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BUILDING MATHEMATICS ACHIEVEMENT MODELS IN FOUR COUNTRIES USING TIMSS 2003

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ABSTRACT. Using the Trends in International Mathematics and Science Study 2003 data, this study built mathematics achievement models of 8th graders in four countries: the USA, Russia, Singapore and South Africa. These 4 countries represent the full spectrum of mathematics achievement. In addition, they represent 4 continents, and they include 2 countries hugely influential in world events (the USA and Russia). In each country, students' self-concept of ability in mathematics, mathematics values, perception of school, teachers' and principals' perceptions of school and other characteristics related to the classroom and school were incorporated to build an achievement model through hierarchical linear modelling. The final achievement models suggested that among student variables, self-concept of ability in mathematics had the highest relation to 8th graders' mathematics achievement in all 4 countries. The relation between mathematics achievement and other student characteristics, along with the family, teacher and school variables, differed across the 4 countries. This suggests that self-concept of ability is a key variable for understanding achievement in high and low achieving countries and that other contextual variables vary in the magnitude of relations to mathematics achievement across countries.

KEY WORDS: mathematics achievement, school climate, self-concept of ability, task values, TIMSS 2003

Introduction

The impact of mathematics proficiency can be viewed from varying perspectives, ranging from likelihood of a student's pursuing post-secondary education to a family's standard of living and income, to a nation's ability to compete in the global economy (Baker & LeTendre, 2005). From these perspectives, then, it is important to understand mathematics achievement, both within and across countries. The purpose of this article is to compare prediction of mathematics achievement in four different countries using large-scale data in order to test whether a model of motivation works in the same way across countries. The data set was from the Trends in International Mathematics and Science Study (TIMSS) 2003. We used a model building and model trimming approach to study relationships between student mathematics achievement and

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personal and environmental variables with a focus on motivational variables.

Theoretical Background

Expectancy-Value Model

Mathematics achievement is closely related to students' academic motivation, which is shaped by the cultural, familial and societal context in which students live. Many motivation constructs have been proposed that refer to people's beliefs in their own ability and competence; these include self-concept, self-efficacy, perceptions of competence and perceptions of ability (Bandura, 1997; Deci & Ryan, 1985; Harter, 1998; Marsh, 1990; Wigfield & Eccles, 2000). While there are differences among these constructs, in general they refer to persons' confidence that they can carry out certain behaviours and perceptions that they have relevant abilities. The expectancy-value model elaborated by Wigfield & Eccles (2000) is one achievement model that focuses on people's beliefs in their own ability and competence. In the expectancy-value model, two key predictors of achievement are self-concept of ability and subjective task values.

Self-concept of ability in the academic domain, or academic self-concept, refers to individuals' perceptions or beliefs in their ability to do well in the academic domain. Academic self-concepts are hierarchical, multidimensional and subject-specific (Marsh, 1990; Shavelson & Marsh, 1986). That is, students tend to have different self-concepts for different school subjects like language arts, mathematics and science. Meta-analysis indicates that self-concept of domain-specific ability is a moderate but systematic predictor of later academic achievement, controlling for initial achievement (Valentine, DuBois & Cooper, 2004). While the meta-analysis is congruent with the supposition that self-beliefs affect achievement, it is also plausible that achievement affects self-beliefs. In fact, Valentine, DuBois and Cooper state that "our results should not be taken as proof that self-beliefs have a causal relation to later achievement" (p. 128). Self-concept of ability is particularly important for understanding mathematics achievement because it has been demonstrated to explain variance in mathematics achievement, course choices in high school and career aspirations (Greene, DeBacker, Ravindran & Krows, 1999; Marsh & Yeung, 1997b; Stevens, Wang, Olivarez & Hamman, 2007). In addition, mathematics self-concept explains variance in mathematics achievement with greater magnitude than science or English self-concept predicts science or English achievement (Marsh & Yeung, 1997a).

The other key predictor of achievement in the expectancy-value model, subjective task values, includes interest enjoyment, utility value and attainment value. Students who value a school subject are more likely to choose to pursue it, to put effort into the pursuit and to experience success than those who do not. Prior research on achievement task values reveals that utility value and attainment value are highly correlated, and some researchers have combined them, applying the term “task importance” to refer to the summated construct (Durik, Vida & Eccles, 2006). Studies have shown that students’ subjective task values predict academic outcomes above and beyond self-concept of ability (Eccles, 2005; Gainor & Lent, 1998; Meece, Wigfield & Eccles, 1990). In general, ability perceptions are stronger predictors of achievement than task values, while task values are better predictors of choices like intentions to take math courses (Wigfield & Eccles, 2000).

Learning Environment

In addition to motivational constructs, students develop perceptions of their learning environment. These perceptions influence how students make meaning of the schooling experience and the way they relate to the school community. Students’ perceptions of their relations with teachers are especially important, and positive perceptions are associated with positive academic, social and psychological outcomes at different schooling stages (Bergin & Bergin, 2009; Davis, 2003). Positive relationships with teachers may satisfy students’ needs for competence and relatedness and affect their academic achievement through mediators such as students’ sense of belonging (Roeser, Midgley & Urdan, 1996).

Besides student–teacher relationships, Lee & Shute (2010) identified two categories of social–contextual factors that are related to K–12 academic achievement. The first category is school climate, which includes academic emphasis, classroom management and principal leadership. Each of these has been demonstrated to correlate with achievement (Freiberg, Huzinec & Templeton, 2009; Lee & Smith, 1999; Leitwood & Hallinger, 2002). In our study, we used the following variables: teacher’s perception of school climate, principal’s perception of school climate, teacher’s perception of school safety, classroom management challenges, number of mathematics topics taught, school and class attendance and school resources. Note that our data included teacher and administrator perceptions. Studies have found that teacher, student and administrator perceptions are largely independent of each other (Walberg, 1979).

