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Cross-Cultural Comparison of the School Factors Affecting Students' Achievement in Mathematical Literacy: Based on the Multilevel Analysis of PISA 2012

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ABSTRACT

Student achievement is a global concern as reflected in recent large-scale standardized assessments. This study compared PISA 2012 student mathematical literacy scores across four countries/regions with varying levels of student performance: Shanghai-China, the United States, Finland and Japan. Sixty-five countries participated in PISA 2012, which measured 15-year-old children's mathematical achievement. The study explored the relationship of principals' perceived levels of leadership, school policy, and educational resources with student attainment of mathematical literacy. School variables were treated as covariates when each effect of principal leadership was interpreted. All variables were included in a multilevel model and analyzed simultaneously. The means and standard deviations of outcome variables and the explanatory and control variables for the model of the study were calculated by including sampling weights and plausible values for mathematical literacy scores. SAS PROC MIXED was used to fit multilevel linear models for the study. The findings indicated that: with students' background controlled, the effect of school educational resources on students' mathematical literacy demonstrated some cultural differences among the four countries. Specifically, class size had a significantly positive effect on students' mathematical literacy in Finland and Japan. There was a negative relationship between student achievement and lack of educational resources. Social, economic, and cultural status showed a positive relationship with mathematical literacy under each of the four different cultural contexts. Results also indicated that students are likely to achieve better if principals perceive that there are no shortages of personnel and equipment.

INTRODUCTION

The learning achievement of students is the key index to measure the development of students, so the study of factors affecting students' learning achievement has always been a heated topic in educational and psychological research. This study uses the Organization for Economic Cooperation and Development's (OECD) Program for International Student Assessment data set (PISA) to explore the relationship of principals' perceived levels of leadership, school policy, and educational resources with student attainment of mathematical literacy. PISA provides data on test scores, schools, and family background for hundreds of thousands of students around the world, which makes it the largest cross-country data set in the world for analyzing the relation between test scores and their potential determinants.

RESEARCH METHOD

Data sources

This study use data on students and schools from the 2012 wave. In PISA 2012, 65 countries/ regions participated in this project. The primary goal of this international project is to assess how well 15-year-old students nearing the completion of compulsory education have acquired the knowledge and skills essential for meeting the challenges in our society. It then develops educational indicators to help governmental bodies and policy makers examine, evaluate, and monitor the effectiveness of the education system in each participating country/region at both national and school levels.

Starting from 2000, PISA takes place every three years. The assessment covers the domains of reading, mathematical, and scientific literacy. In each cycle, about 50% of the testing time (2 hours in total) will be devoted to a major domain among the three for detailed investigation, whereas a summary profile will be provided for the remaining domains. In PISA, literacy refers to the capacity of students to apply knowledge and skills in key domain areas and to reason and communicate effectively as they pose and solve problems in a variety of situations in the real world (OECD, 2013). Approximately 510,000 students were randomly sampled to participate in PISA 2012. The achieved sample represents about 28 million 15-year-old students in the schools of the 65 participating countries/economies, of which 34 were OECD member countries and 31 were partner countries/economies. In addition to the PISA tests, students fill a questionnaire on their characteristics, family structure, and background. Principals of each participating school report their school characteristics, policies, and practices.

The international database is accessible on the official PISA website (www.pisa.oecd.org). PISA 2012 provided not only student scores in subject areas but also supplied contextual information surrounding students and schools. Students and school principals are requested to complete questionnaires in order to gather contextual information. These student and school characteristics are vital to a solid base for policy-oriented analysis of the assessment results.

Moreover, as an optional component of PISA 2012, 11 participating countries complemented the perspectives of students and school principals with data collected from parents. These data provide an outlook on parental perceptions on school quality and school accountability (OECD, 2012). For this study, the student scores in mathematical literacy along with student- and school-level survey responses from the United States, Shanghai-China, Finland and Japan were analyzed simultaneously.

Variable selection

The dependent variable is the student's mathematical literacy score. Background characteristics at the school and students levels are used as control variables. All variables were included in a multilevel model and analyzed simultaneously. The first level is the student level variables, including gender of students and their families socio-economic and cultural (ESCS) (OECD, 2010); The second level is the school level variables, including school type, school size, class size, student-teacher ratio, school educational resources and four types of principals' perceived levels of leadership. PISA2012 defined four types of leadership: Instructional leadership, framing and communicating the school's goals and curricular development, promoting instructional improvements and professional development and the leadership of teacher.

