by the word knowledge test
Attitude to mathematics	A composite variable reflecting the student's attitude towards mathematics.	A composite variable reflecting the student's attitude towards mathematics.
Importance of maths		A composite variable reflecting the perceived importance of mathematics to the student.
CLASSROOM LEVEL		
Grade-level and classroom composition variables:		
Year level	Grade or year level of class	Grade or year level of class
Mean word knowledge	Average score on Word Knowledge test for the class	Average score on Word Knowledge test for the class
Mean SES	Average SES for the class	Average SES for the class
High band		Whether student is in one of the two the top streams in mathematics
No band		Whether classroom is non-set or non-streamed
Classroom teacher variables:		
Age	Teacher's age	
Gender	Teacher's gender	Teacher's gender
Education. qualifications	Teacher's qualifications	Teacher's qualifications
Years teaching		Number of years teaching

	Population 1	Population 2
Classroom teacher variables:		
Factor 1	Problem-solving approach to teaching	Problem-solving approach to teaching
Factor 2	Discipline oriented approach to teaching	Discipline oriented approach to teaching
Factor 3	Process oriented approach to teaching	Process oriented approach to teaching
Factor 4	Eclectic approach to teaching	Eclectic approach to teaching
Factor 5	Algorithmic approach to teaching	Teacher satisfaction with job
Factor 6	Teacher satisfaction with job	
SCHOOL LEVEL		
School variables		
School size		Number of students in the school
Policy to stream		Whether the school has an explicit streaming policy
Mean SES	Average SES for the school	Average SES for the school

School Level Variables

Mean socioeconomic status scores were derived for each school to provide a control for the social composition of the school. For secondary schools only, a measure of the school size was used ranging from schools of less than 250 students through to schools of more than 1250 students. Explicit school policy to stream in mathematics was also included in the analysis.

Method

Hierarchical linear modelling (HLM) was used to look at the interrelationships between factors at the student, classroom and school levels. This procedure allows modelling of outcomes at several levels (e.g. student level, classroom level, school level), partitioning separately the variance and effects at each level while controlling for the variance across levels. To examine the effects of different variables on mathematics achievement, several models were tested each adding successively a new group or layer of variables. The first model included the group of student background variables comprising sex, socioeconomic status, family size, ethnicity and number of books in the home. The second model added a set of mediating variables to the set of student background factors. The mediating variables included results on a standardised word-knowledge test, and attitudes towards maths. The third model contained grade- or year-level and the set of classroom composition variables relating to mean word-knowledge score, and mean socioeconomic status (SES). The next model added the set of teacher variables including the sex of the teacher, age, qualifications, years of teaching, and scores on the scales related to teachers' attitudes and practices in mathematics teaching. The final model added the school-level variables.

Results

Table 2 presents the results for Population 1 (primary school students) and Table 3 presents the results for Population 2 (secondary school students). In the model which included student background variables, shown in the second column of Table 2 and the second column of Table 3, it can be seen that all of the variables, other than ethnicity, had a significant effect on achievement in mathematics for both primary and secondary students. Gender had a significant negative effect on mathematics achievement. That is, girls achievement levels were still not equal to that of boys, at either primary or secondary level. Also, consistent with previous studies, students from a higher SES background, those with more family cultural resources (as measured by books at home), and those from smaller families tended to have higher achievement levels in mathematics.

The student-level mediating variables—word knowledge, attitudes towards maths, perceived importance of mathematics—had strong independent effects. They were influential predictors of maths achievement. But they not only had independent effects, they also transmitted or relayed the effects of the different student background variables. This is evident from the marked drop in the sizes of the estimates for SES, books in the home and family size when the mediating variables were included in the model. It should be noted that the values for the variable *perceived importance of mathematics* for secondary students are bracketed in Table 3. The model did not include this variable because of collinearity problems with the variable, *positive attitudes towards mathematics*. When both were included, the effect was to make the estimate for importance negative. The bracketed estimates for the importance of maths measure were derived running the same model but excluding the measure for attitudes towards maths.

