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A three-level multilevel analysis of Singaporean eighth-graders science achievement

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ABSTRACT

This study explores the sources of variability in achievement in science for Singaporean students as a function of student-, classroom, and school-level factors. Using the 2007 Trends in the International Mathematics and Science Study (TIMSS) dataset, the science achievement scores and questionnaire responses of 4599 eighth-graders from 326 classrooms of 164 schools were analysed. A three-level multilevel linear modelling was employed; the results indicate that the student- and school-level differences, equally, accounted for about one-fifth of the total variance in science achievement. In contrast, more than one-half of the total variance was accounted for by the classroom-level differences. Science self-concept, teaching limitations, and school climate as perceived by the school principals were the strongest predictors of science achievement at the student, classroom, and school levels, respectively.

1. Introduction

Singapore is a city-state, where education has always been a top priority. The educational system is centralised, and the syllabi and assessment guidelines for all the school subjects are provided by the Ministry of Education. Science is one of the fundamental subjects and there is great emphasis on the teaching and learning of this subject. Science education begins formally when students are in third-grade at primary school; however, it is taught and learned in grades one and two curricula indirectly through language and other learning activities. From the upper primary level (third grade) onward, students will have specialist teachers in science. Singapore is a diverse language environment in which Malay, Chinese, Tamil, and English are the main language groups, however, English is the medium of instruction (Quek et al., 2008).

The findings from Trends in the International Mathematics and Science Study (TIMSS) indicate that Singapore has consistently been the top-scoring country in science achievement (Beaton et al., 1996; Martin, Mullis, & Foy, 2008; Martin, Mullis, Gonzalez, & Chrostowski, 2004; Martin, Mullis, Gonzalez, et al., 2000). The mean achievement of Singaporean eighth-graders in TIMSS assessments (1995, 1999, 2003, and 2007), on average, is greater than the international mean by about 81 points. In addition, TIMSS described students' achievement at four points known as "International Benchmarks" in relation to the science achievement test. These points are advanced level with a mean score of 625, high (550), intermediate (475), and low (400). Over the four cycles of the study, the percentage of Singaporean students achieving the advanced level is higher than those from all the participating countries (Martin et al., 2008). The cross-school differences in students' achievement are usually high in top-scoring countries (Martin, Mullis, Gregory, Hoyle, & Shen, 2000). For example, the 2007 TIMSS data show that the range and standard deviation of science achievement is 536 and 100 within classrooms, 418 and 94 between classrooms within schools, and 325 and 73 across schools, respectively, highlighting a large difference in the achievement at all three levels.

In the first educational large-scale study (Coleman et al., 1966), it was reported that school has a slight impact on academic achievement compared to students' socio-economic status (SES). Beginning with the Coleman report, a large number of studies (Borman & Dowling, 2010; Chiu, 2007; Chiu & Klassen, 2010; Chudgar & Luschei, 2009; Hill & Rowe, 1996; Howie, 2003; Lee, 2000; Martin, Mullis, Gregory, et al., 2000; Raudenbush & Willms, 1995) were carried out to examine the effect of the school on achievement and they documented that the school accounted for a considerable portion of variability in students' academic achievement. Thus, there is an international agreement in the literature concerning the role of the school in respect of students' learning.

In contrast, there is no agreement in the past studies pertaining to the question of how the variation in the school outcomes is distributed within and between-school differences. For instance, a cross-country study using the 1995 TIMSS indicates that school accounted for a portion of variance in eighth-graders science achievement that ranged between 7% in Cyprus, Japan, Norway, Slovenia, and South Korea, equally, and 51% in Romania. The average effect of school was 22.97%, whilst it was 39% in Singapore (Martin, Mullis, Gregory, et al., 2000). Students are taught within classrooms, and classrooms, in turn, are organised within schools, thus, information relevant to students' achievement is multilevel in nature. Despite widespread agreement in the literature concerning the contribution of school to students' achievement, it is less known whether the impact of the school stems largely from the

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classroom or school-level factors. This is because two-level hierarchical linear modelling (student as level-1 and the combination of classroom and school as level-2) was used in most of the past studies. Due to the sampling design, it was not possible to differentiate between the effect of the classroom and the school, therefore, whether the students' achievement is influenced more by the classroom-level factors or those of the school level is an open question that is addressed in this study.

1.1. Relationship between the student-level factors and achievement

The link between students' academic self-concept and academic achievement has been explored in past studies (Guay, Marsh, & Boivin, 2003; Guay, Ratelle, Roy, & Litalien, 2010; Ireson & Hallam, 2009; Ma & Kishor, 1997; Marsh & Craven, 1997). The results uncover that there is a strong positive association between the two variables. The relationship between science self-concept and science achievement has also been investigated (Kaya & Rice, 2010; Wang, Oliver, & Staver, 2008; Wilkins, 2004), it was found that a higher level of self-concept is linked to a higher score in science. Consistent with the self-enhancement model, self-concept is one of the important predictors of academic achievement (Guay et al., 2003). Similarly, students' self-confidence proved to be more strongly related to achievement than other affective variables (Stoel, Peetsma, & Roeleveld, 2003).