The second category of social–contextual factors related to K–12 academic achievement is social–familial influences, which include parental involvement (Lee & Shute, 2010). A growing body of research shows that students perform better academically when their parents are involved with their schooling (e.g. Astone & McLanahan, 1991; Coleman, 1990; Feuerstein, 2000; Rumberger & Palardy, 2005). Parental aspirations for children and socialization of achievement values are particularly important. In a meta-analysis, Fan & Chen (2001) found an average correlation of 0.40 between parent aspirations for the student's education and student's academic achievement. In another meta-analysis, Hill & Tyson (2009) found an effect size of 0.39 between parental socialization of academic values and achievement. In addition, parents' participation in school activities shows associations with their children's academic achievement (Hill & Craft, 2003; Keith & Keith, 1993; Parcel & Dufur, 2001).

Model Building

In this study, we used a model building and model trimming approach to study the aforementioned constructs in predicting student mathematics achievement. We built the models by employing multilevel modelling techniques to derive efficient mathematics achievement models. Our data are from TIMSS 2003. For analysis, we selected eighth grade mathematics achievement scores along with student background, motivational variables and school contextual information in four countries. Specifically, we focused on the student motivational constructs of self-concept of ability in mathematics and subjective task values for mathematics and their relations to student mathematics achievement. For contextual variables, we used data indicating parent, teacher, classroom and school characteristics. Including these allowed us to comprehensively compare both the overall and incremental effects of student motivation on mathematics achievement, both within our selected countries as well as across the borders.

Cultural Variation: Comparison of Four Countries

Differences in education systems across countries, together with cultural and societal influences, likely play a role in the formation of both students' and teachers' perceptions and their relations to student learning and achievement within the school context. We selected the USA, Russia, South Africa and Singapore to study because they represent the full spectrum of mathematics achievement (Singapore had the highest and South Africa had the lowest eighth grade mathematics achievement among all countries included in the TIMSS 2003 study), they represent four continents and they include two countries hugely influential in world events (the USA and Russia). The average mathematics scores for Russia were similar to those of the USA (see Table 1 for ranks and mean scores). This selection of countries allows a strong test of whether the pattern of variables that predict achievement is similar across countries.

In all four of our studied countries, eighth grade is compulsory and is part of either primary/elementary or secondary education. Samples from four countries allow us to build possibly different mathematics achievement models and to examine the similarities and differences of how student and school variables related to student mathematics achievement. We include more details on the education systems in the four countries in "Appendix 1".

Research Questions

We had three main research questions: (1) In each country, how did eighth graders' self-concept of ability in mathematics and the values they attached to mathematics relate to their mathematics achievement after controlling for parents' education level, student sex and student perception of school? (2) What teacher and school characteristics contributed to the prediction of eighth graders' mathematics achievement in each country, after controlling for the contributions of student characteristics? (3) How did the four countries included in this study differ in their patterns of achievement prediction?

TABLE 1

Sample size, rank and mean mathematics achievement score by country

Country	*Schools, classes and teachers*	*Students*	*Rank*	*Mean score*
USA	232	4,485	15	504
Russia	214	4,667	12	508
Singapore	164	3,061	1	605
South Africa	255	8,952	45	264

Ranks and mean scores were from TIMSS 2003 International Mathematics Report. The international average was 467

Method

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 collects a vast amount of information from students, their parents, teachers and principals. For TIMSS 2003, in each country, representative samples of students were selected using a two-stage sampling 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. When TIMSS data are analysed, it is important to include a weight variable reflecting the sampling scheme (Joncas, 2004; Martin, 2005). Our consideration of this TIMSS feature is discussed below.

In Russia and South Africa, one class was selected from each participating school; in Singapore, two classes were selected from each participating school and in the USA, one or two classes were selected from each participating school. To accommodate this sampling feature and to be consistent across the analyses for all the four countries, the data from a class were used if that class was the only one from its school, and we randomly selected one class from a school if two classes from that school were included in the TIMSS database. Countries were not modelled as an additional level but were treated as fixed groups for which mathematics achievement models were built. This is because we sought differences among them in their mathematics achievement models rather than to find how much variation existed between countries. The numbers of schools/classes, students and mathematics teachers used in our study are given in Table 1. The data used in our study were of two levels in each country. At level 1, variables were from students, and at level 2, variables were related to schools and classes (which were confounded).

Measures and Preparation of Variables

The TIMSS 2003 database includes many individual items. We examined the items and developed measures that were useful to investigating our hypotheses. Details of scale development are included in "Appendix 2". At the student level, we built measures of student self-concept of ability in mathematics, the values students attached to mathematics and students' perception of school. At the school/class level, scales were created to measure mathematics teachers' and school principals' perceptions of school climate, teachers' perception of school safety and teacher's perceptions of classroom management challenges. The particular TIMSS items used to construct the scales are included in "Appendix 2".

In terms of demographic measures, student and mathematics teacher's sex was coded as dummy variables (0 = female, 1 = male). Parent's highest education level was coded as one of five levels: 1 = no more than primary schooling, 2 = lower secondary schooling, 3 = upper secondary schooling, 4 = post-secondary vocational/technical education but not university and 5 = university or equivalent or higher.

At the school/class level, we also included the number of years of teaching experience of the mathematics teacher, whether the mathematics teacher had a full licence or certificate (0 = no, 1 = yes), number of mathematics topics included in TIMSS assessment that had been taught (this was the number of TIMSS framework topics with a maximum of 44; see Cogan & Schmidt, 2002 for another way of defining broader topic levels), an index variable of school and class attendance (1 = low, 2 = medium, 3 = high) and an index variable of school resources (1 = low, 2 = medium, 3 = high). In addition, expected parental involvement was the number of activities that the principal reported he or she expected of parents and ranged from zero to five.

In the hierarchical linear modelling (HLM) analyses within each country, dummy/dichotomous variables were not centred; consequently, the coefficients for those variables are interpreted as the mean difference between the two groups. All scale variables were transformed into *z* scores across schools but within each country so that results could be reported as standard deviation units within each country.