In summary, gender, number of books in the home, and socioeconomic status had both a direct effect on achievement and a transmitted effect through their influence on word knowledge and attitudes towards mathematics. These findings reinforce earlier studies showing that student background has an effect, both directly and indirectly, on student achievement in mathematics.

Our previous paper has shown that, as well as student-level factors, classrooms and schools also matter (Lamb & Fullarton, 2000). The next stages of the modelling investigated the effects of classroom variables on achievement. As classroom organisation is different at the primary and secondary school levels, these will be discussed separately.

Primary Students: Male Teachers Make a Difference

With the primary school population, several variables at the classroom level exerted strong effects. Year-level had a large influence on achievement. Achievement in Grade 5 classes was higher than achievement in grade 4 classes and higher again than grade 3 classes. In addition to year-level, the social composition of classes (as measured by mean SES) had a strong positive effect on achievement, as did average word knowledge. All else equal, the higher the mean SES of the class the higher the achievement. This also applied to the mean ability of the class as measured by word knowledge.

The addition of the next group of classroom-level factors—teacher attributes and teacher beliefs about mathematics and about teaching mathematics—had little impact. The only factor that was significant was teacher's sex. Neither years of teaching experience nor educational qualifications had a significant effect on mathematics achievement. However, a student with a male teacher would, according to the results, be advantaged in mathematics and the effect is significant. There are several possible explanations for this finding. One is, as suggested by previous research, that female primary teachers, more than male primary school teachers, lack confidence in their ability to teach mathematics. Another possible explanation is related to the types of male teachers who enter primary teaching. The data show that only 27 per cent of the primary teaching population was male, indicating that perhaps the males that do go into primary teaching are a more selected group of mathematics teachers or perhaps have more confidence in their ability than females. None of the teacher attitudes or beliefs had any effect on achievement, nor did school level socioeconomic status.

Table 2
HLM Estimates of Mathematics Achievement: Schools and Students, Population 1, TIMSS

	Level 1 model – student background variables	Level 1 model – student mediating variables	Level 2 model –classroom composition variables	Level 2 model – classroom teacher variables	Level 3 model –school variables
Intercept	530.5***	529.5***	530.1***	529.8***	529.7***
Student-level variables					
Background variables					
Female	-4.0**	-7.3***	-7.0***	-6.9***	-6.9***
Books in the home	8.8***	3.9***	3.9***	3.9***	3.9***
SES	12.1***	7.2***	6.7***	6.7***	6.7***
Ethnicity	0.33	0.1	0.1	0.1	0.1
Family size	-4.7***	-2.5***	-2.5***	-2.5***	-2.5
Mediating variables					
Word knowledge		41.1***	39.4***	39.4***	39.4***
Positive attitudes towards maths		5.0***	5.2***	5.2***	5.2***
Classroom-level variables					
Grade-level and classroom composition					
Year-level			28.8***	28.8***	29.3***
Mean word-knowledge			3.7***	3.6***	3.6***
Mean SES			13.1***	14.0***	11.7**
Teacher attributes					
Age of the teacher				1.0	1.0
Sex of the teacher				-10.0***	-10.0***
Educational qualifications				0.4	0.4
Attitudes towards maths					
Problem-solving approach to teaching				-0.4	-0.4
Discipline oriented approach to teaching				-0.4	-0.4
Process oriented approach to teaching				-0.2	-0.1
Eclectic approach to teaching				-0.3	-0.3
Algorithmic approach to teaching				0.3	0.4
Teacher satisfaction with job				0.1	0.2
School-level Variables					
Mean SES					3.5

Note. *p < 0.10; **p < 0.05; ***p < 0.001.

Secondary Students: Setting Makes the Difference

Table 3 shows that for the secondary school population setting or streaming had an impact on mathematics achievement. Compared to lower band or lower stream classes, there was a strong positive effect for classes in the top band in schools with setting or streaming policies, and a more modest effect for classes in schools with no such policies. Setting and streaming clearly benefited those students in the higher band classes, but led to significantly poorer achievement in lower band classes. The achievement in classes in the lower bands or streams was moderately, though significantly, lower than classes that were not streamed or set.

