



Hierarchical Linear Modeling of the relationship between Attitudinal and Instructional Variables and Mathematics Achievement

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ABSTRACT

Students' achievement in mathematics is often considered necessary for the success of the future of a country. Therefore, the training and preparation of students to do well in mathematics has become fundamental goal of education for most countries and more specifically in Ghana. Applying Hierarchical Linear Modeling on the Trends in International Mathematics and Science Study (TIMSS) 2007 data, the relationship between attitudinal and instructional variables and mathematics achievement among Ghana's grade eight students was examined. Prior to the analyses, exploratory factor analyses were conducted for clusters of similar items to reduce the number of predictor variables. The results indicate that student's gender, educational aspirations, self-confidence in mathematics, value for mathematics, and frequent use of some instructional variables were significant positive predictors at Level 1. Whiles amount of homework, years of teaching, major area of study were significant positive predictors, teaching license or certificate was a significant negative predictor at Level 2.

Indexing terms/Keywords

Mathematics achievement, attitudes, instructional practices, TIMSS 2007, Hierarchical linear modeling, Ghana

Academic Discipline And Sub-Disciplines

Education, Research Methods,

SUBJECT CLASSIFICATION

Mathematics Education

TYPE (METHOD/APPROACH)

Quantitative non-experimental study/Secondary data analysis

INTRODUCTION

Success in mathematics is associated with success in many aspects of life because of its relevance in science, engineering, technology, and mathematics (STEM) programs (Baker & LeTender, 2005; Wobmann, 2003). Students' achievement in mathematics is often considered necessary for the success of the students and their country. Therefore, the training and preparation of students to do well in mathematics has become a fundamental goal of education for most countries. Researchers, policy-makers, and school-based personnel continue to find ways of improving students' achievement in mathematics.

Several studies have been conducted to examine the factors that influence students' mathematics achievement. In one of the first studies, Coleman et al. (1966) reported that the most influential factor on students' learning achievement is the students' family background. However, subsequent research has revealed that while socio-economic status (Baker, Goesling, & LeTendre, 2002; Crane, 2001; O'Dwyer, 2005; Veenstra & Kuyper, 2004; White, 1982; Yang, 2003) and attitude toward mathematics (Broeck, Opdenakker, & Damme, 2005; House, 2003 & 2005; Ma & Kishor, 1997; Ma & Wilkins, 2003; Shavelson, McDonnell, & Oakes, 1989) has been consistently and positively related to mathematics performance, mixed results were obtained for gender (some studies favor boys (Neuschmidt, Barth, & Hastedt, 2008; Frempong, 2010; Teodorovic, 2012), other studies favor girls (Alkhateed, 2001; Azina & Halimah, 2012), and still other studies favoring neither boys nor girls (Bessudnov & Makarov, 2013; Leahey & Guo, 2001)). Further, Else-Quest, Hyde, & Linn (2010) found that all the gender effect sizes in mathematics achievement were small ($d < 0.15$) in their meta-analysis of the 2003 TIMSS and PISA data sets across 69 countries. Likewise, Hyde, Lindberg, Linn, Ellis, and Williams (2008) found small gender effect sizes ($d < 0.10$) in their meta-analysis involving over seven million students from US state assessments.

At the classroom level teacher characteristics such as teacher certification, education, subject matter and pedagogical knowledge, teaching experience, and teacher beliefs are positively and significantly related to students' achievement (Darling-Hammond & Youngs, 2002; Akiba, LeTender & Scriber, 2007; Chepete, 2008; Goldhaber & Brewer, 1997; Kaplan & George, 1998; Nye, Konstantopoulos & Hedges, 2004; Rice, 2003; Wayne & Youngs, 2003; Wilson, Floden, & Ferrini-Mundy, 2002). Studies have also suggested that classroom characteristics such as class size, teaching approach, classroom climate, and classroom practices are important variables that influences student achievements (e.g., Chepete, 2008, Mohamadpour, 2012, Pong and Pallas 2001). Zuzovsky (2013) examined the relationship between the frequent use of instructional practices from the TIMSS background questionnaire and mathematics achievement in schools in low-, medium, and high-achieving countries in TIMSS 2007. She found that the frequent use of interpretation of data in tables or graphs, beginning homework in class, use of computers, group work, and tests or quizzes frequently in mathematics