For student-level variables, the number of cases with incomplete data of each variable was calculated. The highest percentage of cases with incomplete data of all student-level variables was 15.52%, 3.27%, 3.05% and 18.04% for the USA, Russia, Singapore and South Africa, respectively (however, all values of the variable "number of mathematics topics taught" were missing in the Russia sample, and therefore, the variable was not included when analysing data from Russia). For the school/class level variables, the highest percentage of cases with incomplete data was 19.39%, 10.37%, 16.72% and 26.18% for the USA, Russia, Singapore and South Africa, respectively. We used the expectation maximization method to impute missing data on continuous variables. In our HLM analyses, we used the reported school weights at level 2 (school/class level) and did not use any weight at level 1 (student level) because we did not use all the student data (we selected one class from each school instead). This would not distort our results because only at the stage of sampling schools did TIMSS use probability-proportional-to-size sampling (for discussion of sample weights in complex data, see

Kaplan & Ferguson, 1999; Pfeffermann, Skinner, Holmes, Goldstein & Rasbash, 1998; Stapleton, 2002).

The measure of student mathematics achievement was from the TIMSS 2003 database. TIMSS 2003 used a matrix-sampling technique such that a student would only answer questions included in certain subsets of items, called "item blocks". Students' mathematics proficiency was estimated through item response theory, together with a multiple imputation technique (this procedure has been used for other large-scale projects such as the National Assessment of Educational Progress; for a more technical description of the procedure, see von Davier & Sinharay, 2007). By matrix sampling and multiple imputation, each student's mathematics achievement is represented with five plausible values, enough to allow for imputation error (Mislevy, 1991; Schafer, 1997) (however, also see Graham, Olchowski & Gilreath, 2007). The plausible values are not appropriate for use as individual student scores for reporting to the students; however, they can be used to estimate population characteristics, with better performance than point estimates (Wu, 2005). Our data analysis follows usual procedures for analysing multiple imputed datasets, with each set of plausible values analysed separately, and results from the five sets combined to allow for multiple imputation errors (Enders, 2010).

Statistical Analyses

We applied a model building process using HLM (Raudenbush & Bryk, 2002) to study the incremental contribution of variables in predicting student mathematics achievement, as appropriate to our hypotheses. Specifically, student, teacher and school variables were used to build a mathematics achievement model for eighth graders in each of the four selected countries. In each country, 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. Level 1 main effects, cross-level interactions and level 2 main effects were examined. At each step in our model building, we also employed a model trimming procedure to achieve parsimony.

In each country, three sets of HLM models were analysed and modified in the modelling process. We first looked at the variation of student mathematics achievement and examined how much of this variation was at the student or class/school levels (i.e. fully unconditional model—model a). Next, student variables were added to the model as level 1 predictors, and nonsignificant predictors were removed (model trimming). This resultant model (model b) answers the question to what extent the considered student variables predict mathematics achievement. We were particularly interested in the effects of student self-concept of ability and valuing of mathematics on mathematics achievement. Third, teacher and school variables were added to model b as level 2 predictors. In order to achieve model parsimony, the final achievement model (model c) in each country only included statistically or nearly statistically significant main and cross-level interactions (we compared the full model and the final more parsimonious model. With $\alpha = 0.05$, the conclusions on statistical significance of relationships between each individual variable and mathematics achievement were the same across the two models). It included significant level 1 and level 2 predictors, as well as significant interactions between level 1 and level 2 variables. This model (model c) answers the question which teacher and school variables contribute to variation in student mathematics achievement, after controlling for student characteristics.

By comparing model b and model c, we arrived at a good understanding of how the student variables, especially student self-concept of ability in mathematics and valuing of mathematics, worked as antecedents of mathematics achievement within classrooms and schools of different characteristics. Standard errors of estimates can be calculated in HLM, with the variation between plausible values considered. The analysis procedure for each model was run five times, once for each set of plausible values. By this means, in each run, the plausible values played the role of the criterion variable. Our final estimates for each country were the averages of the results from the five analyses.

Following recommendations of Martin, Mullis & Chrostowski (2004), we considered the TIMSS 2003 sampling design during analysis. Specifically, there were several weight variables reported in TIMSS 2003. We chose the one that is most relevant to our study: the school weight variable in each country. Our HLM procedures incorporated weight variables so that the results reflect the characteristics of the population in each country (Pfeffermann et al., 1998).

Results

Scale Development

Details of scale development are included in "Appendix 2". There were eight scales developed within each country. Three of them were at the student level: self-concept of ability in mathematics, mathematics values and student perception of school, and five of them were at the school/

class level: principal's perception of school climate, mathematics teacher's perception of school climate, mathematics teacher's perception of school safety, classroom management challenge due to diversity of students and classroom management challenge due to student misbehaviours.

HLM Analyses

Unconditional Model. The unconditional model (model a) is the same for all the four studied countries: Namely, it is a one-way ANOVA model with random effects:

Level 1 Mathematics $\text{Achievement}_{ij} = \beta_{0j} + r_{ij}$
Level 2 $\beta_{0j} = \gamma_{00} + u_{0j}$

where Mathematics Achievement_{ij} is the mathematics achievement for student i in school/class j. The parameter β_{0j} is the mean mathematics achievement of school/class j. The variance of r_{ij}—the variability of random error at the student level—represents the variation of mathematics achievement between students within the class (σ^2). The γ_{00} is the grand mean of mathematics achievement of all students in a country. The u_{0j} is the random error at the school/class level. Its variance (τ_{00}) indicates the variation of mathematics achievement between schools/classes. Intraclass correlation (ICC; denoted as ρ) was calculated for each unconditional model to explore the relative class differences. Mathematically, the ICC is defined as $\tau_{00}/(\tau_{00} + \sigma^2)$. Estimates of γ_{00}, σ^2, τ_{00} and ρ for each country are in Table 2.

Singapore had the highest grand mean for achievement, the smallest within-school variation and the smallest between-school variation. South Africa had the lowest grand mean and the largest within- and between-school variation, consistent with previous TIMSS data (O'Dwyer, 2005). The relative between-school variation in achievement, compared to total variation, was the largest in South Africa and the smallest in Russia.

