A Multilevel Analysis of Mathematically Low-Achieving Students in Singapore

Dr. Qian Chen

Nanyang Technological University

Address: NIE5-B2-16, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore 637616.
Tel: (65) 6219 6157
Fax: (65) 6515 1458
Email: qian.chen@nie.edu.sg

Abstract

In this study, TIMSS 2007 data were analysed with a particular focus on mathematically low-achieving students at grade four in Singapore. Specifically, the quantity and major characteristics of mathematically low-achieving fourth graders were examined. Furthermore, eight variables at the student level and nine variables at the school/class level were used to build the two-level hierarchical generalized linear model so as to predict the status of mathematically low-achieving fourth grader. The final model suggested that six variables at the student level, i.e. student gender, number of books at home, frequency of test language spoken at home, frequency of mathematics homework, student's self-confidence in learning mathematics, student's perception of school safety, and two variables at the school/class level, i.e. teacher professional development opportunity and principal's perception of school climate significantly predicted the status of mathematically low-achieving fourth grader. Implications for educational research and practice are presented at the end of this paper.

Key words: Low-achieving, Mathematics achievement, Grade four, TIMSS 2007, Singapore.

INTRODUCTION

Over the past two decades, international comparative studies on educational achievement have gained remarkable development. One of the most influential assessment projects is Trends in International Mathematics and Science Study (TIMSS). It has constantly examined the mathematics and science achievement of fourth and eighth graders in the participating countries on a 4-year cycle since 1995. It is indicated that the East Asian countries and regions (Chinese Taipei, Hong Kong SAR, Japan, Korea and Singapore) have consistently been the top achievers among the participating countries over the world (Hensher & Johnson, 1981; Mullis, 2000, 2003; Mullis, Martin, & Foy, 2008; OECD, 2004, 2010; Wilkins, 2004).

The admirable performance of the East Asian school systems has brought about unprecedented attention from the wide community of educational researchers and policy makers around the world. In order to reveal the keys to success, a fast-growing body of studies have been intended to investigate the school education in these school systems from diverse perspectives (Leung, 2001, 2006; Park, 2004; Wößmann, 2005; Zhu & Leung, 2011). Nevertheless, with the widely acclaimed high performance in international assessments, some important educational issues within the East Asian school systems, especially those regarding achievement gaps seem to have been hardly explored. Needless to say, in any country and region, attending to low-achieving students is crucial to the improvement of overall educational achievement level as well as the realization of educational equity. Specifically, it is necessary to develop a sound understanding of this group of students and factors related to their low achievements. Therefore, this study aimed to use TIMSS 2007 data to conduct an in-depth analysis of mathematically low-achieving students at grade four in Singapore. The specific research questions for this study were formulated as follows:

1) In Singapore, what was the quantity of mathematically low-achieving students at grade four, defined as those whose benchmark scores were below the TIMSS *Intermediate* international benchmark?
2) What were major characteristics of the mathematically low-achieving fourth graders in Singapore?
3) What factors significantly predicted the status of mathematically low-achieving student at grade four in Singapore?

THEORETICAL BACKGROUND

A large body of literature has discussed factors related to student achievement (Bloom, 1976; Carroll, 1963; Coleman et al., 1966; Creemers, 1994; Lee & Shute, 2010; Walberg, 2003). These factors can be divided into student-, classroom-, and school-level factors (Teodorović, 2011).

Student-level factors

According to Ismail (2009), several factors may help explain why some students attain higher mathematics performance than others do, including students' personal and home backgrounds, resources for learning, time spent out of school in studying or doing homework in school subjects, self-confidence in learning mathematics, motivation to learn mathematics, and perceptions of being safe in school. In his study, multiple logistic regression analysis was conducted on the data from Malaysian eighth graders in TIMSS 2003. It was found that having self-confidence in learning mathematics, having a large number of books at home, regularly using computers, and being non-Malay have a high positive association with mathematics achievement among Malaysian students (Ismail, 2009).

Akyüz and Berberoğlu (2010) conducted a two-level analysis of TIMSS 1999 data from nine European countries, i.e. Belgium, Slovak Republic, Czech Republic, Hungary, Italy, Lithuania, Netherlands, Slovenia and Turkey. They found that at the student level, home educational resources was significantly related to mathematics achievement in all the countries except Netherlands (Akyüz & Berberoğlu, 2010). Ghagar, Othman and Mohammadpour (2011) conducted multilevel analysis of mathematics achievement of Malaysian and Singaporean eighth graders in TIMSS 2003. It was found that at the student level, mathematics self-concept was the strongest predictor of mathematics achievement in both countries; attitude towards mathematics was also a significant predictor in both countries; home educational resources was significantly associated with mathematics achievement in Singapore but not in Malaysia. Wang, Osterlind and Bergin (2012) used TIMSS 2003 grade eight data to build two-level mathematics achievement model in four countries with varying level of achievement: the USA, Russia, Singapore and South Africa. They found that student's self-concept of ability in mathematics was a key predictor of mathematics achievement in all the four countries; other student variables including gender, parents' highest education level, perception of school etc. differed in the magnitude of relations to mathematics achievement across countries (Wang, et al., 2012).

Based on a review of school effectiveness research, Teodorović (2011) concluded that "student-level variables are very important in determining student achievement in industrialised and better-off developing countries, while their effect is less pronounced in poor developing countries" (p. 220). It is further indicated that variance in student achievement can be mostly attributed to student-level factors (Teodorović, 2012).

Classroom-level factors

Undoubtedly, teacher plays a key role at the classroom level. Teacher's demographic characteristics, perceptions/beliefs, attitudes, and classroom behaviours are widely examined in relation to student achievement. In addition, two factors, i.e. class size and teacher professional development opportunity are also discussed. As in the case with student factors, findings about effects of these factors are mixed.