Year-level had a significant effect on achievement. Achievement in Year 9 classes was higher than for Year 8 and Year 7 classes. Classroom social composition (mean SES) also had a strong independent effect on student achievement in mathematics, as did classroom ability composition. These results show that the higher the mean SES composition of classes, the higher the achievement. Also, the higher the average verbal ability of classes, the higher the achievement. Thus, there are benefits for students to be in classes where they rub shoulders with other higher SES and higher ability students.

Table 3
HLM Estimates of Mathematics Achievement: Schools and Students, Population 2, TIMSS

	Level 1 model – student background variables	Level 1 model – student mediating variables	Level 2 model –classroom composition variables	Level 2 model – classroom teacher variables	Level 3 model –school variables
Intercept	523.0***	524.5***	525.5***	525.5***	525.5***
Student-level variables					
Background variables					
Female	-6.4***	-4.0***	-4.6***	-4.5***	-4.5***
Books in the home	10.1***	6.9***	7.0***	7.0***	7.0***
SES	7.0***	5.1***	4.6***	4.6***	4.6***
Ethnicity	-0.8	-0.9	-0.9	-0.9	-0.9
Family size	-1.9***	-1.0*	-0.9	-0.9	-0.9
Mediating variables					
Word knowledge		26.8***	25.2***	25.2***	25.2***
Positive attitudes towards maths		9.0***	9.1***	9.1***	9.1***
Perceived importance of maths		[1.7***]	[1.7***]	[1.7***]	[1.7***]
Classroom-level variables					
Grade-level and classroom composition					
Year-level			18.3***	18.2***	18.2***
Mean word-knowledge			7.0***	6.8***	6.8***
Mean SES			11.2***	11.2***	11.2***
High band			28.5***	28.5***	28.5***
No band			5.3*	5.3*	5.3*
Teacher attributes					
Sex of the teacher				3.5	3.2
Educational qualifications				-0.4	-0.3
Years in teaching				0.3**	0.3**
Attitudes towards maths					
Problem-solving approach to teaching				-0.2	-0.2
Discipline oriented approach to teaching				-0.2	-0.3
Process oriented approach to teaching				0.4	0.5
Eclectic approach to teaching				-0.2	-0.1
Teacher satisfaction with job				0.3	0.2
School -level Variables					
School size					1.4
Policy to stream in maths					-1.8
SES					-2.1

Note. *p < 0.10; **p < 0.05; ***p < 0 .001.

Teacher Attributes

The next step in the analysis was to add the teacher attribute variables to the achievement models. Sex of the teacher and educational qualifications had no significant effect on student achievement. Years of teaching had a small but significant positive effect, suggesting that the more experienced teachers achieved better results. None of the teacher attitudes to mathematics were found to have any direct effect on student achievement.

School Variables

Neither school size nor mean school SES were found to have any direct or indirect effect on mathematics achievement, controlling for all other variables.

Discussion

What can we learn from the TIMSS data? One thing we learn is that differences between classes and schools matter. Early studies examining patterns of student achievement in mathematics had concluded that schools have little impact above and beyond student intake factors. The results from TIMSS show, consistent with current research on school effectiveness, that not only do schools make a difference, but classrooms as well. There are strong classroom effects and modest school effects on maths achievement. These effects are linked to particular classroom and school-level factors.

For primary schools, grade-level was a major factor. Classroom-composition variables also made a difference. The pooling of pupil resources that is associated with the grouping of students—reflected by mean SES and average verbal ability—influences mathematics achievement. Achievement was highest in those classes and schools with higher concentrations of students from middle class families and students with higher verbal ability. Therefore, the effects of residential segregation more broadly and school-level pupil management policies more locally shape the contexts within which differences in maths learning and achievement develop. Other factors also can play a role. Classes with male primary teachers have higher levels of achievement, a finding that needs further analysis to identify whether this might be related to differences in the scholastic backgrounds of male and female primary teachers or to differences in confidence in the teaching of maths or differences in maths-related teaching practices.