classes were negatively and significantly associated with achievement in all of the countries, with the largest negative effects in low-achieving countries. Somewhat in contrast, the frequent use of students working on mathematics problems on their own and deciding on ways to solve mathematics problems were positively and significantly associated with mathematics performance in high- and medium-achieving countries but negatively and significantly associated with learning outcomes in low-achieving countries.

Due to the importance of mathematics, the government of Ghana has implemented measures to ensure that all Ghanaian students acquire the mathematical skills, insights, attitudes, and values they will need to become successful in their chosen careers and daily life. One measure is Ghana's participation in the Trends in International Mathematics and Science Study (TIMSS) conducted by the International Association for the Evaluation of Educational Achievement (IEA; Anamuah-Mensah, Asabere-Ameyaw, & Mereku, 2004). Ghana began its participation in TIMSS at the 8th grade level in 2003, and continued its participation in 2007 and 2011. The intent of the participation is to examine Grade 8 student's achievement in mathematics and science in Ghana using an international benchmark (Anamuah-Mensah, Asabere-Ameyaw, & Mereku, 2004).

The performance of Grade 8 students in Ghana on the TIMSS mathematics test is not impressive. Ghana ranked 45th out of 46 countries in 2003 (MoE, 2004), 58th out of 59 countries in 2007 (MoE, 2008), and last out of 63 countries in 2011 (Mullis, Martin, Foy, & Arora, 2012). By examining the relationship of students' achievement on the TIMSS mathematics test and attitudinal and instructional variables measured on the TIMSS student and teacher background questionnaire, the hope is to identify significant variables that can be altered to improve mathematics achievement in Ghana. However, apart from the Ministry of Education sanctioned reports and with one exception, studies on factors that influence mathematics achievement of Ghanaian students are limited in number and scope. The one exception is the study completed by Frempong (2010) using the 2003 TIMSS data to determine what student, teacher, and school variables measured in TIMSS 2003 predicted student achievement on the TIMSS test. The findings of Frempong's study indicated that there was significant variation among schools in the mathematics achievement of their students. The findings also revealed that the most successful students in mathematics were males, who have highly educated parents, high academic aspirations, like mathematics, are confident learning mathematics, and attend schools located in towns but not in villages (Frempong, 2010). However, as indicated by the 2007 and 2011 TIMSS, the reports and Frempong's study have not influenced the achievement of Grade 8 students in mathematics. Consequently, the purpose of the present study is to provide additional information to be used by the Ministry of Education to improve mathematics achievement by examining the relationship between the Grade 8 students' performance on the 2007 TIMSS test and the variables measured on the student and teacher questionnaires.

METHODS

Data Source

The data from the 2007 TIMSS for Ghana were used in the present study. To ensure that the students selected from the participating countries are representative samples, TIMSS employed a two-stage stratified sample design. At the first stage, schools are selected with probabilities proportional to their sizes from the list of schools in the country that contain the Grade 8 students (Martin & Mullis, 2012). At the second stage, one or two intact classes are randomly selected from each selected school. The mathematics teachers for the selected classes, the principals from the selected schools, and the students in the sample classrooms are administered their respective questionnaires and, for the students, the achievement test. In 2007, Ghana's TIMSS sample consists of 163 mathematics teachers and 5,294 students (54% boys) in 163 schools.