Akyüz and Berberoğlu (2010) found that after controlling for home educational resources, teacher gender was not significantly related to mathematics achievement in Belgium, Slovak Republic, Italy, Lithuania and Slovenia; however, female teacher was significantly related to lower achievement in Czech Republic and Turkey, higher achievement in Hungary and Netherlands. Wang et al. (2012) found that after controlling for student effects, teacher gender is not significantly associated with students' mathematics achievement in Russia, Singapore and South Africa whereas male teacher is significantly related to higher mathematics achievement in the USA. As far as the relationship between teaching experience and mathematics achievement is concerned, a negative association was identified in Slovak Republic and Slovenia (Akyüz & Berberoğlu, 2010), but a positive one in Netherlands, Turkey (Akyüz & Berberoğlu, 2010) and South Africa (Wang, et al., 2012).

Furthermore, Akyüz and Berberoğlu (2010) found that after controlling other effects, teacher's perception of limitations to classroom teaching was negatively related to mathematics achievement in Belgium, Italy, Netherlands and Slovenia, but not related in Slovak Republic, Czech Republic, Hungary, Lithuania and Turkey. Wang et al. (2012) found that after controlling for other variables, teacher's perception of school climate is a significant predictor of eighth graders' mathematics achievement in Russia, South Africa and Singapore, but not in USA; and teacher's perception of school safety is not a significant predictor in all the four countries.

The nature of the relationship between homework and student achievement remains disputed (Trautwein & Koller, 2003). However, the way teachers assign homework (e.g. frequency, amount) is still an important consideration in many achievement studies (e.g. Akyüz

& Berberoğlu, 2010; De Jong, Westerhof, & Creemers, 2000; House, 2004). In the study by Akyüz and Berberoğlu (2010), after controlling for other variables, teacher's emphasis on homework was found to be positively related to mathematics achievement in Belgium, Slovak Republic and Lithuania, but not related in Czech Republic, Hungary, Italy, Netherlands, Slovenia and Turkey.

Class size is also a commonly researched factor associated with student achievement (Akyüz & Berberoğlu, 2010; Konstantopoulos, 2011; Nye, Hedges, & Konstantopoulos, 2001). Although it is often assumed that being in small class is beneficial to all students, research findings are inconclusive (Baker & Jones, 2005). Akyüz and Berberoğlu (2010) found that with other variables controlled, class size was positively related to mathematics achievement in Belgium, Hungary, Italy, Lithuania and Netherlands, but not related in Slovak Republic, Czech Republic, Slovenia, and Turkey.

Lastly, teacher professional development opportunity is a potential factor related to mathematics achievement. Goldhaber and Brewer (1997) concluded that teachers' subject-specific training has a significant impact on student test scores in mathematics and science. Teachers who are trained and well-prepared are more effective in the classroom and therefore have the greatest impact on student learning (Killion, 1999). However, other studies found that professional development does not contribute to student achievement (Harbison & Hanushek, 1992; Jacob & Lefgren, 2004).

Based on review of effectiveness research, Teodorović (2011) concludes that "classroom-level variables exhibit significant association with student achievement in industrialised and better-off developing countries, and less so in poor developing countries, with composite variables having a considerably larger effect than individual variables" (p. 220).

School-level factors

At the school level, good attendance at school, availability of school resources for mathematics instruction and school climate as perceived by principals are usually considered as important factors related to mathematics achievement. Again, findings about the association are inconsistent across contexts.

Ghagar, Othman and Mohammadpour (2011) found that school location, availability of school resources for mathematics instruction, good attendance at school, school climate as perceived by principals were all significantly associated with eighth graders' mathematics achievement in Malaysia, after controlling for other variables; in Singapore, school climate as perceived by principals was significantly related to mathematics achievement, but availability of school resources for mathematics instruction and good attendance at school were not so, after controlling for other student-level and classroom level variables. Wang et al (2012) found that with other variables controlled for, school and class attendance significantly predicted eighth graders' mathematics achievement in Russia, but not so in the USA, Singapore and South Africa; availability of school resources for mathematics instruction was significantly associated with mathematics achievement in South Africa, but not in the USA, Russia and Singapore; principal's perception of school climate was a significant predictor of mathematics achievement in the USA and Singapore, but not so in Russia and South Africa.

With regard to school-level factors in effectiveness research, Teodorović (2011) concludes that they show the least consensus, "with their likely effect sizes ranging from null to modest in industrialised and better-off developing countries, but they are very important for poor developing countries" (p. 220).

To sum up, research literature shows that many factors at different levels relate to students' mathematics achievement, however, findings about the relationships are yet inconclusive, depending on research contexts and the set of variables involved in the analysis. Therefore, it is necessary to continue context-specific secondary analysis of achievement data so that new evidence and insights in this aspect can be produced. Moreover, multilevel modelling has become a well-accepted approach to analysis of achievement data. Nevertheless, as compared to the conventional linear modelling approach which uses achievement scores as outcome variable, hierarchical generalized linear modelling (HGLM) or multilevel logistic regression modelling has scarcely been used by achievement researchers. It is also noted that some of the reviewed studies have been built on secondary analysis of TIMSS data (e.g.Louis & Mistele, 2011; Thomson, 2008; Zuzovsky, 2008). Due to the use of nationally representative samples in such large-scale assessments, these studies have obvious advantages in terms of generalizability of research findings. However, it must be acknowledged that secondary analysis studies are limited to a certain extent in selecting variables for analysis. In the next section, research methods for this study are described in detail.

METHODS

Data Source and Sample

TIMSS is one of the largest and most complex cross-national data collection efforts of educational achievement. In addition to assessing students' mathematics and science proficiency, TIMSS also gathers a lot of background information from students, their teachers and school principals through questionnaire survey. Data for this study were drawn from grade four datasets of Singapore in the TIMSS 2007 international database.

