Quality mathematics classroom instructional practices: Evidence from TIMSS 2011

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Introduction

The East Asian school systems, including Chinese Taipei, Hong Kong, Japan, Korea and Singapore, have consistently been identified as top performers in international assessments of student achievement, such as Trends in International Mathematics and Science Study (TIMSS) (Mullis, Martin, Foy, & Arora, 2012; Mullis et al., 2000). In order to unravel the mystery of success, many researchers have looked into various aspects of the educational processes and contexts in these systems, including curriculum, teachers, students, culture, etc. (e.g. Chen, 2012, 2014; Leung, 2005; Zhu & Leung, 2011). Among those, teachers' classroom instructional practices are certainly essential to student achievement.

Numerous studies have examined the relationships between instructional strategies and students' mathematics achievement, and many of them have been based on secondary analysis of large-scale assessment data like TIMSS (e.g. House, 2009; Sabah & Hammouri, 2010). In particular contexts, specific instructional strategies have been found significantly associated with mathematics achievement scores. However, it should be noted that the extant body of research literature have two limitations. One is that few studies have examined the above-mentioned relationships across contexts, thus relevant similarities and differences among contexts remain unknown. The other is that many of the secondary studies have not taken into account the multilevel nature of TIMSS data and mainly employed inappropriate techniques like multiple regressions to analyze the data making their research findings questionable. It is increasingly recognized that the conventional techniques based on ordinary least squares regression fail to deal with the multilevel nature of educational data, whereas hierarchical linear modeling (HLM) is most appropriate to do so (Raudenbush & Bryk, 2002).

Given the limitations, the purpose of this study was to investigate the relationships between mathematics classroom instructional practices and mathematics achievement across the five East Asian school systems by using HLM techniques. The specific research questions were as follows:

1. In Chinese Taipei, Hong Kong, Japan, Korea, and Singapore respectively, how did eighth graders' mathematics achievement vary between students within school/class and between schools?
2. After controlling for student characteristics, how were the mathematics classroom instructional practices related to mathematics achievement?
3. What were the similarities and differences in above aspects among the five school systems?

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Methods

Data source and sample

Data for this study were drawn from the TIMSS 2011 international database. Specifically, grade 8 datasets of Chinese Taipei, Hong Kong, Japan, Korea, and Singapore were used for analysis.

According to Martin and Mullis (2013), the TIMSS 2011 assessment employed a stratified two-stage cluster sample design. At the first stage, schools were selected using probability-proportional-to-size sampling; at the second stage, one or two classes were randomly sampled in each school. In this study, the data were of two levels: student as level 1 and the combination of the class and school as level 2, because generally only one class was selected in each school.

Sample size is a crucial issue in multilevel modeling, as there is more than one sample size. According to Hox (2009), the estimated parameters are affected by both lower and higher level sample sizes, but the higher level sample size is much more important than the lower level one. In this study, after cases with missing data were deleted, the sample sizes at both level 1 (total number of students) and level 2 (total number of schools) were slightly reduced, but they were still sufficient and met the standard suggested in the literature (Hox, 2009). The specific number of schools, students, together with the rank and mean mathematics achievement score for the five school systems (Mullis et al., 2012, p. 42) are given in Table 1.

Table 1. Sample size, rank and mean score of the five East Asian school systems

School System	School	Student	Rank	Mean Score (SE)
Chinese Taipei	148 (150)	4961(5042)	3	609 (3.2)
Hong Kong	113 (117)	3975 (4015)	4	586 (3.8)
Japan	133 (138)	4356 (4414)	5	570 (2.6)
Korea	145 (150)	4982 (5166)	1	613 (2.9)
Singapore	165 (165)	5916 (5927)	2	611 (3.8)

Note: Numbers in the brackets in the school and student column are full sample size.

Measures

The dependent (predicted) variable for this study was eighth graders' mathematics scores in TIMSS 2011. TIMSS 2011 used five plausible values to estimate the mathematics proficiency of each student. With regard to the independent (predictor) variables, a total of fourteen variables were used. The properties of the independent variables for level 1 and level 2 are given in Table 2.