Achievement Test

The Mathematics Assessment at Grade 8 contains four content areas: number, algebra, geometry, and data and chance. The TIMSS Assessment Frameworks [(Mullis, Martin, Ruddock, O'Sullivan, & Preuschoff, 2009) also specify three cognitive domains, knowing, applying, and reasoning. To ensure adequate coverage for reporting purposes, the number of questions is greater than the number a student could be expected to answer in one testing session of 45 minutes. A multiple-matrix sampling design is used whereby the assessment booklets for each class are distributed randomly to the students subject to the condition that a student receives the two booklets with no common items. Each student sits for testing sessions followed by a 30-minute session to complete the student questionnaire. Each assessment item appears in two booklets, and 14 booklets are required for the full set of items. The student questionnaire is common for all students. Breaks are taken between the sessions.

Given the multiple matrix design, a set of five plausible values were computed for each student as measures of the mathematics achievement. The plausible value method is a multiple imputation method used in large-scale assessment to obtain the estimate of the score each student would have obtained had the student attempted all the items on the test. Typically, the multiple imputations method generates imputed scores for the items that were not administered to a student, conditional on the student background characteristics and their responses to the attempted items (Gonzalez, Galia, & Li, 2004; Martin, 2005).

Independent variables

The student questionnaire for 2007 contained single items and items that were clustered together. An example of a single item is educational level of mother and education level of father. An example of a cluster included 12 items to determine the attitude of the students toward mathematics with each item responded to using a five-point, fully labelled Likert scale (e.g., I enjoy learning mathematics, Mathematics is not one of my strengths).



Exploratory factor analysis (EFA) was conducted to determine if the items within a cluster of items were unidimensional or multidimensional. Prior to the exploratory factor analysis, the maximum likelihood with expectation maximization (EM) algorithms was employed to replace all the missing values at both the student level and teacher level for 2007. This is because employing the listwise deletion procedure would have resulted in 40% loss of the initial sample. First the Kaiser-Guttman rule (Guttman, 1954) and Scree Test (Cattell, 1966) were used to determine the number of common factors. The number of factors for the attitude scale was three. Principal factor extraction followed by the promax transformation with $k = 4$ yielded a three factor pattern matrix with an interpretable simple structure. The three factors were labelled self-confidence, value of mathematics, and perceived difficulty with mathematics. The correlations among the pairs of factors were moderate, and Cronbach's alpha for the three factors were, respectively, 0.77, 0.74, and 0.61. Both the students (17 items) and the teachers (12 items) were asked about the instructional practices in the class (e.g., Practice adding, subtracting, multiplying, and dividing without using a calculator, solve geometric problem, decide procedures for complex problems, begin homework in class). The results of the factor analysis revealed that there was no interpretable solution of the student cluster of instructional practices and only one factor for the teacher cluster of instructional practices. Therefore, the individual instructional items were considered separately for the students' model.

Taking the factor analysis results into account, the following 23 student variables were considered: gender, educational aspiration, attitude toward mathematics (self-confidence, value of mathematics, and perceived difficulty of mathematics), and 17 instructional variables.

At the teacher level, seven variables were considered: gender, highest level of formal education, major area of study, teaching license or certificate, years of teaching, amount of homework, and the composite instructional practices variable.

Analysis

While data were collected from students, teachers (classroom), and principals (school), the sample from Ghana was such that the number of teachers was equal to the number of sampled schools. That is, there was only one teacher per school. Consequently, a two-level Hierarchical Linear Model (HLM) was used to analyze the data where students were nested within classrooms. Since there are no *a priori* hypotheses about between-school differences for the student predictor variables, the predictor coefficients were fixed. Only the intercepts, which correspond to the school means, were allowed to vary. The general equations for the two level model are:

$$Y_{ij} = \beta_{0j} + \sum_{q=1}^Q \beta_{qj} X_{qij} + r_{ij}$$

$$\beta_{0j} = \gamma_{00} + \sum_{a=1}^A \gamma_{aj} W_{aj} + u_{0j},$$

where Y_{ij} is the mathematics achievement score of student i in school j ,

β_{0j} is the intercept coefficient which in this case is the mean of class/school j

β_{qj} is the level-1 intercept of student variable q for class/school j ,

X_{qij} is the score of student i in class/school j for variable q , $q = 1, 2, \dots, Q$,

γ_{00} is the grand mean or overall average mathematics score for all classes/schools,

γ_{0j} is the level-2 coefficient of class/school j for variable a , $a = 1, 2, \dots, A$,

W_{aj} is the score for class/school j ,

r_{ij} is the random effect of student i in class/school j , and

u_{0j} is the residual effect for class/school j .