Student's attitude towards science is another factor affecting achievement that has been adequately investigated in past studies (Akpinar, Yildiz, Tatar, & Ergin, 2009; Caleon & Subramaniam, 2008). Caleon and Subramaniam (2008) reported that Singaporean students have a positive attitude towards the enjoyment of science, preference for science-related careers, and an appreciation of the importance of science in the society. The findings, internationally, show that students who have a more positive attitude towards science achieve higher score in science than those with a less positive attitude (Martin et al., 2008). The relationship between students' aspiration for further education and academic achievement is investigated in prior studies (Borman & Dowling, 2010; Chepete, 2008; Martin, Mullis, Gregory, et al., 2000); the results show that students who planned to continue their studies beyond secondary education performed better than other students.

The difference between male and female students in science achievement has been explored and it was found that male students outperformed their female peers (Chiu, 2007; Kuhn & Holling, 2009; Sanchez & Wiley, 2010). The TIMSS 2007 results, internationally, indicate that female eighth-graders performed significantly higher in science than male students. Similarly, Singaporean female students achieved a higher average than their male peers, however, the difference was not statistically significant (Martin et al., 2008). In contrast, recent findings indicate that there is no significant difference between secondary and high school male and female students in science achievement (Liu, Lee, & Linn, 2010).

The effect of students' SES (e.g., parents' education and home educational resources) on achievement in science has been investigated in past studies (Chiu, 2007; Gorard & See, 2009; Martin, Mullis, Gregory, et al., 2000; Martin et al., 2008; Senler & Sungur, 2009; Tomul & Celik, 2009; Wang & Wildman, 1995). The findings show that students from homes where parents have a higher level of education, and have more educational resources tend to perform better in science than students from homes where parents have a lower level of education and have less educational resources. A reanalysis of the data of Coleman et al. (1966) using the multilevel modelling technique, revealed that family background characteristics accounted for 68.33% of the total variance in students' achievement (Borman & Dowling, 2010).

1.2. Relationship between the classroom-level factors and achievement

Inconsistent with the earlier school effectiveness studies (Coleman et al., 1966; Jencks et al., 1972), recent enquiries showed that schools make a difference in students' achievement, and the greater part of the difference is attributed to teachers (e.g., Darling-Hammond, 2000). Teacher is one of the main components of a classroom that play a fundamental role in the learning process of individuals (Croninge, King Rice, Rathbun, & Nishio, 2007; Darling-Hammond & Hudson, 1988; George & Kaplan, 1998; Rivkin, Hanushek, & Kain, 2005). An essential issue in educational policies is whether or not a teacher's qualifications (e.g., certification status, degree level, preparation, and teaching experience) predict students' achievement (Croninge et al., 2007). Darling-Hammond (2000) reported that the measures of teacher preparation and certification are highly linked to students' achievement both before and after controlling for students poverty and language status. Teacher's gender and teaching experience were found to have no significant association with students' science achievement (Liu et al., 2010). The findings indicate that students' science achievement is higher in schools where the science teachers had a positive view of school climate compared to other schools (Martin et al., 2008).

The teaching and learning process takes place in context and not in isolation (Oakes, 1989). In any formal educational system, students are grouped into classrooms, and classrooms are organised into schools. In this system, students' academic achievement is not only influenced by their characteristics, such as ability and family background, it is also affected by many factors at the classroom and school levels. Thus, the classroom and school are the contexts of the learning process. The context or compositional effect refers to the effects of the social context of the classroom and school on individual students' achievement, which is the so-called “frog pond” (Hox, 2002) that stems from the seminal work of Robinson (Robinson, 1950). For example, a student with a low level of educational aspiration who attends a school where the educational aspiration of the student body is high may perform better academic achievement than a student with a similar level of educational aspiration who attends a school where the average educational aspiration of the student body is low. In other words, the school average of educational aspiration may influence students' achievement above and beyond the individual level of educational aspiration. The effects of the classroom and school contextual or compositional factors were tested in this study to examine the extent to which the compositional effects influence students' achievement. Therefore, all the student-level predictors were aggregated to the classroom level by averaging the data from all students within each classroom and then they were aggregated to the school level by averaging the data from all students within each school.

1.3. Relationship between the school-level factors and achievement

The teaching and learning process may occur in many different places (e.g., home), it can be delivered through different ways (e.g., TV, the Internet, tutorial teacher, or friends), however, school still remains as the main channel that bridges students to the society (Freiberg, 2005). Researchers have suggested that school climate is an essential factor in effective schools that can significantly predict students' academic achievement (Hoy & Hannum, 1997; Van Horn, 2003). The empirical evidence indicates that a positive school climate is associated with academic achievement, school success, effective violence prevention, students' healthy development, and teacher's retention (Cohen, McCabe, Michelli, & Pickeral, 2009). In another study the researcher reported that academic peers, as a school climate indicator are strongly associated with students' academic achievement, whereas the effect of other indicators, such as attitude towards school, student morale, student behaviour, and disciplinary climate are small and not statistically significant (Marks, 2010).