TABLE 2

Results from fully unconditional hierarchical linear model of mathematics achievement

	USA	*Russia*	*Singapore*	*South Africa*
Grand mean, γ_{00}	496.86	497.83	642.04	235.76
Within-school variance, σ^2	2,664.44	3,836.32	1,339.71	4,061.84
Between-school variance, τ_{00}	2,482.16	2,093.24	1,336.29	5,649.15
Intraclass correlation, ρ	0.48	0.35	0.50	0.58

Model Building at Student Level. Model building at the student level (level 1) in each country began by adding all student-level predictors. This initial model was the same for all four countries. Specifically, the five student-level variables (parents' highest education level, student sex, student self-concept of ability in mathematics, mathematics values and student perception of school) were modelled as predictors of mathematics achievement. The effects of those predictors, together with the school/class mean mathematics achievement, were modelled as random coefficients.

After model trimming, the results from model b for each country are given in Table 3. Later, we compared model b with model a to examine how much the student-level variables contributed to the prediction of student mathematics achievement.

From model b, parents' highest education level was related to student mathematics achievement in Russia and South Africa but not in the USA and Singapore. In all four studied countries, student self-concept of ability in mathematics was related to their mathematics achievement, controlling for the effects of other predictors in the model. The relationship was the largest in Russia and the smallest in Singapore. In addition, the higher values students attached to mathematics in South Africa, the better their mathematics achievement. Valuing mathematics did not contribute uniquely to prediction of mathematics achievement in the USA, Russia or Singapore, after controlling for the effects of other variables in the model. Student perception of school did not contribute uniquely to prediction of mathematics achievement in the USA, Singapore or South

TABLE 3

Fixed effects of student-level variables with no teacher/school variables in the hierarchical linear models

Fixed effect	*USA*	*Russia*	*Singapore*	*South Africa*
Grand mean, γ_{00}	499.11**	499.23**	642.03**	236.75**
Parents' highest education level, γ_{10}	–	5.07*	–	5.25**
Student sex, γ_{20}	–	–	–	–
Self-concept in ability in mathematics, γ_{30}	27.29**	33.43**	16.07**	17.02**
Math values, γ_{40}	–	–	–	7.86**
Student perception of school, γ_{50}	–	−4.48*	–	–

– not statistically significant and therefore removed from model

*$p < 0.01$; **$p < 0.001$

Africa. Surprisingly, student perception of school was *negatively* related to their mathematics achievement in Russia.

Final Achievement Model. After model building and model trimming at the student level (level 1) and at the school/class level (level 2), the final mathematics achievement model (model c) was obtained for each country. The four final achievement models are in Table 4.

Here, we summarize the major findings from the final achievement models. The full HLM analyses, together with tables of estimated fixed effects and variance components for random effects, are available from the first author upon request.

TABLE 4

Final mathematics achievement model by country

USA	L1	Math Achievement$_{ij}$ = $\beta_{0j} + \beta_{1j}$ (self-concept of ability in math) + r_{ij}
	L2	$\beta_{0j} = \gamma_{00} + \gamma_{01}$ (teacher's sex) + γ_{02} (number of math topics taught) + γ_{03} (principal's perception of school climate) + γ_{04} (classroom management challenge due to student misbehaviours) + u_{0j}
		$\beta_{1j} = \gamma_{10} + \gamma_{11}$ (teacher licence) + γ_{12} (classroom management challenge due to student misbehaviours) + u_{1j}
Russia	L1	Math Achievement$_{ij}$ = $\beta_{0j} + \beta_{1j}$ (parent highest education level) + β_{2j} (self-concept of ability in math) + β_{3j} (student's perception of school) + r_{ij}
	L2	$\beta_{0j} = \gamma_{00} + \gamma_{01}$ (school and class attendance) + γ_{02} (math teacher's perception of school climate) + u_{0j}
		$\beta_{1j} = \gamma_{10} + u_{1j}$
		$\beta_{2j} = \gamma_{20} + u_{2j}$
		$\beta_{3j} = \gamma_{30} + u_{3j}$
Singapore	L1	Math Achievement$_{ij}$ = $\beta_{0j} + \beta_{1j}$ (self-concept of ability in math) + r_{ij}
	L2	$\beta_{0j} = \gamma_{00} + \gamma_{01}$ (principal's perception of school climate) + γ_{02} (math teacher's perception of school climate) + γ_{03} (classroom management challenge due to diversity of students) + u_{0j}
		$\beta_{1j} = \gamma_{10}$
South Africa	L1	Math Achievement$_{ij}$ = $\beta_{0j} + \beta_{1j}$ (parents' highest education level) + β_{2j} (self-concept of ability in math) + β_{3j} (math values) + r_{ij}
	L2	$\beta_{0j} = \gamma_{00} + \gamma_{01}$ (number of years as teacher) + γ_{02} (expected parental involvement) + γ_{03} (resources for math instruction) + γ_{04} (math teacher's perception of school climate) + γ_{05} (classroom management challenge due to diversity of students) + u_{0j}
		$\beta_{1j} = \gamma_{10} + u_{1j}$
		$\beta_{2j} = \gamma_{20} + u_{2j}$
		$\beta_{3j} = \gamma_{30} + u_{3j}$

For the USA, student self-concept of ability in mathematics was a strong predictor of mathematics achievement. This effect was not homogenous across schools/classes. For those in a class taught by a fully certified teacher, a 1 standard deviation increase in self-concept of ability in mathematics was related to mathematics achievement increase of 27.94 points, controlling for the other predictors; for those in a class taught by a not fully licenced teacher, the effect was only 13.08. The more classroom management challenges due to student misbehaviours, the less the positive relationship between student self-concept of ability in mathematics and mathematics achievement and the lower the mathematics achievement. In the USA, students on average scored 26.92 points higher if the mathematics teacher was male rather than female, for both boys and girls. One might wonder if the higher scores were due to higher levels of mathematics knowledge among the male teachers. However, the data set does not contain variables that describe levels of teachers' mathematics knowledge, so this hypothesis cannot be tested with the current data. Also, in the USA, the greater the number of TIMSS mathematics topics that had been taught, the *lower* the student mathematics achievement, with an effect of 1.19 points. Students from schools with more positive principal's perception of school climate had higher mathematics achievement.