Both residual effects, r_{ij} and u_{0j} , are assumed to be normally and independently distributed with mean of zero and

variance σ^2 and τ_{00} , respectively.

Five HLM analyses were sequentially conducted (Raudenbush & Bryk, 2002). First, the analysis of the null model, which had no predictors at the student and classroom/teacher levels, was conducted to obtain an estimate of the total potential explainable variance at the student level and at the classroom/teacher level. Second, the predictors at the student level were added to obtain initial estimates of the predictor coefficient for each student variable. Third, the same analysis was conducted at the classroom level to obtain initial estimates of the predictor coefficient for each class/school variable. Fourth, a full analysis was conducted with all the predictor variables entered at the student and classroom levels. Fifth, a parsimonious model was conducted to remove variables from the full model in analysis four to obtain a final set of significant variables at the student level and at the class/school level. A back and forth approach was taken to remove the weakest predictor across the two levels, then the weakest was brought back into the model and the second weakest across the two levels was removed. If the weakest was still not significant, then the variable was removed. The procedure



continued in this manner until there were no non-significant predictors at each level. The HLM 7 program (Raudenbush et al., 2011) was used to perform the analyses of the TIMSS 2007 datasets.

RESULTS

The final results of the HLM analysis from the parsimonious model are presented in Table 1. The upper section of Table 1 contains the coefficients for the student level and the lower section contains the coefficients for class/teacher level. For example, the coefficient for gender for 2007 was 15.71, which indicates that boys tended to perform better than girls on the TIMSS 2007 mathematics test. Grade 8 students in 2007 with higher educational aspirations ($b = 4.08$) tended to have higher scores on the 2007 mathematics test than students with lower educational aspirations. Similarly, students with high self-confidence in mathematics and valued mathematics in 2007 ($b = 13.23$ and $b = 7.58$) tended to outperform students with low self-confidence in mathematics and place low value on mathematics

Six of the 17 instructional variables were significantly related to performance. One of the instructional variables – *we practice adding, subtracting, multiplying, and dividing without using a calculator* – had a positive association ($b = 5.60$) with mathematics achievement. The remaining five variables - *solve problems about geometric shapes* ($b = -5.15$), *decide on our own procedures for solving complex problems* ($b = -3.46$), *begin our homework in class* ($b = -8.19$), *we use calculators* ($b = -5.48$), and *we use computers* ($b = -7.43$) – were negatively related to mathematics achievement

Table 1: Significant Predictors of the Parsimonious Model

	<i>B</i>	<i>S.E</i>	<i>t-ratio</i>	<i>p-value</i>
Student Variables				
Students' gender	15.71	2.73	5.76	0.000
Level of aspiration	4.08	0.73	5.59	0.000
Self-confidence in mathematics	13.23	1.59	8.31	0.000
Value of mathematics	7.58	2.18	3.48	0.005
Perceived difficulty in mathematics	-11.89	2.17	-5.48	0.001
Practice adding, subtracting, multiplying, and dividing without using a calculator	5.60	1.27	4.42	0.001
Solve geometric problem	-5.15	1.51	-3.41	0.003
Use calculators	-5.48	1.86	-2.94	0.007
Use computers	-7.43	1.66	-4.45	0.000
Decide procedures for complex problems	-3.46	1.12	-3.01	0.003
Begin homework in class	-8.19	1.60	-5.11	0.000
Teacher level variables				
Teaching license or certificate	-23.90	8.52	-2.80	0.006
Years of teaching	1.30	0.58	2.25	0.027
Education- Mathematics	15.45	7.36	2.10	0.037
Amount of homework	9.90	3.90	2.54	0.012
Teachers' instructional practices	2.59	1.09	2.38	0.018