Good attendance at school (GAS) is the evaluation of the school principals concerning the seriousness of students' behaviour which is measured by: arriving late at school, skipping class and absenteeism. The findings, internationally, show that the average achievement is higher in schools where these problems are not serious (Martin et al., 2008; Mullis, Martin, & Foy, 2008). A cross-national study indicates that GAS accounted for a slight portion of the variance in the achievement of Singaporean eighth-graders (Jurdek, 2009), indicating that these problems are not serious among the Singaporean schools. In the 2007 TIMSS, Singapore, with only 4% of schools, was one the lowest countries having serious problem with students' behaviour. However, the achievement average of this group of schools was lower by 211 scale points compared to schools where the students' behaviour was not serious (Martin et al., 2008).

2. Research questions

This research is designed to answer the following questions:

1. How the variability in the science achievement of Singaporean eighth-graders is distributed within classrooms, between classrooms, and across schools?
2. What proportion of the variance in the science achievement of Singaporean eighth-graders is associated with science self-concept, attitude towards science, educational aspiration, gender, the language spoken at home, parents' education, and home educational resources?
3. What proportion of the variance in the science achievement of Singaporean eighth-graders is associated with teacher's gender, teaching experience, level of education, major of study, perception of school climate, teaching limitations, and the average of the student-level factors?
4. What proportion of the variance in the science achievement of Singaporean eighth-graders is associated with school climate, school resources for teaching science and the school mean of the student-level factors?

3. Method

3.1. Participants

The study involves 4,599 eighth-graders nested within 326 classrooms from 164 Singapore secondary schools which participated in TIMSS 2007. TIMSS uses a two-stage cluster sampling design. Schools were sampled at random, and one intact classroom was selected. However, Singapore added a third stage, and students were randomly selected from two classrooms per school, instead of one intact classroom (Joncas, 2008). The average class size was 14 students per classroom. Consequently, the data structured a three-level multilevel system: student as level-1, classroom as level-2, and school as level-3. It is worth mentioning that the level-1 sample size was reduced to 4,552 students after deletion of cases with missing data.

3.2. Measures

Since 214 items were used to measure students' achievement in science, the matrix-sampling or rotated-booklet design was used in which individual students only completed a small sample of the items. Consequently, TIMSS computed four different types of score: raw scores, standardised scores, Rasch scores, and a set of five plausible values (Foy & Olson, 2009). The five plausible values, which are an estimate of how a student might have performed had he or she been administered the total items (Hastedt, 2006), are served as the predicted or outcome variable.

As for the predictors, at the student level, science self-concept, attitude towards science, educational aspiration, gender, the language most frequently spoken at home, parents' education, and home educational resources were derived from the student's questionnaire and used to explain the student-level variance in science achievement. At the classroom level, the science teacher's characteristics (gender, teaching experience, level of education, and major of study), teaching limitations, and teacher's perception of school climate were obtained from the teacher's questionnaire and employed to explain the classroom-level variance in science achievement. At the school level, school resources for science instruction, school climate as perceived by the school principals, and GAS were derived from the school principal's questionnaire and used to explain the school-level variance in science achievement. The detailed information of the predictors is given in Appendix A.

3.3. Data considerations and data analysis

Missing data is a challenging issue in multilevel analysis, especially at the group or upper levels (Gibson & Olejnik, 2003; McCoach, 2010), because any group-level unit with missing data excludes all individual units nested within the group-level unit from the analyses. At the student level, the outcome variable was without missing data, but there were missing data among the predictors ranging from 0.1% for the “language spoken at home” and “educational aspiration”, equally, to 0.7% for “parents' education”. According to Tabachnik and Fidell (2007), if a small fraction of data (e.g., 5% or less) is randomly missing in a large dataset, the problem is not serious. Thus, the listwise deletion method was used for treatment of missing data. At the classroom level, the total of missing data ranged from a low of 1.2% for the “teacher's level of education” to 4.3% for the “teacher's major”. At the school level, similarly, the highest amount of missing data was 4.3% for “school resources”. To handle missing data at the classroom and school levels, expectation maximisation (Enders, 2010; Rubin, Witkiewitz, Andre, & Reilly, 2007) was used.

One of the most important assumptions of multilevel modelling is that the residual or within-group errors should be normally distributed (Raudenbush & Bryk, 2002). To check this assumption, a Q–Q probability plot was produced (Appendix C) using the residual files generated by hierarchical linear modelling (HLM) software (Raudenbush, Bryk, Cheong, Congdon, & Toit, 2004) after the full model was fitted. The plot resembles a 45 degree line, thereby indicating that the residuals are normally distributed (Raudenbush et al., 2004). In order to detect multicollinearity among the predictors, a correlation matrix was performed (Field, 2009; Orme & Orme, 2009) for which the results are given in Appendix B. As the correlation coefficients among the predictors themselves are far less than the criterion limit [0.80] (Field, 2009; Orme & Orme, 2009), it was concluded that multicollinearity was not an issue in this study. To check outliers in the outcome variable, the five plausible values were converted to the standard scores. Nearly all the standard scores were within three standard deviations of the mean, indicating that there were no outliers in the outcome variable (Hair, Anderson, Tatham, & Black, 1998; Stevens, 2002).