For Russia, like the USA, student self-concept of ability in mathematics was a strong predictor of mathematics achievement. A one standard deviation increase in student self-concept of ability in mathematics was related to mathematics achievement increase of 33.44 points, with other predictors controlled. The higher their parents' education level, the higher their mathematics achievement. The more *negative* their perception of school, the higher students' mathematics achievement. Good school and class attendance and positive mathematics teachers' perception of school climate were positively related to students' mathematics achievement in Russia.

For Singapore, student self-concept of ability in mathematics predicted mathematics achievement, but not as strongly as in Russia after controlling for other variables. A 1 standard deviation increase in student self-concept of ability in mathematics was related to mathematics achievement increase of 16.03 points. This effect was homogenous across schools. Positive perception of school climate from both school principals' and mathematics teachers' perspectives was positively related to student mathematics achievement. The more classroom management challenges due to diversity of students, the lower students' mathematics achievement.

In South Africa, student self-concept of ability in mathematics predicted mathematics achievement at a level similar to Singapore. A 1 standard deviation increase in student self-concept of ability in mathematics was related to mathematics achievement increase of 16.96 points, after controlling for other predictors. Parents' highest education level and student mathematics values were also positively related to student mathematics achievement. With 1 standard deviation increase in mathematics values, student mathematics achievement would be 7.96 points higher, after controlling for other predictors. The mathematics teacher's teaching experience and perception of school climate were positively related to student mathematics achievement, controlling for other predictors. Students from schools with better instructional resources and from classes with fewer classroom management challenges due to student misbehaviours displayed higher mathematics achievement. Perhaps surprisingly, expected parental involvement in school activities was *negatively* related to student mathematics achievement when other predictors were controlled.

The proportion of variance explained by adding level 1 and level 2 predictors was obtained by comparing the σ^2 (between students, within schools/classes variance) and τ_{00} (between-schools/classes variance) estimates from the unconditional model, the model with only student-level variables and the final achievement model. Adding student variables resulted in a 27% reduction in the variance of mathematics achievement between students within each school/class in the USA (32% in Russia, 18% in Singapore and 12% in South Africa). Including school and teacher variables reduced the variance between schools by 60% in the USA (19% in Russia, 42% in Singapore and 34% in South Africa).

Discussion and Conclusion

Student self-concept of ability in mathematics had a positive relationship with mathematics achievement in all four selected countries. This relationship was the highest in Russia and the lowest in the USA mathematics classrooms that lacked a fully licenced teacher, while controlling for other variables. The magnitude was similar in South Africa and Singapore when other variables were controlled.

In contrast, mathematics value was related to mathematics achievement only in South Africa, and this relationship was less than half that of self-concept of ability in mathematics. This finding is not surprising because in general, ability perceptions are stronger predictors of achievement performance than task values (Wigfield & Eccles, 2000).

More positive school climate, perceived by school principals (USA), mathematics teachers (Russia and South Africa) or both (Singapore), predicted higher student mathematics achievement. Classroom management challenges due to student misbehaviours (USA) or due to student diversity (Singapore and South Africa) were negatively related to student mathematics achievement. Better school and class attendance were associated with higher mathematics achievement in Russia only. School resources had a positive relationship only in South Africa.

In the USA, a noticeable association with mathematics achievement is the teacher's sex. Students who had a male mathematics teacher on average scored 26.92 points higher in than those who had a female mathematics teacher, after controlling for the other variables included in the model. The differences in mathematics achievement between students of male and female mathematics teachers may arise from cultural expectations that mathematics is a male subject and that males should perform better than females in mathematics, and if females do teach mathematics, they will be less successful than their male counterparts (Warwick & Jatoi, 1994). It is possible that female mathematics teachers expect less from their students than male mathematics teachers. It is also possible that weaker students tend to choose female teachers. We could not test whether male mathematics teachers were more knowledgeable about mathematics than female teachers due to a lack of relevant variables in the data set. In the future, it is worthwhile to explore potential mediating variables that may help explain the mechanism of the relation between teacher's sex and student mathematics achievement.

On the other hand, this study found no gender differences between boys' and girls' mathematics achievement in the four studied countries, after controlling for the other variables included in the models. However, it is possible that the other predictors may serve as mediating variables between student gender and mathematics achievement. For example, girls' self-concept of ability in mathematics may be lower than that of boys although no gender gap existed when putting both gender groups on the same standing of self-concept of ability in mathematics. Wilkins (2004) conducted a study using HLM to predict student mathematics and science self-concepts from achievement across countries and found that on average male students had higher academic self-concept than female students although the gender gap was minimal or slightly reversed in some countries.

In the USA, the greater the number of TIMSS mathematics topics that had been taught at the eighth grade, the *lower* the student mathematics achievement. Cogan & Schmidt (2002) reported the numbers of TIMSS mathematics topics that could be found in official content standards, represented in textbooks or taught by teachers in each of 36 countries. Compared to the other countries, the USA had more teachers teaching more topics. In the USA, all 44 mathematics topics were in the content standards, 41 topics were represented in the textbooks and all the 21 broader mathematics topics were taught by at least one teacher at the eighth grade. In addition, every topic had at least half of teachers covering it. Cogan & Schmidt (2002) referred to this as the "mile wide, inch deep" nature of the US curriculum. In contrast, as a top-performing country in TIMSS mathematics, Japan only had 12 TIMSS mathematics topics found in content standards and 15 represented in textbooks at the eighth grade. It is likely that for some countries, different mathematics topics are taught and emphasized in different academic years. Trying to cover many mathematics topics in 1 year could be the cause of lower student mathematics achievement; we argue that curriculum and mathematics instruction should focus on deeper understanding of topics.

In Russia, the more *negative* their perception of school, the higher students' mathematics achievement. A one standard deviation increase in students' perception of school was related to mathematics achievement decrease of 4.67 points, with other predictors controlled. While this relationship was statistically significant when the other predictors were controlled, with $p = 0.002$, the zero-order correlation between students' perception of school and their mathematics achievement was minimal (about 0.002) and not statistically significant. In addition, there was a small yet statistically significant positive correlation (0.09) between students' perception of school and student self-concept of ability. This suggests that students' perception of school was a suppressor variable, and we should not expect such a negative relationship in general between students' perception of school and student mathematics achievement in Russia (Maassen & Bakker, 2001).