According to Joncas (2008a), the TIMSS 2007 assessment generally employed a two-stage stratified cluster sample design. At the first stage, schools were selected using probability-proportional-to-size sampling; at the second stage, one or two classes were randomly sampled in each school. Particularly, Singapore had a third sampling stage where students were sampled within classes. It is suggested that in analysing TIMSS data, it is important to include a weight variable reflecting the sampling scheme (Joncas, 2008b; Rutkowski, Gonzalez, Joncas, & von Davier, 2010).

In Singapore, two classes were selected from each participating school. The numbers of schools, classes, students and mathematics teachers, together with the rank and mean mathematics achievement score for the two systems are given in Table 1.

TABLE 1
Sample Size, Rank and Mean Score of Singapore

School	*Class*	*Mathematics Teacher*	*Student*	*Rank*	*Mean Score*
177	354	378	5041	2	599

Rank and mean scores were from TIMSS 2007 International Mathematics Report (Mullis, et al., 2008).

Due to the nested structure of the data and the sample design, three-level (student, class and school) modelling was initially attempted, but found to be unsuccessful afterwards. Finally, two-level modelling was chosen for this study. At level 1, variables were from students, and at level 2, variables were related to schools and classes.

Measures and Preparation of Variables

The outcome variable for this study was a dummy variable (1=being mathematically low-achieving student, 0=not being mathematically low-achieving student), which was created based on fourth graders' benchmark score in TIMSS 2007 (1=below 400, 2=at or above 400 but below 475, 3= at or above 475 but below 550, 4= at or above 550 but below 625, 5= at or above 625). TIMSS 2007 used five plausible values to derive five benchmark scores so as to describe the mathematics performance of each student in an international setting, where the score of 400, 475, 550 and 625 denoted the *Low*, *Intermediate*, *High* and *Advanced* international benchmark respectively (More details about the four international benchmarks are given in Appendix 1). In this study, if individual student's benchmark scores were below 3 (i.e. the *Intermediate* benchmark 475), he or she was treated as mathematically low-achieving student.

As far as the predictor variables are concerned, at the student level, a total of eight variables were used, i.e. student gender (0=girl, 1=boy), student immigration background (0=both parents were born in the country, 1=at least one parent was not born in the country), number of books at home as proxy for family SES (1=0-10, 2=11-25, 3=26-100, 4=101-200, 5=over 200), frequency of test language spoken at home (1=never, 2=sometimes, 3=almost always, 4=always), frequency of mathematics homework (1=never, 2=less than once a week, 3=1or 2 times a week, 4=3 or 4 times a week, 5=every day), positive affect to mathematics, self-confidence in learning mathematics, and perception of school safety. At the school/class level, a total of nine variables were used, i.e. teacher gender (0=female, 1=male), number of years of teaching experience, class size for mathematics instruction (number of students in mathematics class), teacher's perception of few or no limitations on mathematics instruction due to student factors, teacher's perception of school climate, index of good attendance at school (1=low, 2=medium, 3=high), availability of school resources for mathematics instruction, principal's perception of school climate, and teacher professional development opportunity. A total of six scales were developed to respectively measure student's positive affect to mathematics, self-confidence in learning mathematics, teacher's perception of few or no limitations on mathematics instruction due to student factors, teacher's perception of school climate, availability of school resources for mathematics instruction, and principal's perception of school climate. In addition, two index variables, i.e. student's perception of school safety and teacher professional development opportunity were created based on relevant items in the student questionnaire and teacher questionnaire respectively. Details of scale and index development are included in Appendix 2.

Particularly, in the HGLM analyses, dummy/dichotomous variables were not centred. As a result, the coefficients for those variables were interpreted as the mean log-odds difference between the two groups. All scale and index variables were transformed into z scores (M=0, SD=1) so that results could be reported as standard deviation units.

For all the variables, the number of cases with incomplete data of each variable was calculated. The highest percentage of cases with incomplete data for all student-level variables was 2.29%, and that for the school/class level variables was 11.96%. The multiple imputation (MI) method was used to impute missing data on the variables. Consequently, five imputed datasets were produced for subsequent data analysis.

Data Analysis

In this study, all analyses involved use of the five imputed datasets. Each imputed dataset was analysed separately and then the results were averaged across the five datasets. Furthermore, for each imputed dataset, there were five outcome variables indicating whether students were mathematically low-achieving students or not. Thus, when analysing each imputed dataset, all analyses concerned with the outcome variable were actually replicated five times, using a different outcome variable each time, and the results were combined into a single result that included information on standard errors which incorporated both sampling and imputation error, similar to the procedures suggested by Foy and Olson (2009).

Multiple programs, i.e. SPSS 20, International Database (IDB) Analyser as well as HLM 7 were used to prepare and analyse the data. IDB Analyser software was developed by IEA (2009) specifically for managing and analysing TIMSS international data files (Foy & Olson, 2009). In this study, student file, teacher file and school file for Singapore were merged into one through IDB Analyser's merge module for subsequent data preparation and analyses. SPSS 20 and IDB Analyser's analysis module were used to conduct reliability analysis of scales and indices, descriptive and between-group inferential analyses (independent samples T-test). HLM 7 was used for two-level HGLM analyses. It is noteworthy that because of the use of merged file, the reported mathematics teacher weights MATWGT was involved in the analyses where appropriate, which could correctly reflect the characteristics of the student population.

In the two-level HGLM analyses (Raudenbush & Bryk, 2002), full maximum likelihood method was used to estimate the model parameters. A model building process was applied to study the incremental contribution of variables in predicting the status of mathematically low-achieving students. Specifically, student, class and school variables were used to build a model for fourth graders in Singapore. The level 1 unit of analysis was students and the level 2 unit of analysis was schools/classes. The model building process was first conducted at level 1 and then at level 2. At each step in the model building, a model trimming procedure was employed to achieve parsimony.