A three-level hierarchical linear modelling was applied utilising HLM 6.07 (Raudenbush et al., 2004). As mentioned, a multistage cluster sampling design was used in the TIMSS. The likelihood of selection sample units is not equal in the multistage cluster sampling (Asparouhov, 2005; Rabe-Hesketh & Skrondal, 2006). To avoid the bias in parameter estimates and to produce nationally representative findings, sample weights—HOUSE (the student sample weight), SCIWGT (the science teacher weight), and SCHWGT (the school weight), were used at the student, classroom, and school level, respectively (Foy & Olson, 2009; Rutkowski, Gonzalez, Joncas, & von Davier, 2010).

Centering or scaling of predictors or exploratory variables in hierarchical linear modelling refers to subtracting a mean or any other constant value from all the individual raw scores of the predictors and changing the raw metric into the deviance from the mean score or the constant value (Tabachnik & Fidell, 2007; Wu & Wooldridge, 2005). This assists in changing the interpretation of the intercept (Kreeft & de Leeuw, 1998), as in regression the intercept is defined as the expected score on the outcome variable for someone whose scores on all the predictors in the model are zero (Raudenbush & Bryk, 2002). Since in the social sciences, attributes usually have no meaningful or real zero (Kreeft & de Leeuw, 1998), the predictors must be transferred. Consequently, the intercept will be interpreted as an expected score on the outcome variable for someone whose scores on a particular predictor is equal to the group mean or grand mean depending on the type of centering approach the analyst uses. All the predictors were centred on the grand mean at both the student and classroom levels (Enders & Tofighi, 2007; Hofmann & Gavin, 1998; Hox, 2002; Kreft, Deleeuw, & Aiken, 1995).

4. Results

Multilevel data analysis begins with estimating the unconditional, null or one-way random effect analysis of variance [ANOVA] (Raudenbush & Bryk, 2002). This model does not explain any variance of the outcome variable; rather, it is motivated to partition the total variance in the outcome variable into the different levels in the data. In response to the first research question, the null model was estimated. The HLM equations of the unconditional model are

Student-level model: $Y_{ijk} = \pi_{0jk} + e_{ijk}$, where Y_{ijk} is science achievement of student i within classroom j within school k; π_{0jk} is the mean achievement of classroom j within school k; and e_{ijk} is student effect or the deviation of student i score from the classroom mean score.

Classroom-level model: $\pi_{0jk} = \beta_{00k} + r_{0jk}$, where β_{00k} is mean achievement in school k and r_{0jk} is classroom effect or the deviation of classroom j mean score from the school mean.

School-level model: $\beta_{00k} = \gamma_{000} + u_{00k}$, where γ_{000} is the grand mean or achievement average across all schools in the sample and u_{00k} is school effect or the deviation of school k mean score from the grand mean.

The estimated variance components from the unconditional model were $\sigma^2 = 2067.42$, $\tau_\pi = 6283.84$, and $\tau_\beta = 2370.58$ at student, classroom and school levels, respectively (Table 1 the null model). The intra-class correlation (ICC), which represents the proportion of the variance in science achievement between-classrooms within schools and across schools, was computed as:

$$\textit{Classroom level ICC}, \tau_\pi / \left(\sigma^2 + \tau_\pi + \tau_\beta\right) = 6283.84/(2067.42 + 6283.84 + 2370.58) = 0.5856.$$

$$\textit{School level ICC}, \tau_\beta / \left(\sigma^2 + \tau_\pi + \tau_\beta\right) = 2370.58/(2067.42 + 6283.84 + 2370.58) = 0.2233.$$

This indicates that 58.56% and 22.33% of the total variance in science achievement was accounted for by the classroom- and school-level differences, respectively. The rest of the variance $[1-(0.5856+0.2233) = 0.1911]$ was due to within-classroom differences.

In response to the second research question, two models were estimated using the student-level factors. In order to assess the effect of the individual factors on science achievement, the factors were divided into two groups and then added to the model sequentially. The first model was estimated with the attitudinal factors, the HLM equations are presented here and the results are given in Table 1.

4.1. Student-level model

$Y_{ijk} = \pi_{0jk} + \pi_{1jk}$ (self-con$_{ijk}$ − **self-con...**) + π_{2jk} (attitude$_{ijk}$ − **attitude...**) + π_{3jk} + (aspiration$_{ijk}$ − **aspiration...**) + e_{ijk}, where π_{1jk}… π_{3jk} are the coefficients of the predictors that indicate the direction and the strength of the association between each predictor and achievement. The bold and italicised parts of the model represent that the predictors were centred on the grand mean.

$$\begin{aligned}\text{Classroom-level model: } \pi_0 &= \beta_{00} + r_0\\ \pi_1 &= \beta_{10} + r_1\\ \pi_2 &= \beta_{20} + r_2\\ \pi_3 &= \beta_{30} + r_3\end{aligned}$$

$$\begin{aligned}\text{School-level model: } \beta_{00} &= \gamma_{000} + u_{00}\\ \beta_{01} &= \gamma_{100} + u_{10}\\ \beta_{02} &= \gamma_{200} + u_{20}\\ \beta_{03} &= \gamma_{300} + u_{30}\end{aligned}$$

Model one accounted for 14.98% of the total student-level variance. Science self-concept was the strongest predictor of achievement; a one scale-point increase in science self-concept increased achievement by 19.11 points. This was followed by attitude towards science and educational aspiration. Likewise, a one scale-point increase in attitude towards science increased achievement by 6.33 points, and an increase of one level in aspiration for further education increased achievement by 5.12 points.