Expected parent involvement in school activities did not have a statistically significant effect on student mathematics achievement in the USA, Russia or Singapore, but was *negatively* related to student mathematics achievement in South Africa when other predictors were controlled. This could be because principals in the participating South African schools expect parents to become involved mainly in cases of low achievement. In our study, expected parental involvement in school activities was reported by the school principal rather than by the parents. School principals may expect parental involvement for many different reasons, but actual parent involvement (e.g. parental aspirations and socialization of achievement values) might have a more direct effect on student mathematics achievement (Fan & Chen, 2001; Hill & Tyson, 2009).

We tested cross-level interactions during our model building and model trimming process. This allows us to look into the differences in the effects of student motivational constructs on mathematics achievement. We only found two statistically significant cross-level interactions in the USA. While having fully licenced teachers did not have a direct effect on eighth graders' mathematics achievement, it did strengthen the relationship between students' self-concept of ability in mathematics and their mathematics achievement. Classroom management can be challenging. Those classroom management challenges due to student misbehaviours not only directly affected eighth graders' mathematics achievement negatively in the USA but also weakened the relationship between students' self-concept of ability in mathematics and their mathematics achievement.

A summary of statistical significance of predictors on student mathematics achievement is displayed in Table 5. It can be seen that the only identical patterns of prediction of eighth grade students' mathematics achievement across the four countries were the statistical significance of self-concept of ability in mathematics, the statistical nonsignificance of student sex and the statistical nonsignificance of mathematics teacher's perception of school safety. Although teacher licence was statistically nonsignificant in all four countries, its interaction with self-concept of ability was statistically significant in the USA. More variables were statistically significantly related to student mathematics achievement in South Africa, the lowest-achieving country than in Singapore, the highest achieving country. Those significant predictors in South Africa may reflect the poor education conditions for the majority of learners (UNESCO International Bureau of Education, 2006/2007). While the national average of TIMSS mathematics was comparable between USA and Russia, different predictors were related to mathematics achievement in those two countries. While it is difficult to group the variables that were statistically significant in each country, it seems that in the USA, compared to Russia, variables more directly related to instruction (e.g. teacher's sex, mathematics topics, classroom management) had statistically significant relationships with mathematics achievement.

Within each country, the predictions by student variables when teacher and school variables are considered (model c) are similar to the corresponding predictions when teacher and school variables are not considered (model b). For example, in Russia, the prediction of student self-concept of ability on student mathematics achievement was 33.43 (Table 3) when the school context was not considered; the corresponding

TABLE 5

Statistical significance of variables on mathematics achievement in each country

	Significant effect?			
	USA	*Russia*	*Singapore*	*South Africa*
Student variables				
Parent's highest education level	N	Y	N	Y
Student sex	N	N	N	N
Student self-concept of ability in mathematics	Y	Y	Y	Y
Mathematics values	N	N	N	Y
Student's perception of school	N	Y	N	N
Teacher and school variables				
Mathematics teacher's sex	Y	N	N	N
Number of years of teaching experience	N	N	N	Y
Teacher licence	N	N	N	N
Number of mathematics topics taught	Y	N/A[a]	N	N
School and class attendance	N	Y	N	N
School resources for mathematics instruction	N	N	N	Y
Mathematics teacher's perception of school climate	N	Y	Y	Y
Principal's perception of school climate	Y	N	Y	N
Mathematics teacher's perception of school safety	N	N	N	N
Classroom management challenge due to diversity of students	N	N	Y	Y
Classroom management challenge due to student misbehaviours	Y	N	N	N
Expected parental involvement	N	N	N	Y
Cross-level interactions				
USA only: Teacher licence × Self-concept of ability in mathematics				
Classroom management challenge due to student misbehaviours × Self-concept of ability in mathematics				

Y statistically significant at 0.05 level, *N* not statistically significant at 0.05 level
[a]Data on this variable were not available in Russia

prediction was 33.44 when we considered individual class and school context as measured by the school/teacher variables.

Within each country, on average, student variables had similar relations to mathematics achievement across schools. The only exceptions are the cross-level interactions in the USA, where the prediction by self-concept of ability in mathematics on mathematics achievement depended on whether the mathematics teacher had a full licence and how much challenge there was in the classroom management due to student misbehaviours.

The school context seems to matter the most in the USA, followed by Singapore and South Africa. In the US, about 60% of the between-school variance in eighth graders' mathematics achievement was reduced by modelling school context variables. In contrast, the school context contributed to only 19% of the between-school variance in Russia.

The largest proportion of variance reduced by adding student characteristics was 32% in Russia, where student self-concept of ability in mathematics had the largest prediction effect. In contrast, only 12% of the variance in eighth graders' mathematics achievement was reduced by adding student-level predictors in South Africa.

Our study has several strengths. First, our study incorporated appropriate design weight, and as a consequence, the results are generalizable to the full populations of eighth graders in the four studied countries. Second, our study used appropriate statistical techniques (HLM) to examine the contributions of school and teacher variables on student mathematics achievement and on the motivation–achievement relationship. Third, our study indicates that studies of student mathematics achievement must acknowledge the influences of the school context, although the significant contextual influences vary across countries.

However, due to the characteristics of the data, this study also has some limitations. First, this study used cross-sectional observational data. The data are correlational and do not support causal claims. This limited us in exploring the direction of the influence of students' perceptions and their academic achievement. Therefore, our results are preliminary and correlational, and further investigation is needed to fully understand their implications. Although this study does not provide evidence of a causal relationship between student self-concept of ability in mathematics and mathematics achievement, it does provide evidence of a strong association between them. This significant association was found in all four selected countries. Some studies have shown that students' perceptions, especially self-concept of ability, and their academic achievement are reciprocally related (e.g. Guay, Marsh & Boivin, 2003; Marsh & Craven, 2006; Marsh, Trautwein, Lüdtke, Koller & Baumert, 2005). In this study, we put students' perceptions as antecedents of their mathematics achievement but at the same time point out that students' prior mathematics achievement may have an effect on their perceptions and current mathematics achievement. In a recent study with a sample of Australian students, Hemmings, Grootenboer & Kay (2010) found that both prior achievement and mathematics attitudes were significant predictors of mathematics achievement and that prior achievement and attitudes were moderately correlated. Without longitudinal data, it is not possible to fully model the reciprocal relationship between academic outcomes and students' perceptions. Second, there are potential variables that are not included in this study that may contribute to the prediction of students' mathematics achievement. For example, Lee & Shute (2010) identified two large categories of social–contextual factors that are related to K–12 academic achievement. Some of those factors such as peer influence were not available in TIMSS 2003. Third, although we built mathematics achievement models for four countries, we did not try to model why differences existed between countries; that is, we did not include cultural and country variables. The purpose of this study was not to find out how differences in mathematics achievement between countries were due to different country characteristics, although we believe that those characteristics very likely contribute to those differences.