For each of the five imputed datasets, three sets of HGLM models were analyzed and modified in the modelling process. Firstly, the fully unconditional model (Model A) was examined, which did not contain any predictors. Secondly, student variables were added to the model as level 1 predictors, and nonsignificant predictors were removed (model trimming). Thirdly, class and school variables were added to model B as level 2 predictors. In order to achieve model parsimony, the final model (Model C) only included statistically significant variables. With $\alpha = 0.05$, the conclusions on statistical significance of relationships between each individual variable and outcome variable were the same across Model B and Model C. It included significant level 1 and level 2 predictors.

RESULTS

Descriptive Statistics of Scales

As mentioned earlier, six scales were developed to respectively measure student's positive affect to mathematics, self-confidence in learning mathematics, teacher's perception of few or no limitations on mathematics instruction due to student factors, teacher's perception of school climate, availability of school resources for mathematics instruction, and principal's perception of school climate. Descriptive statistics together with the reliability coefficients for these scales are included in Appendix 2.

Quantity of Mathematically Low-achieving Students at Grade Four

Table 2 displays the quantity and mean score of mathematically low-achieving students, as compared to the rest of student population at grade four.

TABLE 2
Quantity and Mean Score of Mathematically Low-achieving Fourth Graders

	Sample Size	*Population Size*	*Percentage (se)*	*Mean Score (se)*
Mathematically Low-achieving Students	457	4071	8.25 (0.9)	435 (6.1)
Non-mathematically Low-achieving Students	4584	45305	91.75 (0.9)	614 (3.1)

se = standard error.

It is apparent from the table that there were 4071 mathematically low-achieving fourth graders in Singapore, they accounted for 8.25% of the student population at grade four, and their average mathematics score in TIMSS 2007 was 435.

Major Characteristics of Mathematically Low-achieving Students at Grade Four

Independent samples T-test was carried out to compare mathematically low-achieving students with the rest of student population at grade four in terms of the considered variables, the results are given in Table 3. In this way, the major characteristics of this particular group of students were identified.

TABLE 3

Major Characteristics of Mathematically Low-achieving Fourth Graders

Characteristics	Mathematically Low-achieving Students	Non-mathematically Low-achieving Students	Sig.
Student gender	0.60	0.51	***
Student immigration background	0.39	0.37	-
Number of books at home	2.34	3.07	***
Frequency of test language spoken at home	2.22	2.74	***
Frequency of mathematics homework	3.63	3.93	***
Positive affect to mathematics	8.54	9.70	***
Self-confidence in learning mathematics	8.94	11.29	***
Student's perception of school safety	2.79	3.53	***
Teacher gender	0.39	0.33	***
Number of years of teaching experience	10.67	9.83	***
Teacher's perception of few or no limitations on mathematics instruction due to student factors	11.07	12.28	***
Teacher's perception of school climate	27.12	27.78	***
Teacher professional development opportunity	3.54	3.46	**
Class size for mathematics instruction	35.43	38.43	***
Good attendance at school	2.57	2.56	-
Availability of school resources for mathematics instruction	36.74	36.70	-
Principal's perception of school climate	29.00	30.10	***

**p<0.01, ***p<0.001, - denotes no significant difference.

According to the table above, mathematically low-achieving students were significantly different from the rest of student population at grade four in the majority of variables. Specifically, they consisted of bigger proportion of boys, had less number of books at home (lower family SES), spoke test language at home and did mathematics homework less frequently, had lower self-confidence in learning mathematics and worse perceptions of school safety.

Furthermore, they were taught mathematics by teachers who were comprised of larger proportion of males, had longer teaching experience, enjoyed more teacher professional development opportunities, handled smaller class, but perceived more limitations on mathematics instruction due to student factors and worse school climate. Lastly, mathematically low-achieving fourth graders attended schools whose principals had worse perceptions of school climate.

Factors Predicting the Status of Mathematically Low-achieving Students at Grade Four

In the HGLM analyses, only the results from population-average models (with robust standard errors) were considered because population-average questions rather than school-specific questions were of interest in this study (Raudenbush & Bryk, 2002). The unconditional model (Model A) was as follows:

Level 1: $\text{Prob}\,(Y_{ij}=1|\,\beta_j) = \varphi_{ij}$

$$\log\,[\varphi_{ij}\,/(1-\varphi_{ij})] = \beta_{0j}$$

Level 2: $\beta_{0j} = \gamma_{00} + u_{0j}$

where γ_{00} is the average log-odds of being mathematically low-achieving student across the schools. The variance of u_{0j} is the variance between schools in school-average log-odds of being mathematically low-achieving student. The results from Model A are given in Table 4. According to the table, in Singapore, the odds of being mathematically low-achieving student at grade four was $e^{(-2.40)} = 0.09$, corresponding to a predicted probability of 0.08.

Model building at the student level (level 1) began by adding all student-level predictors. Specifically, the eight student-level variables were modelled as predictors of status of mathematically low-achieving student. The effects of these predictors were modelled as fixed coefficients while the intercept was treated as random. After model trimming, the results from Model B are also given in Table 4. Later on, Model B was compared with Model A to examine how much the student-level variables contributed to the prediction of status of mathematically low-achieving student.