Model two was estimated by adding gender, the language spoken at home, parents' education, and home educational resources. This model explained only 3.60% of the students-level variance. Home educational resources yielded the strongest link to achievement, with each scale point higher on the home educational resources, science achievement is expected to increase by 13.49 scale points, after accounting for the other factors in the model. Gender was the second strongest predictor, after controlling for the attitudinal and the family background factors, male students outperformed female students by 11.58 points. This was followed by the language spoken at home; students who spoke English at home more frequently achieved 10.33 points higher than those who did less frequently. There was no statistically significant link between parents' education and achievement, when the other factors in the model were taken into account.

In response to the third research question, three models were estimated. Model three was constructed with the teacher-related variables (gender, teaching experience, level of education, and major of study). The HLM equations of the model are presented here and the results are given in Table 1.

Student-level model: $Y_{ijk} = \pi_0 + e$
Classroom-level model: $\pi_0 = \beta_{00} + \beta_1$ (gender) + β_2 (experience) + β_3 (education) + β_4 (major) + r_0

$$\begin{aligned}\text{School-level model: } &\beta_{00} + \gamma_{000} + u_{00}\\ &\beta_{01} + \gamma_{010} + u_{01}\\ &\beta_{02} + \gamma_{020} + u_{02}\\ &\beta_{03} + \gamma_{030} + u_{03}\\ &\beta_{04} + \gamma_{040} + u_{04}\end{aligned}$$

Model three accounted for only 4.12% of the total classroom-level variance in science achievement. Teacher's gender is significantly linked to achievement, on average, students taught by male teachers achieved 26.73 points lower than their peers who were taught by female teachers. The other three variables had no significant link to achievement.

Model four was estimated by introducing school climate as perceived by the science teachers and teaching limitations. The model accounted for 6.44% of the classroom-level variance; however, it contributed to 53.97% of the school-level variance. Teaching limitations was the most important predictor of achievement, a one scale-point increase in teaching limitations decreased achievement by 44.39 points, after controlling for teacher's gender and school climate. The relation of school climate as perceived by science teachers with

Table 1
Parameter estimate.

	Null Model	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6	Model-7	Full model
Intercept	559.80**	559.95**	560.03**	559.90**	559.81**	559.99**	559.65**	559.73**	559.95**
	(5.94)	(5.67)	(5.56)	(5.88)	(5.03)	(2.61)	(5.21)	(2.70)	(4.26)
Student-level factors									
Science self-concept		19.11**	16.97**						16.91**
		(1.09)	(1.10)						(1.09)
Attitude towards science		6.34*	6.39*						6.42*
		(1.56)	(1.54)						(1.55)
Educational aspiration		5.11*	4.25*						4.26*
		(1.21)	(1.17)						(1.17)
Gender			11.58**						11.52**
			(1.88)						(1.88)
Language spoken at home			10.33**						10.30**
			(1.79)						(1.78)
Parents' education			2.11						2.09
			(1.81)						(1.18)
Home educational resources			13.49*						13.41*
			(4.23)						(4.22)
Classroom level factors									
Teacher's gender				−26.73*	−20.58*	−5.52			−22.79*
				(10.69)	(10.22)	(4.95)			(9.533)
Teaching experience				0.85	–	–			0.28
				(2.40)					(1.61)
Teacher's level of education				6.97	–	–			10.62
				(8.47)					(7.83)
Teacher's major				−17.37	–	–			−5.79
				(10.79)					(9.05)
Teaching limitations					−44.39**	−11.74*			−39.15**
					(5.89)	(3.29)			(5.20)
Teacher's perception of school climate					29.15*	8.67			19.34*
					(8.27)	(4.53)			(7.27)
Mean-math self-concept						−11.53			
						(9.97)			
Mean-attitude towards science						46.00**			
						(12.22)			
Mean-educational aspiration						97.20**			
						(7.55)			
Mean-students gender						−6.10			
						(9.01)			
Mean-language spoken at home						−3.53			
						(6.20)			
Mean-parents' education						36.50**			
						(9.44)			
Mean–home educational resources						177.14**			
						(34.22)			
School level factors									
GAS							−36.81*	−7.84	−23.29*
							(10.08)	(5.16)	(8.20)
School resources							−12.39	–	−3.02
							(18.38)		(17.23)
School principal's perception of school climate							51.66**	14.12*	40.94**
							(11.56)	(5.82)	(9.20)
Mean-science self-concept								−17.13	
								(17.15)	
Mean-attitude towards science								41.08*	
								(18.85)	
Mean-educational aspiration								103.67**	
								(13.85)	
Mean-students gender								−5.43	
								(9.78)	
Mean-language spoken at home								6.68	
								(7.68)	
Mean-parent education								46.52*	
								(13.41)	
Mean-home educational resources								179.64*	
								(62.01)	
Variance components									
Student-level variance σ^2	2067.42	1757.71	1694.48	2067.43	2067.40	2067.42	2067.45	2067.46	1694.48
Classrooms-level variance	6338.01	5905.37	5796.42	6076.67	5685.05	1347.40	6322.21	4159.92	5026.69
School-level variance	2416.88	2145.08	1974.55	2443.81	1112.52	256.18	1097.15	7.35	317.56
Student-level reliability	0.43	0.42	0.40	0.44	0.28	0.25	0.25	0.25	0.26
Classroom-level reliability	0.98	0.98	0.98	0.98	0.97	0.90	0.98	0.97	0.98