Results from our study offer several implications for practitioners in the USA. Although the study was not experimental, it appears that teacher qualifications might have a causal effect on achievement. It might be useful to establish standards for teacher qualifications and enforce those standards. Due to the interaction effect on mathematics achievement between teacher licence and student self-concept of ability, a qualified/certified mathematics teacher may indirectly affect student mathematics achievement through student self-concept of ability. Second, it is important to consider the role model of the mathematics teacher. Mathematics may still be considered as a "male" subject. Whereas the mathematics achievement of girls is comparable to that of boys at eighth grade in the USA, having a male mathematics teacher was associated with higher average mathematics achievement of the class. It would be important to investigate why. It is possible that male teachers were more competent and knew more mathematics than females, or that more females were teaching mathematics outside of their area of expertise and knew less mathematics than the males, or that the results reflect sexist attitudes of students who expect to learn less from female teachers. Future research should investigate these possibilities. Third, consistent with the expectancy-value model, students' self-concept of ability in mathematics exhibited a strong relation with mathematics achievement. This can serve as a central piece for understanding how students learn. For example, how teachers deal with frustration and how they address mistakes in the classroom may affect students' self-concept of ability in mathematics directly and mathematics achievement directly and/or indirectly. Fourth, the "mile wide, inch deep" type of curriculum may hinder students' deep understanding of mathematics topics. In the USA, it would be useful to focus more on fewer topics.

Appendix 1

Education Systems in the USA, Russia, Singapore and South Africa

In the USA, education is provided mainly by the government. At the primary and secondary school levels, curricula, teaching and other policies are set through locally elected school boards with jurisdiction over the school districts. Schooling is compulsory for all children in the USA, and approximately 85% of the US students enter the public schools largely because they are free (Wieczorek, 2008). Funds for education come primarily from taxes collected by state, local and federal governments. By 2003, student–teacher ratio of primary and secondary schools was about 16.5:1 (UNESCO International Bureau of Education, 2006/2007).

In Russia, education is provided mainly by the state and is regulated by the federal Ministry of Education. Eleven years of general education in Russia is compulsory since September 1, 2007, but the data reported in this article were gathered before that date. Until 2007, compulsory education was limited to 9 years with grades 10 – 11 optional. General education schools (covering grades 1 – 11) are the most common type of schools (80% of all schools). An additional 15% of general education schools offer intensive learning programmes in specific fields (languages, science, sports etc.) (UNESCO International Bureau of Education, 2006/2007).

In Singapore, the Ministry of Education directs formulation and implementation of education policies. It has control of the development and administration of the government and government-aided primary schools, secondary schools and junior colleges. It also supervises private schools. The enrolment at the primary and secondary levels was high (94% at the primary level and 93% at the secondary level in 2001). After finishing 6 years of primary schooling, students are placed in the Special, Express, Normal (Academic) or Normal (Technical) courses according to how they perform at the Primary School Leaving Examination; the different curricular emphases are designed to match students' learning abilities and interests (UNESCO International Bureau of Education, 2006/2007).

In South Africa, the vast majority of learners continue to be educated in conditions of neglect of infrastructure, services, equipment, learning environment and quality of teaching. Using unqualified and under-qualified primary school educators is a common phenomenon, particularly in rural schools. In government-funded public schools, the average ratio of students to teachers is 32.6:1, while private schools on average have one teacher for every 17.5 students (UNESCO International Bureau of Education, 2006/2007). Note that apartheid policies in South Africa did not end until 1994, and the data reported in this article were gathered only 9 years later. There are large disparities between advantaged and disadvantaged students, and many of the Black students are not native speakers of the language of the TIMSS test (Howie, Scherman & Venter, 2008). South Africa showed by far the greatest variability in TIMSS mathematics scores in the 1995 and 1999 administrations (O'Dwyer, 2005).

Appendix 2

Scale Development

Within each country, the 15 items measuring students' self-perceptions and their perceptions of school were analysed using EFA with varimax rotation after appropriately reverse coding some items. We also compared EFA results with those from oblique rotation methods. Decisions on the number of factors to be extracted were based on scree plots of eigenvalues as well as checking loadings and the interpretability of results (Costello & Osborne, 2005). Results from EFA in the four countries were consistent. Three student factors were extracted for each country: self-concept of ability in mathematics, mathematics values and student perception of school. Two items ("I would like to take more math" and "I enjoy learning math") cross-loaded on two factors and were dropped. The items and descriptive statistics are presented in Table 6. Each of the three factors displayed acceptable internal consistency, except the measure of student self-concept of ability in mathematics in South Africa (Cronbach's $\alpha = 0.41$). We retained this scale despite its low internal consistency in order to maintain the same set of variables in each analysis. The mean of items under each factor was calculated and further standardized within each country. The resultant z scores were used as factor scores (see DiStefano, Zhu & Mindrila, 2009 for a discussion of using factor scores).

Within each country, the 16 items measuring school climate (eight items from the school principal questionnaire and eight items from the mathematics teacher questionnaire) were analysed using EFA. Results from EFA in the four countries were consistent. Within each country, two factors were extracted, one consisting of the eight items measuring school principal's perception and the other the eight items measuring mathematics teacher's perception, suggesting that school principals' perception was a different dimension than mathematics teachers' perception (Walberg, 1979). The mean of items under each factor was calculated and further standardized within each country. The resultant z scores were used as factor scores.