The results shown in the lower panel of Table 1 reveal that students taught by teachers with a teaching license/certificate performed less well than students taught by teachers without a teaching license/certificate ($b = -23.90$). In contrast, students taught by a teacher with a mathematics education major and a lot of teaching experience outperformed students taught by teachers without a mathematics education major ($b = 15.45$ and $b=1.30$). Students whose teachers frequently assigned homework tended to obtain higher scores on the mathematics test than students whose teachers infrequently assigned homework ($b = 9.90$). Lastly, students with teachers who had strong instructional practices tended to perform at a higher level on the mathematics test than students with teachers who did not employ strong instructional practice ($b = 2.59$).

Variance Explained

The proportions of variance in the mathematics achievement scores explained by the significant predictors at both levels are displayed in Table 2. The initial variance at the student level is 4782.77, which represents 60.8% of the total variance. The variance at the classroom level is 3080.49, which represents 39.2% of the total variance. This indicates that 39% of the variance in students' mathematics achievement is between schools. Further, the variance at the teacher level is



significantly different from zero ($p < 0.05$). As shown, the significant student predictors explained about 24% of the variance of mathematics achievement at the student level. The five significant teacher level predictors explained 36% of the variance in the mathematics achievement at the teacher/classroom level.

Table 2: Proportion of Variance Explained at Student and Teacher Levels

Level	Initial	Final	Percent Variance Explained
	Variance	Variance	
Student	4782.77	3616.59	24.38%
Teacher/principal	3083.49	1922.65	35.96%

DISCUSSION AND CONCLUSION

The results of the HLM analyses of the TIMSS 2007 data revealed that 11 student-level variables were significantly related to mathematics achievement in Ghana. The effects of some of these student-level variables were positive (e.g., gender, educational aspiration, self-confidence, and value for mathematics), and others were negative (e.g., perceived difficulty, begin homework in class, frequent use of calculators and computers). Five teacher variables were significantly related to Ghana's grade eight students' mathematics achievement in TIMSS 2007. Interestingly, whereas the effects of Mathematics education major, teaching experience, amount of homework, and teacher's instructional practices were positively related mathematics achievement, the effect of teaching license was negative; suggesting that possession of a teaching license is negatively associated with mathematics achievement.

The findings of this study are consistent with findings of previous studies. For instance, analyzing the TIMSS 2003 data from Ghana, Frempong (2010) found that, boys obtained higher mathematics achievement scores than girls. This finding is not surprising because in Sub-Saharan Africa, boys have consistently outperformed girls in mathematics achievement (MoE, 2004, 2008; Chowa, Masa, Ramos, & Ansong, 2013; Basse, Joshua, & Asim, 2011). Consistent with the findings of Chepete (2008), students who held high educational aspirations outperformed students who held low educational aspirations. Similar results were found in studies conducted in more advanced countries like USA and Canada (Broeck, Opdenakker, & Damme, 2005; House, 2003 & 2005; Ma & Kishor, 1997; Ma & Wilkins, 2003; Shavelson, McDonnell, & Oakes, 1989).

Consistent with previous research (e.g., Phan, 2008; Patterson, Perry, & Decker, 2003; Rodriguez, 2004; Trautwein & Koller, 2003), the amount of mathematics homework teachers gave to their students was positively related to students' mathematics achievement in 2007. Similarly, students who were more engaged in the instructional practices performed at a higher level than students who were not so engaged in 2007. This finding is consistent with the findings of House and Teles (2011) who used the TIMSS 1995 data to investigate classroom strategies that are significantly related to mathematics learning and achievement and found that students' learning and achievement were higher in classes where teachers employed a variety of activities such as explanation of the rules and definitions, solved examples pertaining to new topics, and solved real life experiences related problems.