From Model B, student gender, number of books at home, frequency of test language spoken at home, frequency of mathematics homework, self-confidence in learning mathematics, and student's perception of school safety were significantly associated with the log-odds of being mathematically low-achieving student. Among the six predictors, student's self-confidence in learning mathematics was the strongest one. A one standard deviation increase in it reduced the log-odds of being mathematically low-achieving student by 0.70, which was associated with a relative odds ratio of $e^{(-0.70)} = 0.5$, after controlling for the other predictors in the model and the random school effect u_{0j}. That is, if two students were similar in other ways but differed by one standard deviation in their self-confidence in learning mathematics, then the odds of being mathematically low-achieving student for the student with higher self-confidence were 0.5 times the odds for the student with lower self-confidence. Interestingly, the relationship between student gender and the log-odds of being mathematically low-achieving student was positive. The odds of being mathematically low-achieving student for boys were $e^{0.35} = 1.42$ times the odds for girls. Surprisingly, student's positive affect to mathematics was not significantly related to the log-odds of being mathematically low-achieving student.

After model building and model trimming at the student level (level 1) and at the school/class level (level 2), the final model (Model C) was obtained. The details of the final model are also displayed in Table 4. According to Model C, teacher professional development opportunity and principal's perception of school climate were significantly related to the log-odds of being mathematically low-achieving student. Unexpectedly, the relationship between teacher professional development opportunity and the log-odds of being mathematically low-achieving student was positive. Holding constant the other predictors in the model and the random school effect u_{0j}, a one standard deviation increase in teacher professional development opportunity increased the log-odds of being mathematically low-achieving student by 0.29, which was associated with a relative odds ratio of $e^{0.29}$ =1.34. In simple words, student whose mathematics teacher enjoyed more professional development opportunities was more likely to be mathematically low-achieving student.

TABLE 4 Results for Population-Average Models with Robust Standard Errors

	Unconditional Model (A)		*Level-1 Model (B)*		*Final Model (C)*	
	Coeff.	*se*	*Coeff.*	*se*	*Coeff.*	*Se*
Intercept	-2.40***	0.10	-3.17***	0.12	-3.21***	0.12
Level 1						
Student gender			0.35**	0.11	0.35**	0.11
Student immigration background			-	-	-	-
Number of books at home			-0.42***	0.07	-0.42***	0.07
Frequency of test language spoken at home			-0.33***	0.06	-0.33***	0.07
Frequency of mathematics homework			-0.18**	0.06	-0.18**	0.06
Positive affect to mathematics			-	-	-	-
Self-confidence in learning mathematics			-0.70***	0.05	-0.71***	0.05
Student's perception of school safety			-0.39***	0.06	-0.40***	0.06
Level 2						
Teacher gender					-	-
Number of years of teaching experience					-	-
Teacher's perception of few or no limitations on mathematics instruction due to student factors					-	-
Teacher's perception of school climate					-	-
Teacher professional development opportunity					0.29**	0.10
Class size for mathematics instruction					-	-
Good attendance at school					-	-
Availability of school resources for mathematics					-	-
Principal's perception of school climate					-0.24**	0.08
Variance	1.10		0.73		0.64	
Deviance	12310.46		11856.47		11843.46	

Coeff. = Coefficient; se =standard error; - Not statistically significant; **p<0.01, ***p<0.001.

The final model can be formulated as below:

Level 1: $\log [\varphi_{ij}/(1- \varphi_{ij})] = \beta_{0j} + \beta_{1j}$ (student gender) + β_{2j} (number of books at home) + β_{3j} (frequency of test language spoken at home) + β_{4j} (frequency of mathematics homework) + β_{5j} (self-confidence in learning mathematics) + β_{6j} (student's perception of school safety)

Level 2: $\beta_{0j} = \gamma_{00} + \gamma_{01}$ (teacher professional development opportunity) + γ_{02} (principal's perception of school climate) + u_{0j}

$\beta_{1j} = \gamma_{10}$

$\beta_{2j} = \gamma_{20}$

$\beta_{3j} = \gamma_{30}$

$\beta_{4j} = \gamma_{40}$

$\beta_{5j} = \gamma_{50}$

$\beta_{6j} = \gamma_{60}$.

The model fit statistic McFadden's ρ^2 was calculated by computing the proportion reduction in deviance obtained from the final model relative to the unconditional model, which was equal to 0.04. Adding the student-level variables to the unconditional model reduced 34% of the intercept variance in adjusted school log-odds of being mathematically low-achieving students. After including the school/class-level variables in the student-level model, the variance was further reduced by 12%. The final model explained a total of 42% of the intercept variance.

CONCLUSION AND DISCUSSION

In this study, the quantity and major characteristics of mathematically low-achieving fourth graders in high-performing Singapore were examined. It was found that in Singapore, there were 4071 mathematically low-achieving fourth graders, which accounted for 8.25% of the student population at grade four. This particular group of students significantly differed from the rest of the student population in many aspects, including gender composition, number of books at home (as proxy for family SES), self-confidence in learning mathematics, mathematics teacher's teaching experience, teacher's and principal's perception of school climate etc.

Furthermore, HGLM techniques were used in this study to predict the status of mathematically low-achieving student at grade four in Singapore. Among the six student-level significant predictors, student's self-confidence in learning mathematics was found to be the strongest, which is essentially in accord with the previous findings that student's self-confidence or self-concept of ability in mathematics has the largest relation to mathematics achievement in the USA, Russia, South Africa and Malaysia (Abd.Ghagar, et al., 2011; Wang, et al., 2012).

One unexpected finding is that student's positive affect to mathematics was not significantly associated with the log-odds of being mathematically low-achieving student. One possible explanation is that Singaporean students do not think of learning mathematics as a pleasurable activity; whether they like it or not, they are motivated to study mathematics hard by instrumental reasons, e.g. pass various exams to attend the desired secondary schools and universities. As noted by Leung (2001), the traditional view in East Asian countries has been that "studying is a serious endeavour" (p. 41). Students need to study hard, but do not need to enjoy the study.