TABLE 6

Items and descriptive statistics for scales

Scale and item	USA			Russia			Singapore			South Africa		
	M	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*
Student self-concept of ability in mathematics			0.83			0.83			0.81			0.41
I usually do well in math	3.17	0.83		2.77	0.84		2.68	0.90		3.14	0.82	
Math is more difficult for me than for many of my classmates (reverse coded)	2.87	1.03		2.77	1.03		2.63	0.90		2.38	1.06	
Math is not one of my strengths (reverse coded)	2.61	1.15		2.78	0.99		2.49	1.06		2.40	1.11	
I learn things quickly in math	2.84	0.93		2.44	0.91		2.63	0.88		2.99	0.98	
Mathematics values			0.76			0.74			0.73			0.75
I think learning math will help me in my daily life	3.46	0.76		3.40	0.76		3.41	0.70		3.63	0.75	
I need math to learn other school subjects	3.23	0.81		3.37	0.72		3.11	0.76		3.33	0.90	
I need to do well in math to get into the university of my choice	3.60	0.70		3.30	0.84		3.60	0.62		3.52	0.83	
I would like a job that involved using math	2.43	1.02		2.41	0.90		2.53	0.92		3.28	0.96	
I need to do well in math to get the job I want	3.13	0.94		3.19	0.90		3.08	0.85		3.46	0.89	
Student perception of school			0.74			0.71			0.73			0.67
I like being in school	2.80	0.94		3.03	0.81		3.22	0.74		3.69	0.70	
I think that students in my school try to do their best	2.60	0.94		2.91	0.84		3.05	0.81		3.45	0.80	
I think that teachers in my school care about the students	3.10	0.95		3.42	0.71		3.19	0.79		3.52	0.82	
I think that teachers in my school want students to do their best	3.49	0.80		3.68	0.58		3.60	0.64		3.60	0.81	
Mathematics teacher's perception of school climate			0.87			0.77			0.87			0.85
Teacher's job satisfaction	3.54	0.82		3.08	0.55		3.34	0.79		3.23	0.94	
Teacher's understanding of school's curricular goals	3.93	0.75		3.85	0.46		3.74	0.68		3.54	0.89	
Teacher's degree of success in implementing school's curriculum	3.79	0.72		3.28	0.50		3.64	0.68		3.41	0.91	
Teacher's expectations for student achievement	4.04	0.78		3.12	0.44		3.71	0.73		3.74	0.94	
Parental support for student achievement	3.13	0.99		2.39	0.67		3.20	0.81		2.42	1.07	
Parental involvement in school activities	2.98	1.09		2.50	0.70		2.78	0.90		2.27	1.04	
Students' regard for school property	2.86	0.93		2.81	0.64		2.79	0.89		2.46	1.09	

TABLE 6

(continued)

	USA			*Russia*			*Singapore*			*South Africa*		
Scale and item	*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*
Students' desire to do well in school	3.07	0.85		2.91	0.57		3.35	0.85		2.91	1.03	
Principal's perception of school climate			0.88			0.77			0.89			0.85
Teachers' job satisfaction	4.03	0.64		3.22	0.49		3.80	0.61		3.21	0.89	
Teachers' understanding of school's curricular goals	4.21	0.67		3.84	0.47		4.06	0.59		3.61	0.76	
Teachers' degree of success in implementing school's curriculum	3.96	0.69		3.39	0.55		3.89	0.67		3.43	0.78	
Teachers' expectations for student achievement	4.03	0.77		3.21	0.44		3.92	0.75		3.64	0.87	
Parental support for student achievement	3.48	0.96		2.55	0.62		3.40	0.76		2.29	1.07	
Parental involvement in school activities	3.18	1.04		2.69	0.67		2.55	0.82		2.21	1.02	
Students' regard for school property	3.67	0.77		3.05	0.63		3.92	0.69		2.62	1.05	
Students' desire to do well in school	3.59	0.73		3.09	0.54		3.89	0.72		3.06	0.91	
Mathematics teacher's perception of school safety			0.81			0.69			0.82			0.83
This school is located in a safe neighbourhood	3.35	0.68		0.72	2.78		3.36	0.52		2.52	0.94	
I feel safe at this school	3.48	0.55		0.87	3.02		3.40	0.53		2.62	0.91	
This school's security policies and practices are sufficient	3.15	0.69		0.78	3.09		3.16	0.52		2.18	0.90	
Classroom management challenge due to diversity of students			0.67			0.61			0.56			0.66
Students with different academic abilities	1.70	0.92		2.32	0.74		1.87	0.84		1.79	0.99	
Students who come from a wide range of backgrounds	0.98	0.97		0.73	0.85		1.17	0.99		1.67	1.13	
Students with special needs	0.95	0.95		1.06	1.02		0.51	0.81		1.07	1.07	
Classroom management challenge due to student misbehaviours			0.84			0.74			0.89			0.82
Uninterested students	1.59	0.96		1.86	0.96		1.52	0.91		1.66	0.96	
Low morale among students	1.22	0.93		0.98	1.05		1.33	0.92		1.49	1.00	
Disruptive students	1.38	0.94		1.10	1.06		1.30	0.96		1.48	1.03	

Within each country, four items from the mathematics teacher questionnaire measuring teachers' perception of school facility and safety were analysed using EFA. One item ("School facility needs significant repair") did not load on the factor in Russia or South Africa and was dropped from further analysis in all four countries. Within each country, the other three items loaded on a factor that was labelled school safety. The scale displayed good internal consistency in each country. The mean of the three items measuring school safety was calculated and further standardized within each country. The resultant *z* scores were used as factor scores.

Within each country, EFA was also used to analyse the six items measuring mathematics teachers' responses regarding classroom management. The results from the four countries were consistent. Two factors were extracted, the first one a measure of challenge of classroom management due to diversity of students and the second one a measure of challenge of classroom management due to student misbehaviours. Each factor had three items. The mean of items under each factor was calculated and further standardized within each country. The resultant *z* scores were used as factor scores.

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