In the HLM analyses within each school system, dummy/dichotomous variables were not centered. Therefore, the coefficients for those variables were interpreted as the mean difference between the two groups. All other variables were transformed into z scores (*M=0, SD=1*) across schools but within each system so that results could be reported as standard deviation units within each system. Furthermore, for each system, a (bivariate) correlation matrix was generated to check the assumption of multicollinearity required for multilevel analysis. It was confirmed that multicollinearity was not a problem for this study. Due to the limit of page space, the correlation matrices and descriptive statistics for all the independent variables were not presented in this paper.

Missing data is a crucial issue in multilevel analysis, as it could occur in more than one level. If 5% or less of data is randomly missing in a large data set, the problem is not serious and almost any method of handling missing values produces similar results (Tabachnick & Fidell, 2007). Since the proportions of missing data were found to be almost below 5% in the five systems, the listwise deletion method was used when running analysis in this study.

Table 2. Independent Variables at Level 1 and Level 2

<table>
<tr><th>Variable Name</th><th>Description</th></tr>
<tr><td colspan="2">Level 1 Student Variable</td></tr>
<tr><td>SGENDER-student gender</td><td>0=girl, 1=boy.</td></tr>
<tr><td>IMMIGR-immigration background</td><td>0=no (born in the test country),
1=yes (not born in the test country).</td></tr>
<tr><td>HOMER- home educational resources</td><td>Rasch score calculated based on number of books in the home, number of home study supports, and highest level of education of either parent. International Mean=10, International SD=2.</td></tr>
<tr><td colspan="2">Level 2 School/Class Variable</td></tr>
<tr><td colspan="2">In teaching mathematics to this class, how often do you usually ask students to do the following?</td></tr>
<tr><td>IP1-Listen to me explain how to solve problems.</td><td rowspan="11">1=never, 2=some lessons, 3=about half the lessons, 4= every or almost every lesson.</td></tr>
<tr><td>IP2- Memorize rules, procedures, and facts.</td></tr>
<tr><td>IP3- Work problems (individually or with peers) with my guidance.</td></tr>
<tr><td>IP4- Work problems together in the whole class with direct guidance from me.</td></tr>
<tr><td>IP5- Work problems (individually or with peers) while I am occupied by other tasks.</td></tr>
<tr><td>IP6- Apply facts, concepts, and procedures to solve routine problems.</td></tr>
<tr><td>IP7- Explain their answers.</td></tr>
<tr><td>IP8- Relate what they are learning in mathematics to their daily lives.</td></tr>
<tr><td>IP9- Decide on their own procedures for solving complex problems.</td></tr>
<tr><td>IP10- Work on problems for which there is no immediately obvious method of solution.</td></tr>
<tr><td>IP11-Take a written test or quiz</td></tr>
</table>

Data analysis

Due to the nested structure of the data and the sample design, a two-level HLM modeling approach (Raudenbush & Bryk, 2002) was used to examine the relationships between the independent variables and the dependent variable. In each school system, 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.

For each school system, three sets of HLM models were produced. Firstly, the proportions of variation of student mathematics achievement at the student and class/school levels were examined (i.e. fully unconditional model—Model A). Secondly, student variables were added to the model as level 1 predictors. This resultant model (i.e. partially conditional model—Model B) answers the question to what extent the considered student variables predict mathematics achievement. Thirdly, the eleven instructional practice variables were added to model B as level 2 predictors. This model (i.e. fully conditional model—Model C) answers the question of how the instructional practice variables contribute to variation in student mathematics achievement, after controlling for student characteristics.

Furthermore, in the HLM analyses, the HLM 6.0 software (Raudenbush, Bryk, Cheong, Congdon, & Toit, 2004) enabled the use of five plausible values as dependent variable, and the restricted maximum likelihood method was chosen to estimate the model parameters. The mathematics teacher weight MATWGT reported in the international database was used at both level 1 and level 2 to correctly reflect the characteristics of the student population.