It is not surprising to find in this study that other student-level variables, particularly number of books at home (as proxy for family SES) were significantly associated with the log-odds of being mathematically low-achieving student, given plenty of evidence from previous achievement research (e.g. Teodorović, 2012; Wößmann, 2005).

At the school/class level, teacher professional development opportunity was found to be positively related to the log-odds of being mathematically low-achieving student. That is, student whose mathematics teacher enjoyed more professional development opportunities was more likely to be mathematically low-achieving student. This finding was surprising at first glance because it was assumed that less teacher professional development opportunities would relate to lower student achievement. However, on second thought, this finding seems reasonable and even encouraging given that this group of students would benefit from mathematics teachers who enjoyed more professional development opportunities.

IMPLICATIONS

This study provides several implications for educational research and practice. Firstly, this study used cross-sectional observational data, thus claims about causal relationship are inappropriate. This made impossible exploring the direction of the influence of students' perceptions and the status of mathematically low-achieving students. Further research can explore the possibilities in this regard. However, this study does provide evidence about the strong association between student's self-confidence in learning mathematics and mathematics achievement.

Secondly, it was found that boys were more likely to be mathematically low-achieving students than girls at grade four in Singapore. Clearly, reasons behind this phenomenon need to be explored so that the gender-based achievement gap can be diminished.

Thirdly, teacher professional development opportunity was found to be positively associated with the log-odds of being mathematically low-achieving student in Singapore. Given the great efforts and resources put into this area, it seems necessary for teacher educators and other parties concerned in Singapore to examine current teacher professional development activities from both quantitative and qualitative perspective so that effective strategies for closing achievement gaps can be identified.

Fourthly, this study produced a predictive model of mathematically low-achieving students at grade four in Singapore based on TIMSS 2007 data. The model fit statistic McFadden's ρ^2 for this model was equal to 0.04. According to Hensher and Johnson (1981), values in the 0.2 to 0.4 range are considered highly satisfactory. Therefore, the model from this study needs to be improved so as to better predict the status of mathematically low-achieving fourth grader in Singapore. Moreover, a replicate study with the soon available TIMSS 2011 data will be able to provide new evidence and insights about the changes in the predictive model over the period. Thereby, the high-low achievement gap and the particular group of mathematically low-achieving students within high-performing Singapore can gain sustainable attention. At the same time, relevant educational research and practices can be constantly revisited for improvement.

Lastly, by focusing on Singapore, this study makes a good starting point to understand the mathematically low-achieving students in the high-performing school systems. Similar efforts can be extended to other high-performing systems, which will help us develop a more comprehensive understanding of issues regarding achievement gap in the East Asian area. In addition, relevant similarities and differences among these places can be identified.

REFERENCES

Abd.Ghagar, M. N., Othman, R., & Mohammadpour, E. (2011). Multilevel analysis of achievement in mathematics of Malaysian and Singaporean students. *Journal of Educational Psychology and Counseling, 2*, 285-304.

Akyüz, G., & Berberoğlu, G. (2010). Teacher and classroom characteristics and their relations to mathematics achievement of the students in the TIMSS. *New Horizons in Education, 58*(1), 77-95.

Baker, R., & Jones, A. (2005). How can international studies such as the international mathematics and science study and the programme for international student assessment be used to inform practice, policy and future research in science education in New Zealand? *International Journal of Science Education, 27*(2), 145-157. doi: 10.1080/0950069042000276695

Bloom, B. (1976). *Human characteristics and school learning*. New York, NY: McGraw-Hill.

Carroll, J. B. (1963). A model of learning. *Teacher College Record, 64*, 723-733.

Coleman, J., Campbell, E., Hobson, C., McPartland, J., Mood, A., & Weinfeld, F. (1966). *Equality of educational opportunity*. Washington DC: U.S. Department of Health, Education and Welfare.

Creemers, B. P. M. (1994). *The effective classroom*. London: Cassell.

De Jong, R., Westerhof, K. J., & Creemers, B. P. M. (2000). Homework and student math achievement in junior high schools. *Educational Research & Evaluation, 6*(2), 130-157. doi: 10.1076/1380-3611(200006)6:2;1-E;F130

Foy, P., & Olson, J. F. (2009). *TIMSS 2007 User Guide for the International Database*. Chestnut Hill, MA: International Study Center, Boston College.

Goldhaber, D., & Brewer, D. (1997). Evaluating the effect of teacher degree level on educational performance. In W. Fowler (Ed.), *Developments in School Finance, 1996* (pp. 197-210). Washington, DC: NCES.

Harbison, R. W., & Hanushek, E. A. (1992). *Educational performance of the poor: Lessons from rural northeast Brazil*. New York, NY: Oxford University Press.

Hensher, D., & Johnson, L. W. (1981). *Applied discrete choice modelling*. London: Croom Helm.

House, J. D. (2004). The effects of homework activities and teaching strategies for new mathematics topics on achievement of adolescent students in Japan: Results from the TIMSS 1999 assessment. *International Journal of Instructional Media, 31*(2), 199-210.

Ismail, N. A. (2009). Understanding the gap in mathematics achievement of Malaysian students. *Journal of Educational Research, 102*(5), 389-394.

Jacob, B. A., & Lefgren, L. (2004). The impact of teacher training on student achievement: Quasiexperimental evidence from school reform efforts in Chicago. *Journal of Human Resources, 39*(1), 50-79.

Joncas, M. (2008a). TIMSS 2007 sample design. In J. F. Olson, M. O. Martin & I. V. S. Mullis (Eds.), *TIMSS 2007 Technical Report* (pp. 77-92). Chestnut Hill, MA: International Study Center, Boston College.

Joncas, M. (2008b). TIMSS 2007 sampling weights and participation rates. In J. F. Olson, M. O. Martin & I. V. S. Mullis (Eds.), *TIMSS 2007 Technical Report* (pp. 154-192). Chestnut Hill, MA: International Study Center, Boston College.