Note; *p<.05; **p<.001; inside the parentheses are standard errors.

achievement was also significant; a one scale-point increase in teacher's perception of school climate increased achievement by 29.15 points after controlling for the other two factors in the model.

After controlling for the classroom-level factors, the portion of the classroom-level variance in achievement remained significantly to be estimated. Thus, all the student-level variables were aggregated to the classroom level and then added to model five. Model five accounted for 76.30% and 76.97% of the classroom- and school-level variance in achievement, respectively. A few interesting results emerged, classroom-mean of home educational resources was the most important predictor, and a one scale-point increase in the classroom-mean home educational resources is associated with 177.14 points higher in achievement. This was followed by classroom–mean of education aspiration; in which a one scale-point increase in classroom–mean aspiration for further education increased achievement by 97.20 points. Classroom–mean attitude towards science was the third important predictor; a one scale-point increase in classroom-mean attitude towards science increased achievement by 46 points. Classroom–mean parents' education was the next most important predictor in which a one scale-point increase in classroom–mean parents' education is associated with a higher classroom achievement average by 36.50 points.

In response to the fourth research question, two models were estimated. Model six was constructed with three school-level factors: GAS, school resources for science instruction, and school climate as perceived by the school principals. The HLM equations for model six are

Student-level model: $Y_{ijk} = \pi_0 + e$
Classroom-level model: $\pi_0 = \beta_{00} + r_0$
School-level model: $\beta_{00} = \gamma_{000} + \gamma_{001}$ (GAS) $+ \gamma_{002}$ (school resources) $+ \gamma_{003}$ (school climate) $+ u_{00}$

The results indicate that out of the total school-level variance in science achievement, 54.60% is accounted for by these three factors. School climate was the most important predictor; one scale-point higher in positive view of the school principals of school climate associated with 51.76 points higher in achievement average. This was followed by GAS, for which one scale-point increase in this factor, science achievement would decrease by 37.05 points. School resources for science instruction had no statistically significant link to achievement, when the other two factors in the model were taken into account. Similar to the classroom level, after removing school resources (because it had no significant link to achievement) all the student-level factors were added to model seven. Model seven accounted for almost the total (99.33%) variance in the school achievement average. The school–mean of home educational resources was the strongest predictor. After controlling for the school climate and GAS, a one scale-point increase in school–mean home educational resources increased achievement average by a score of 179.64. This was followed by the school–mean of educational aspiration, parents' education, and attitude towards science. After controlling for the other factors in the model, schools with students who planned to continue their study beyond the secondary school, schools with students whose parents had a higher level of education, and schools with students who have a more positive attitude towards science, achieved a higher average compared to other schools.

To assess the relations of the predictors from the three levels, all the factors were entered into the model simultaneously (the full model). The full model explained 18.03%, 20.69% and 86.86% of the student-, classroom- and school-level variance, respectively.

5. Discussion

Science achievement varies significantly across the Singaporean schools; some schools performed better than other schools. The student- and school-level factors accounted for a similar portion (about one-fifth) of the total variance in achievement, whilst the classroom-level factors explained a substantial part of the variance (more than half). Thus, consistent with past studies (Fullarton, 2004; Kaya & Rice, 2010; Liou, 2010; O'Dwyer, 2000), schools differ in students science achievement, even in Singapore where the educational system is centralised and the total population is urban based. Additionally, science achievement differs substantially from one classroom to another within schools. The proportion of the explained variance in science achievement by the school-level differences in this study is within the range found by Coleman and colleagues in the first large-scale study (1966) and the range found in a recent cross-national study of eighth-graders science achievement (Martin, Mullis, Gregory, et al., 2000). Parents are often looking for a school to improve students' academic achievement (Rumberger & Palardy, 2004), thus, it is important to them which school their children go to, however, the classroom to which they are assigned within a school is much more important. The results of this study, in relation to the first research question and the reviewed literature, provide additional insight for the debate on the question whether or not schools make a difference which began with the “Coleman report” (Coleman et al., 1966).

The students' attitudinal factors contributed to a considerable proportion of the variance in science achievement. Self-concept in learning science was the strongest predictor. The coefficient of self-concept was almost three times greater than that of attitude towards science. This supports the findings from previous studies (Howie, 2006; Ma & Kishor, 1997; Papanastasiou, 2008; Wilkins, 2004). Science self-concept refers to a student's perception or belief in his or her own ability to do well in science (Wilkins, 2004). Therefore, it is expected that students with a higher level of self-concept perform better in science than other students. Interestingly, after controlling for the family background factors the coefficient of self-concept reduced slightly, highlighting that the family background factors do not mediate the relation of self-concept and achievement.