In TIMSS 2007, students were asked to indicate how often they were engaged in 17 instructional activities during their mathematics lessons. Of the 17 instructional variables, one – *we practice adding, subtracting, multiplying, and dividing without using a calculator* – positively influenced mathematics achievement, whereas five – *solve problems about geometric shapes, decide on our own procedures for solving complex problems, begin our homework in class, we use calculators, and we use computers* – negatively influenced mathematics achievement. This finding is somewhat consistent with the findings of Zuzovsky (2013) who employed hierarchical multilevel regression analysis to explore the relationship between the frequent use of the 17 instructional practices and mathematics achievement in low-, medium-, and high-achieving countries. Zuzovsky found that the frequent use of instructional practices targeted at developing computational skills such as *we practice adding, subtracting, multiplying, and dividing without using a calculator* were positively and significantly associated with mathematics achievement, with the stronger association in low-achieving countries. She also found that whereas the frequent use of the instructional variables *solve problems about geometric shapes, decide on our own procedures for solving complex problems, begin our homework in class, we use calculators, and we use computers* were negatively associated with mathematics achievement in low-achieving countries, *solve problems about geometric shapes, decide on our own procedures for solving complex problems and we use calculators* were positively associated with mathematics achievement in medium and, more-so, high-achieving countries. It can be deduced from this finding that replacing all teacher-centered instructional activities with more student-centered activities might not be equally beneficial to all students in all participating countries. The frequent use of such student-centered instructional activities that are more demanding practices might be advantageous to high-achieving students who are usually from high-achieving countries and less beneficial to low-achieving students from low-achieving countries.

Students taught by teachers with teaching license or certificates performed less well in mathematics achievement than students taught by uncertificated teachers. In contrast Darling-Hammond (2000) found that students of teachers in the United States with full certification obtained higher scores in mathematics achievement. However and in agreement with Goldhaber and Brewer (1997), students in Ghana taught by teachers with a mathematics education major performed at a higher level than students taught by teachers who did not have a mathematics education major. Teaching experience or



years of teaching was positively related to mathematics achievement, which is consistent with the findings of previous studies (Greenwald, Hedges, & Laine, 1996; Rice, 2003; Chidolue, 1996; Fetler, 2001).

The results of this study illuminated useful information regarding Ghana's grade 8 students' performance in mathematics on the TIMSS 2007 assessment. However, the finding that only 24% and 36% of the variability in mathematics achievement were explained by the student- and teacher- level variables might indicate a likely underrepresentation of predictors of mathematics achievement in Ghana. More predictor variables should be included in the modeling procedure in order to get full picture of students' mathematics learning and achievement. Also the direct and indirect effects of these variables on mathematics achievement may be considered in future research.

One limitation of the current study is related to the source of literature that guided the selection of variables, informed the direction of data analyses and interpretation of the results. Not many studies have been conducted to examine students' mathematics achievement from developing countries; hence the literature reviewed was primarily from developed countries. In addition, not many African countries participated in the TIMSS assessments. It is therefore likely that this study might have ignored some important variables that are of particular importance in developing countries

In light of the findings and limitation of the study, it is concluded that the poor performance of Ghana as a country in the TIMSS 2007 is partially attributable to inconsistent use of homework, failure to engage students in their learning, lack of progress of girls, lack of students' interest and confidence in mathematics, and students' lower educational aspiration. It is recommended that the Inspectorate Division of the Ghana Education Service strengthen its supervisory and monitoring activities to ensure that appropriate instructional activities and practices are taken place in Ghanaian classrooms. Further, steps should be taken to ensure that teachers frequently give mathematics homework and also to ensure that the homework is marked and reviewed in class. Further, teacher training institutions need to revise their curriculum so that pre-service teachers will be given the opportunity to learn modern and innovative teaching methods and strategies. Pre-service teachers also need to become aware of how to engage their students more actively in their learning. Additionally more pre-service students should be encouraged into specialized mathematics and science training colleges to complete specialized mathematics and science specialties or majors. Further, in light of the findings, consideration should be given to requiring all pre-service teachers to obtain a B.Ed. with specialization in mathematics if they plan to teach mathematics

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