Killion, J. (Ed.). (1999). *What works in the middle: Results-based staff development*. Oxford, OH: National Staff Development Council.

Konstantopoulos, S. (2011). How consistent are class size effects? *Evaluation Review, 35*(1), 71-92. doi: 10.1177/0193841X11399847

Lee, J., & Shute, V. J. (2010). Personal and social-contextual factors in K-12 academic peferomance: An integrative perspective on student learning. *Educational Psychology, 45*(3), 185-202. doi: 10.1080/00461520.2010.493471

Leung, F. K. S. (2001). In search of an East Asian identity in mathematics education. *Educational Studies in Mathematics, 47*, 35-51.

Leung, F. K. S. (2006). Mathematics education in East Asia and the West: Does culture matter? In F. K. S. Leung, K.-D. Graf & F. J. Lopez-Real (Eds.), *Mathematics education in different culture: A comparative study of East Asia and the West* (pp. 21-46). New York: Springer.

Louis, R. A., & Mistele, J. M. (2011). The differences in scores and self-efficacy by student gender in matehmatics and science. *International Journal of Science and Mathematics Education*, 1-28. doi: 10.1007/s10763-011-9325-9

Mullis, I. V. S. (2000). TIMSS 1999 International Mathematcs Report: Findings from IEA's Repeat of the Third International Mathematcs and Science Study at the Eighth Grade. Chestnut Hill, MA: International Study Center, Lynch School of Education, Boston College.

Mullis, I. V. S. (2003). TIMSS 2003 International Mathematics Report : Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth grade. Chestnut Hill, MA: International Study Center, Boston College, Lynch School of Education.

Mullis, I. V. S., Martin, M. O., & Foy, P. (2008). TIMSS 2007 International Mathematics Report: Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth Grades. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Nye, B., Hedges, L. V., & Konstantopoulos, S. (2001). The Long-term effects of small classes in early grades: Lasting benefits in mathematics achievement at grade 9. *Journal of Experimental Education, 69*(3), 245. doi: 10.1080/00220970109599487

OECD. (2004). First Results From PISA 2003: Executive Summary.

OECD. (2010). PISA 2009 Results: Executive Summary.

Park, K. (2004). *Factors contributing to East Asian students'high achievement:Focusing on East Asian teachers and their teaching* Paper presented at the APEC Educational Reform Summit, Beijing,China.

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical Linear Models : Applications and Data Analysis Methods* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Rutkowski, L., Gonzalez, E., Joncas, M., & von Davier, M. (2010). International large-acale assessment data: Issues in secondary analysis and reporting. *Educational Researcher, 39*(2), 142-151 doi: 10.3102/0013189X10363170

Teodorović, J. (2011). Classroom and school factors related to student achievement: What works for students? *School Effectiveness and School Improvement, 22*(2), 215-236. doi: 10.1080/09243453.2011.575650

Teodorović, J. (2012). Student background factors influencing student achievement in Serbia. *Educational Studies, 38*(1), 89-110. doi: 10.1080/03055698.2011.567027

Thomson, S. (2008). Examining the evidence from TIMSS: Gender differences in Year 8 science achievement in Australia. *Studies in Educational Evaluation, 34*, 73-81. doi: 10.1016/j.stueduc.2008.04.003

Trautwein, U., & Koller, O. (2003). The relationship between homework and achievement--Still much of a mystery. *Educational Psychology Review, 15*(2), 115-145.

Walberg, H. J. (2003). Improving educational productivity. Washington, DC: Education Resources Information Center.

Wang, Z., Osterlind, S. J., & Bergin, D. A. (2012). Building mathematics achievement models in four countries using TIMSS 2003. *International Journal of Science and Mathematics Education, 10*, 1-28.

Wilkins, J. L. M. (2004). Mathematics and Science Self-Concept: An International Investigation. [Article]. *Journal of Experimental Education, 72*(4), 331-346.

Wößmann, L. (2005). Educational production in East Asia: The impact of family background and schooling policies on student performance. *German Economic Review, 6*, 331-353. doi: 10.1111/j.1468-0475.2005.00136.x

Zhu, Y., & Leung, F. K. S. (2011). Motivation and achievement: Is there an East Asian model? *International Journal of Science and Mathematics Education, 9*, 1189-1212. doi: 10.1007/s10763-010-9255-y

Zuzovsky, R. (2008). Closing achievement gaps between Hebrew-speaking and Arabic-speaking students in Israel: Findings from TIMSS-2003. *Studies in Educational Evaluation, 34*, 105-117. doi: 10.1016/j.stueduc.2008.04.006

Appendix 1

TABLE 5

TIMSS 2007 International Benchmarks of Mathematics Achievement for Grade 4

Advanced International Benchmark – 625
Students can apply their understanding and knowledge in a variety of relatively complex situations and explain their reasoning. They can apply proportional reasoning in a variety of contexts. They demonstrate a developing understanding of fractions and decimals. They can select appropriate information to solve multi-step word problems. They can formulate or select a rule for a relationship. Students can apply geometric knowledge of a range of two- and three-dimensional shapes in a variety of situations. They can organize, interpret, and represent data to solve problems.
High International Benchmark – 550
Students can apply their knowledge and understanding to solve problems. Students can solve multi-step word problems involving operations with whole numbers. They can use division in a variety of problem situations. They demonstrate understanding of place value and simple fractions. Students can extend patterns to find a later specified term and identify the relationship between ordered pairs. Students show some basic geometric knowledge. They can interpret and use data in tables and graphs to solve problems.
Intermediate International Benchmark – 475
Students can apply basic mathematical knowledge in straightforward situations. Students at this level demonstrate an understanding of whole numbers. They can extend simple numeric and geometric patterns. They are familiar with a range of two-dimensional shapes. They can read and interpret different representations of the same data.
Low International Benchmark – 400
Students have some basic mathematical knowledge. Students demonstrate an understanding of adding and subtracting with whole numbers. They demonstrate familiarity with triangles and informal coordinate systems. They can read information from simple bar graphs and tables.