Attitude towards science and aspiration for further education had an almost similar effect on science achievement. Similar to the self-concept, the strength of the relations of these two factors with achievement remained stable when the family background factors were controlled, however, the coefficients of home educational resources, the language spoken at home, and gender were substantially larger than those of attitude and aspiration. This shows that students who are confident in learning science do not necessarily have a high level of positive attitude towards science and have more of an aspiration for education; rather, the family background indicators play a stronger role than attitude and aspiration.

Although the links between home educational resources and the language spoken at home with achievement were stronger than those of attitude and aspiration, the family background factors accounted for much smaller (five times) proportion of variance in science achievement than did the attitudinal factors. This might indicate that the variation in the family background factors is relatively slight among Singaporean students, whilst there is considerably variability in the attitudinal factors, particularly in self-concept. Several interesting result emerged between the individual and the contextual effects of the student-level factors. All the student-level factors yielded a significant link to achievement as the individual effect, except for parents' education. In contrast, gender and language were not significantly associated with achievement as the contextual effect either at the classroom level or at the school level. Self-concept was the most important predictor of achievement amongst the other factors at the individual level and its coefficient was greatly larger than those of attitude and aspiration. It was expected that self-concept to be the strongest predictor at the contextual levels as well. In contrast, it yielded no significant link, whilst attitude and particularly aspiration were highly linked to achievement at both the classroom and school level. The reason for this result is not clear, however, it may reflect the point that a competitive climate is dominant on the classrooms and schools environment, and students in groups with a higher measure of aspiration tend to be more eager to continue their education.

The results indicate that the attitudinal factors accounted for a much greater portion of variance in achievements compared to family background. Since schools do not have control over family background factors (parents' education, home educational resources), even though they affect students' achievement, these factors cannot be changed by schools. In contrast, schools do have control over students' attitudinal factors (self-concept, attitude towards subject matters, and educational aspiration). In addition, creating, developing, reforming, and reinforcing self-concept in learning school subjects, and positive attitude among students towards subject matters are of the most important objectives of the educational system in any society. Furthermore, students spend more time in school than in other places outside the home, and most of the developmental tasks with which students are confronted in school need to be solved in school. Thus, schools have a considerable impact on students' development (Eccles & Wigfield, 2002). Consequently, this finding has an important implication for educational practitioners in Singapore to reinforce and promote attitudinal characteristics through the curriculum, extra curriculum activities, and the teaching and learning process.

Consistent with the literature (Darling-Hammond, 2000; Howie, 2004; Martin et al., 2008), students whose home language is other than the language that is used in TIMSS assessment (English) stayed significantly behind their peers who spoke English at home, even after controlling for the attitudinal and family background factors. Usually, students whose native language is different from the language used for the instruction belong to the minority or immigrant groups that are economically disadvantaged compared to the other students. However, in the present study some indicators of SES (parents' education, home educational resources) were taken into account, the difference between English and non-English speaking students in science achievement might be attributed to the other SES indicators, such as family structure (the number of siblings, living with two parents, single parent, or stepparents, parents occupation and family income). Further research can explore the sources of difference in science achievement between these two groups of students.

Parents' education had no significant link to individual student's scores, even after controlling for all the factors from the three levels, whereas it yielded a significant link to achievement at both classroom and school level as contextual factor. A possible explanation for this inconsistency is that parents have less time to spend with their children at home to assist them in homework and assignments and the home educational possessions (computer, study deck, and books) compensate for the effect of parents' education. In contrast, parents maintain a close connection with the school and they are involved in school activities and influence students' achievement indirectly. In addition, from the theoretical perspective, the attitudinal characteristics (self-concept, attitude, and aspiration) play a more important role in academic achievement than the parents' education. This is confirmed by obtaining a low significant coefficient of the parents' education before the other student-level factors were controlled.

The large classroom-level difference in science achievement can be attributed to teacher's gender, teaching limitations, teacher's perception of school climate, and many other factors, such as the policy for assigning students into different classrooms within the school, which are not included in this study. Gender was the only teacher's characteristic that was significantly linked to achievement. The science scores average was higher in classrooms in which students taught by female teachers. After controlling for the teaching limitations and teacher's perception of school climate, the effect of the gender of teachers was considerably reduced; furthermore, after controlling for the classroom-level contextual factors, teacher's gender was no longer significant. This highlights that teacher's gender itself is not an influential factor on students achievement, rather, it depends on the student body in the classroom.

Consistent with the TIMSS findings, internationally (Martin et al., 2008), the association between teaching limitations and achievement was strongly negative; even after the classroom-level aggregated factors were taken into account. The teaching limitations refer to the classroom restrictions measured by different indicators, such as students with different academic abilities in a classroom, students who come from a wide range of family backgrounds, students with special needs, uninterested students, and disruptive students. Teachers in classrooms with such students spend a great amount of time for disciplinarily preparation, which restricts the instructional time. This confirms the result obtained for good attendance at school (GAS).