Result

Table 3 shows the whole sets of HLM models for the five East Asian school systems.

According to Table 3, among the five school systems, Korea had highest grand mean for mathematics achievement, followed by Singapore, Chinese Taipei, Hong Kong, and Japan. The relative between-school variation in achievement, compared to total variation, was largest in Singapore, followed by Hong Kong, Chinese Taipei, Japan, and Korea.

At the student level, home educational resources was positively associated with mathematics achievement across all the five school systems. A unit of standard deviation in it was respectively associated with 32.13, 2.40, 25.28, 37.02, and 13.63 points increase in mathematics achievement, respectively. On the other hand, the relationship between student gender, immigration background and mathematics achievement varied across the systems. Significant gender differences in favor of boys were found in Hong Kong, Japan, and Korea. Compared to native students, students with immigration background scored significantly lower in Chinese Taipei and Korea, but significantly higher in Hong Kong. The Model B resulted in 11.4% reduction in the variance of mathematics achievement between students within each school/class in Chinese Taipei, 3.9% in Hong Kong, 8.8% in Japan, 15.1% in Korea, and 3.5% in Singapore, and reduced the variance between schools by 43.2% in Chinese Taipei, -5.6% in Hong Kong, 31.9.% in Japan, 65.2% in Korea, and 16% in Singapore.

After controlling for student characteristics, the majority of the eleven instructional practice variables were not significantly associated with mathematics achievement. Specifically, none of the instructional practice variables was significantly related to mathematics achievement in Chinese Taipei and Korea; IP11 was the only significant predictor in Hong Kong, and it was negatively related to mathematics achievement; IP5 was the unique significant predictor in Japan, and it was negatively related to mathematics achievement; IP6, IP8, IP9, and IP11 were four significant predictors in Singapore, the former three were positive correlates while the latter one was a negative correlate. The Model C resulted in 11.4% reduction in the variance of mathematics achievement between students within each school/class in Chinese Taipei, 3.9% in Hong Kong, 8.8% in Japan, 15.1% in Korea, and 3.5% in Singapore, and reduced the variance between schools by 44.2% in Chinese Taipei, -6.5% in Hong Kong, 34.6.% in Japan, 64.6% in Korea, and 25.8% in Singapore.

Table 3. HLM models for the five East Asian school systems

	Variable	Chinese Taipei	Hong Kong	Japan	Korea	Singapore
Model A	Intercept	606.87^{***}	579.30^{***}	568.94^{***}	611.53^{***}	610.91^{***}
	L1 Var. σ^2	8661.28	2744.95	6067.45	7334.65	3960.52
	L2 Var. τ_{00}	2431.05	4589.88	903.33	714.92	3070.58
	ICC	0.22	0.37	0.13	0.09	0.44
Model B	Intercept	612.05^{***}	566.28^{***}	567.62^{***}	610.46^{***}	610.01^{***}
	SGENDER	0.24	21.06^{***}	4.89^{*}	6.57^{*}	-0.23
	IMMIGR	-77.18^{***}	8.72^{**}	-24.87	-38.72^{*}	5.06
	HOMER	32.13^{***}	2.40^{*}	25.28^{***}	37.02^{***}	13.63^{***}
	L1 Var. σ^2	7672.17	2639.16	5534.19	6228.37	3823.74
	L2 Var. τ_{00}	1380.50	4845.79	615.20	249.05	2578.36
Model C	Intercept	612.27^{***}	566.97^{***}	567.75^{***}	610.78^{***}	609.11^{***}
	IP1	0.90	-8.01	0.08	-0.37	1.84
	IP2.	-0.96	5.72	0.67	-0.04	-8.74
	IP3.	-4.94	10.53	4.25	4.79	-1.95
	IP4.	-3.50	-10.60	0.78	-3.64	-6.47
	IP5.	-3.34	5.91	-5.07^{*}	0.62	-1.76
	IP6.	3.47	4.99	1.91	1.27	10.13^{*}
	IP7.	5.60	-1.21	-1.16	-1.50	-1.12
	IP8.	-3.77	4.35	1.01	-2.15	14.08^{**}
	IP9.	2.12	-10.97	4.27	3.75	15.29^{**}
	IP10.	7.44	1.80	1.43	-0.43	-9.00
	IP11.	-1.72	-12.43^{*}	-2.85	1.66	-8.62^{*}
	SGENDER	0.19	21.11^{***}	5.05^{*}	6.37^{*}	-0.17
	IMMIGR	-77.34^{***}	8.79^{**}	-25.52	-38.87^{*}	5.08
	HOMER	31.94^{***}	2.33^{*}	25.09^{***}	36.80^{***}	13.56^{***}
	L1 Var. σ^2	7671.69	2639.07	5533.89	6226.05	3823.65
	L2 Var. τ_{00}	1356.62	4887.68	590.65	253.06	2278.50