For secondary schools, class and school effects were also influential. Policies regarding pupil management are critical. Schools which formally group students according to maths achievement or ability promote differences in mathematics achievement. The benefits of this practice are large for students who enter higher band or top stream classes. They receive substantial gains in achievement. The cost is for those students in the lower band or stream classes. They had significantly lower levels of achievement compared to their top streamed peers and also their unstreamed peers. It suggests that the different learning environments created through selective pupil grouping work to inhibit student progress in the bottom streams and accelerate it for those in the top streams. Teachers matter less in this context. Their beliefs about mathematics and teaching mathematics, and feelings of self-worth as a teacher, had no significant effect on achievement, after controlling for other factors. The one exception was teaching experience, as measured by years of teaching. This factor did have a significant effect, suggesting that more experienced teachers promote higher achievement.

References

.Ainley, J., Graetz, B., Long, M., & Batten, M. (1995). *Socioeconomic status and school education.* Canberra: AGPS.

Anderson, L. W., Ryan, D. W., & Shapiro, B. J. (1989). *The IEA classroom environment study.* Oxford: Pergamon Press.

Bosker, R. J., & Witziers, B. (1996). *The magnitude of school effects or Does it really matter which school a student attends?* Paper presented at the Annual Meeting of the American Educational Research Association, New York.

Coleman, J. S., Campbell, E. Q., Hobson, C. J., Partland, J., Mood, A. M., Weinfeld, F. D., & York, R. L. (1966). *Equality of educational opportunity.* Washington, D.C.: U.S. Government Printing Office.

Jencks, C., Smith, M., Acland, H., Bane, M., Cohen, D., Gintis, H., Heyns, B. & Michelson, S. (1972). *Inequality: a reassessment of the effect of family and schooling in America.* New York: Basic Books.

Keeves, J. P. (1972). *Educational environment and student achievement: A multivariate study of the contribution of the home, the school and the peer group to change in mathematics and science performance during the first year at secondary school.* Stockholm: Almqvist & Wiskell.

Lamb, S.P. (1997). Access to level of mathematics study in high school: social area and school differences. In F. Biddulph & K. Carr (Eds.), *People in mathematics education.* Proceedings of the twentieth annual conference of the Mathematics Education Research Group of Australasia (pp. 286-293). Rotorua, NZ: MERGA.

Lamb, S., & Fullarton, S. (2000, in press). Classroom and teacher effects in mathematics achievement: Results from TIMMS. In J. Malone, J. Bana & A. Chapman (Eds.), *Mathematics education beyond 2000* Proceedings of the twenty-third annual conference of the Mathematics Education Research Group of Australasia. Perth: MERGA..

Larkin, A. I., & Keeves, J. P. (1984). *The class size question: A study at different levels of analysis*. Melbourne: Australian Council for Educational Research.

Lee, V. E., & Smith, J. B. (1997). High school size: Which works best and for whom? *Education Evaluation and Policy Analysis, 19*(3), 205 - 228.

Mortimore, P., Sammons, P., Stoll, L., Lewis, D., & Ecob, R. (1988). *School matters: The junior years*. Somerset, England: Open Books.

Nuttall, D., Goldstein, H., Prosser, R., & Rasbash, J. (1989). Differential school effectiveness. *International Journal of Educational Research, 13*(7), 769-776.

Raudenbush, S. W., & Willms, J. D. (Eds.). (1991). *Schools, classrooms and pupils: International studies of schooling from a multilevel perspective*. New York: Academic Press.

Scheerens, J. (1993). Basic school effectiveness research: Items for a research agenda. *School Effectiveness and School Improvement, 4*(1), 17-36.

Scheerens, J., Vermeulen, C. J. A. J., & Pelgrum, W. J. (1989). Generalizability of instructional and school effectiveness indicators across nations. *International Journal of Educational Research, 13*(7), 789-799.

Smith, D., & Tomlinson, S. (1989). *The school effect.* London: Policy Studies Institute.

Thorndike, R. L. (1973). *Reading comprehension education in fifteen countries*. Stockholm: Almqvist & Wiksell.