Variation in school climate and GAS is a possible explanation for the school-level differences in achievement. Schools where the principals described the climate of the school positively (teacher's job satisfaction is high, teacher's expectations for students achievement are high, parents support students learning, parental involvement in school activities is high, students' regard for school property is high, and students' desire to do well in school) considerably outperformed schools in which these characteristics are low. This result supports previous findings (Martin et al., 2008; Mullis et al., 2008). Schools with a positive atmosphere, in which the relationship among teachers themselves, teachers with the school administrators, and teachers with students are close, the students are well supervised and their progress is monitored by both the school and at home, are well organised, consequently, the school will achieve a higher average. One of the interesting points concerning the school principal's perception of school climate is that after controlling for the school-level compositional of the student-level factors, the coefficient of school climate decreased dramatically. This is a clear indication shows that the combination of student's characteristics (SES, parents' education, educational aspiration, and positive attitude towards subject matters) is very important in creating a positive school atmosphere. The effect of the school-level compositional factors on the link between school climate and achievement will be clearer by comparing the results of model seven and the full model. After controlling for the compositional factors the coefficient of school climate decreased significantly, highlighting the importance of the school combination, whilst after controlling for the student- and classroom-level factors, there was a slight decrease in the coefficient of the school climate.

In contrast to the school climate, the link between GAS and achievement was negatively significant. This is an expected result as students' behaviours – arriving late at school, missing class, and absenteeism – may disrupt the continuity in the classroom, and decrease the time for learning (Martin et al., 2008). In addition, the high rate of these behaviours may affect achievement indirectly through family background. The reason for this is the link between GAS and achievement was no longer significant when the contextual factors (school–mean of home educational resources, school–mean of parents' education, and school–mean of aspiration) were controlled. Most of the students with poor attendance at school do not live with both parents (Malcolm, Wilson, Davidson, & Kirk, 2003). Students who live with a single parent or stepparents achieve lower scores than their peers who live with both parents (Chiu, 2007, 2010). Students with poor attendance at school often come from homes where parents work long hours, they place a low value on children's education, and they are not able to provide school uniforms or equipment (Webb & Vulliami, 2004). Thus, schools with students who come from such families affect negatively the school achievement average. However, in Singapore, which is one of the TIMSS participating countries in which a very small percentage of schools have a serious problem with respect to the students' behaviour, students from schools where students' behaviour is serious achieved a considerably lower average. This calls for appropriate action from the school administrators to change or at least reduce the seriousness of these problems through the school disciplinary regulations.

There was no statistically significant link between school resources for science instruction and school achievement average, even before the other school-level factors were taken into account. A possible explanation for the insignificance of this factor is that there is little variation in school resources across the Singaporean schools and almost all schools are well equipped and supported with the necessary materials for science instruction (Quek et al., 2008).

6. Conclusion

The variability in achievement in science by Singaporean eighth-graders was modelled as a function of student-, classroom- and school-level factors. The results showed that more than half of the variability in science achievement was accounted for by the classroom-level difference, however, the student- and school-level differences, each, explained about one-fifth of the variance. Several models were estimated at the student, classroom, and school level to explain the variation. At the student level, the model with the attitudinal factors explained a much greater portion of the variance than the model with the family background factors, and self-concept was the strongest predictor of variability. At both the classroom and school levels, the compositional factors explained the greater part of the variance; teacher's gender, teaching limitations, and the classroom-mean of home educational resources at the classroom level, and school climate as perceived by the school principals and the school–mean of home educational resources were the strongest predictors of achievement. It was concluded that the science education in Singapore is driven largely by the classroom-level factors.

7. Implications and limitations

One of the key findings of this study was that the classroom-level differences accounted for a large amount of the total variance in student achievement. Thus, cross-classroom comparisons based on experimental and longitudinal data will be very helpful for policymakers to understand how the attitudinal (e.g., self-concept, attitudes, and educational aspiration), socioeconomic (e.g., parents occupation and education, income, and home possessions) and other process variables, such as teaching approaches, are associated with science achievement.

In consistent with many past studies (Chiu & Klassen, 2010; George & Kaplan, 1998; Lamb & Fullarton, 2002) parents' education at the student level had no significant link to achievement, even after controlling for the classroom- and school-level factor, thus, in future studies, researchers can look into this contradictory result. The student-level factors, particularly, parents' education, language spoken at home, home educational resources, and self-concept yielded inconsistent results from the individual level to the contextual levels. Singapore is a multi-ethnic country in which Chinese, Indian, and Malay are the main ethnic groups, and it is the fact that there are discrepancies among them with respect of family background characteristics. Thus, if these factors are replicated in future studies, comparing the impact of these factors on achievement across the ethnic groups is informative.

This study involved some limitations. First, except for science achievements scores, all the factors were self-reported by the students, teachers, and the school principals. This may be a potential source of inaccuracy of the data. Second, the TIMSS result does not contribute to the students' formal grading system; rather, it is to evaluate students' achievement in science. Consequently, it is difficult to estimate whether or not students have attempted their best during the tests. Third, these results are pertinent to the Singapore context and they may not be applicable for other educational contexts. Fourth, this is a correlational study based on a cross-sectional data set, thus, the findings do not promise any cause and effect implication.

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