σ^2- the variation of mathematics achievement between students within the class; τ_{00}-the variation of mathematics achievement between schools/classes; ICC (Intraclass correlation) $=\tau_{00}/(\tau_{00} + \sigma^2)$, -relative between-school variation in achievement compared to total variation;
$^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

Conclusion and discussion

The results of this study showed that less than half of the variation in mathematics achievement was between schools in all the five East Asian school systems, with the least (9%) in Korea and most (44%) in Singapore. In other words, in all the five school systems, the variance in mathematics achievement was more attributable to student factors than school and class factors in these systems. This finding is quite consistent with those from other studies (e.g. Chen, 2014; Teodorović, 2012).

Among the three student variables, home educational resources was the only significant, positive correlate across all the five East Asian school systems. This is not surprising because this variable is a measure of family social economic status (SES), which has been consistently identified as significant student-level predictor in many achievement studies (e.g. Chen, 2014; Mohammadpour & Ghafar, 2012).

More importantly, this study indicated that although almost all the eleven instructional practice variables were significantly related to mathematics achievement as found in correlation analysis, most of them were no longer so after the effect of the three student variables were controlled for, as shown in the multilevel models. This finding is fresh and extremely profound when the role of classroom instructional practices in boosting mathematics achievement is considered. Given that prior studies mainly used conventional single-level regression analysis methods and thereby identified most of the classroom instructional practices as significant correlates of mathematics achievement (House, 2002, 2009), this study illustrated that the use of HLM techniques really made a difference.

Furthermore, this study identified quite a few similarities as well as differences among the five East Asian school systems (See Table 3). Overall, it seems impossible to conceptualize an East Asian model because the role of many variables differed across the contexts.

Implication

This study provides several implications for educational research and practice. Before discussing these, it is worth mentioning that this study used cross-sectional observational data, thus claims about causal relationship are inappropriate.

Firstly, this study found that after student effects were controlled for, only a few classroom instructional practice variables were significantly associated with mathematics achievement. Therefore, it seems not helpful to enhance mathematics achievement if teachers increase or decrease the frequency of most of the eleven classroom instructional practices. This is especially true for Chinese Taipei and Korea. In these cases, how to improve teachers' classroom instructional practices for better mathematics achievement becomes an interesting research task. It is possible that other crucial classroom instructional practice variables for these school systems were not included in the TIMSS database. Future research needs to explore more kinds of instructional practices so that those significant can be identified.

Secondly, it was found in this study that when analyzing Hong Kong data, inclusion of more variables in the model resulted in larger unexplained level 2 variance, which is unusual in HLM analysis. Specifically, both Model B and Model C failed to help explain/reduce the between-school variance in student achievement; instead, they increased the between-school variance from 4589.88 to 4845.79, and then to 4887.68. Further research need to explore the reasons behind this.

Lastly, in this study, the eleven classroom instructional practice variables were analyzed as individual variables. Further research can attempt to categorize these into different types of teaching approaches through exploratory factor analysis, and thereby investigate the effects of different approaches on student achievement.

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