Source: TIMSS 2007 International Mathematics Report (Mullis, et al., 2008, p. 68)

Appendix 2

Scale and Index Development

Six scales and two index variables were developed based on the recoded questionnaire items with reference to *TIMSS 2007 User Guide* (Foy & Olson, 2009). When recoding the original items for scale development, the general principle was that a higher code represented a more favourable characteristic. The scale for student's positive affect to mathematics was based on student's responses to three items in the student questionnaire, and each item was recoded on 4-point scale (1=Disagree a lot, 2=Disagree a little, 3=Agree a little, 4=Agree a lot). The scale for student's self-confidence in learning mathematics was based on student's responses to four items in the student questionnaire, and each item was recoded on 4-point scale (1=Disagree a lot, 2=Disagree a little, 3=Agree a little, 4=Agree a lot). The scale for teacher's perception of few or no limitations on mathematics instruction due to student factors was based on teacher's responses to five items in the teacher questionnaire, and each item was recoded on 4-point scale (1= A lot, 2=Some, 3= A little, 4=Not at all). The scale for teacher's perception of school climate was based on teacher's responses to eight items characterizing his/her school in the teacher questionnaire, and each item was recoded on 5-point scale (1=Very low, 2=Low, 3=Medium, 4=High, 5=Very high). The scale for availability of school resources for mathematics instruction was based on principal's responses to ten items characterizing the extent to which the school's instruction capacity is affected by shortage of resources, and each item was recoded on 4-point scale (1=A lot, 2=Some, 3=A little, 4=None). The scale for principal's perception of school climate was based on principal's responses to eight items characterizing his/her school in the school questionnaire, and each item was recoded on 5-point scale (1= Very low, 2=Low, 3=Medium, 4=High, 5=Very high). Reliability analyses indicated that the six scales were fairly reliable measures, with all Cronbach's alpha values above 0.7. The items and descriptive statistics are displayed in Table 6.

In addition, two indices were created by summating relevant items which were recoded into dummy variables. The index of student's perception of school safety was calculated by adding up student's responses to five items in the student questionnaire: 'In school, did any of these things happen during the last month? (a) something of mine was stolen; (b) I was hit or hurt by other student(s); (c) I was made to do things at I didn't want to do by other students; (d) I was made fun of or called names; (e) I was left out of activities by other students (0=No, 1=Yes)'. Reliability analysis revealed that Cronbach's alpha value for this index was 0.58. Despite relatively low reliability, this index was retained for use in data analysis. The index of teacher professional development opportunity was created by summing six recoded items related to professional development in the teacher questionnaire: 'In the past two years, have you participated in professional development in any of the following? (a) mathematics content, (b) mathematics pedagogy/instruction, (c) mathematics curriculum, (d) integrating information technology into mathematics, (e) improving students' critical thinking or problem solving skills, (f) mathematics assessment (0=No, 1=Yes)'. Reliability analysis revealed that this index variable was acceptable, with Cronbach's alpha value being 0.81.

The summated scores for each scale and index variable were standardized into z score for subsequent HGLM analysis.

TABLE 6

Items and Descriptive Statistics for Scale

Scale and Item	*M*	*SE*	*α*
Positive affect to mathematics			0.86
I enjoy learning mathematics.	3.22	0.02	
Mathematics is boring.	3.19	0.02	
I like mathematics.	3.20	0.02	
Self-confidence in learning mathematics			0.75
I usually do well in mathematics.	2.92	0.02	
Mathematics is harder for me than for many of my classmates.	2.67	0.02	
I am just not good at mathematics.	2.70	0.02	
I learn things quickly in mathematics.	2.81	0.02	
Teacher's perception of few or no limitations on mathematics instruction due to student factors			0.80
Students with different academic abilities.	2.11	0.04	
Students who come from a wide range of backgrounds.	2.61	0.05	
Student with special needs.	2.80	0.06	
Uninterested students.	2.31	0.05	
Disruptive students.	2.36	0.05	
Teacher's perception of school climate			0.82
Teachers' job satisfaction.	3.46	0.04	
Teachers' understanding of the school's curricular goals.	3.80	0.04	
Teachers' degree of success in implementing the school's curriculum.	3.63	0.03	
Teachers' expectations for student achievement.	3.86	0.04	
Parental support for student achievement.	3.29	0.04	
Parental involvement in school activities.	3.21	0.04	
Students' regard for school property.	3.11	0.04	
Students' desire to do well in school.	3.37	0.03	
Availability of school resources for mathematics instruction			0.90
Instructional materials.	3.92	0	
Budget for supplies.	3.89	0	
School buildings and grounds.	3.47	0	
Heating/cooling and lighting systems.	3.77	0	
Instructional space.	3.29	0	
Computers for mathematics instruction.	3.71	0	
Computer software for mathematics instruction.	3.61	0	
Calculators for mathematics instruction.	3.81	0	
Library materials relevant to mathematics instruction.	3.59	0	
Audio-visual resources for mathematics instruction.	3.63	0	
Principal's perception of school climate			0.83
Teachers' job satisfaction.	3.82	0	
Teachers' understanding of the school's curricular goals.	3.97	0	
Teachers' degree of success in implementing the school's curriculum.	3.81	0	
Teachers' expectations for student achievement.	3.93	0	
Parental support for student achievement.	3.60	0	
Parental involvement in school activities.	3.27	0	
Students' regard for school property.	3.79	0	
Students' desire to do well in school.	3.82	0	