Table 1.Summary of Predicting variables

Variable	Description
Student-level variables	
Gender	Categorical variable:1-female, 2-male
ESCS	Continuous variable: economic, social, cultural status
School-level variables	
School Type	Categorical variable:1-public, 2-private
School Size	Continuous variable: the total number of students in a school
Class Size	Continuous variable: the average number of class in school
Student-Teacher Ratio	Continuous variable: the number of students in school divided by the number of school teachers
Educational Resources	Continuous variable: shortage or inadequacy of educational resources in school
LEADPD	Continuous variable: promoting instructional improvements and professional development
LEADINST	Continuous variable: instructional leadership
LEADCOM	Continuous variable: framing and communicating the school's goals and curricular development
LEADTCH	Continuous variable: the leadership of teacher

Data Analysis

The data structure of PISA2012 is multilevel with students are nested in schools, and schools are nested in each country. Here these predictors for variables contain all these levels. The challenge is to combine all levels of these predictors into an appropriate statistical analysis. Multilevel model provides a tool taking into account all levels assumption and the dependence between these levels. In this study, all variables were included in a multilevel model and analyzed simultaneously. The means and standard deviations of outcome variables and the explanatory and control variables for the model of the study were calculated by including sampling weights and plausible values for mathematical literacy scores.

In PISA database, PISA reports student performance through five plausible values in each subject. The plausible values are random choosing from the marginal posterior distribution of the latent trait for each student in mathematical literacy (OECD, 2012). SAS PROC MIXED (Version 9.3) was used to fit multilevel linear models for the study. The model statistics were obtained by running each model 405 times—with the 1 total weight and 80 replicate sample weights for each of the 5 plausible values. Missing data were deleted listwise and the missing data in this study were assumed to be MAR. PROC MIXED is known to handle missing data where the dropout process is random (MAR) correctly (Verbeke & Molenberghs, 2000).

PISA also develops a particular replication method for estimating sampling variances, which is named as the Fay's variant of the Balanced Repeated Replication method (OECD, 2012). According to the PISA Data Analysis Manual SAS® (OECD, 2009), all statistical analyses or procedures concerning the PISA data should be weighted and that unweighted analyses will yield biased estimates of the standard errors for population parameter estimates.

According to the principle of multilevel linear model, a multilevel model is formulated without explanatory variables first. Then the explanatory variables are added to the model at student and school levels simultaneously. In multilevel model, the former is called the unconditional model, and the latter is the conditional model. The unconditional model for the study was formulated with each plausible value for a student as follows:

$$Y_{ij}=\beta_{0j}+\mu_{0j}+r_{ij}$$

The conditional multilevel model was:

$$Y_{ii}=\gamma_{00} + \gamma_{01}SchoolType_{ij} +\gamma_{02}SchoolSize_{ij}+\gamma_{03}ClassSize_{ij}+\gamma_{04}\ Student\text{-}Teacher\ Ratio_{ii}+\gamma_{05}\ Educational\ Resource_{ij}+\gamma_{06}LEADCOM_{ij}+\gamma_{07}LEADINST_{ij}+\gamma_{08}LEADPD_{ij}+\gamma_{09}LEADTCH_{ij}+\gamma_{10}\ Gender_{ij}+\gamma_{20}\ ESCS_{ij}+\mu_{0j} +r_{ij}$$

RESULT

This study compared PISA 2012 student mathematical literacy scores with principal perceptions across four countries/regions with varying levels of student performance: Shanghai-China, the United States, Finland and Japan. The study explored the relationship of principals' perceived levels of leadership, school policy, and educational resources with student attainment of mathematical literacy. Finland had the largest sample size among the four countries/regions (279 schools and 7,895 students), followed by Japan (190 schools and 6,185 students) whereas the United States (144 schools and 4,363 students). The detailed information is shown in Table 2.

The means and standard deviations of the outcome variables and the explanatory and control variables for the model of the study are found in Table 3. The statistics were calculated by including sampling weights--as well as plausible values for mathematical literacy scores--to avoid estimation bias. As seen in this table, Shanghai-China showed the highest average score in math literacy (612.68) followed by Japan (536.41), Finland (518.75) and the United States (481.37). These results show that the math abilities for the four countries are very different from each other. The mean of the scale was set at 500 and the SD at 100 when the PISA literacy scale was established (OECD, 2012). Table 3 shows that the United States had the highest result in principals' perception of their leadership. Shanghai-china has the largest school size and class size, while the United States had the highest scores in Student-Teacher Ratio.

Table2. Sample Size.

Unit	Country			
	United States (%)	Finland (%)	Japan (%)	Shanghai-China (%)
Students	4363	7895	6185	5100
Schools	144	279	190	153
Females	2149(49%)	3908(49%)	2945(48%)	2600(51%)
Males	2214(51%)	3987(51%)	3240(52%)	2500(49%)

Table 3. Descriptive Statistics of Explanatory and Outcome Variables.

Variable	Country							
	United States		Finland		Japan		Shanghai-China	
	M	SD	M	SD	M	SD	M	SD
Mathematical Literacy	481.37	89.86	518.75	85.29	536.41	93.52	612.68	-100.98
ESCS	0.17	0.94	0.37	0.77	-0.07	0.71	-0.36	0.96
School Size	1392	867.49	419	195	751	402.6	1434	1043.58
Class Size	24.51	8.38	18.31	4.27	37.21	6.12	39.29	-7.56
Student-Teacher Ratio	17.42	10.05	10.6	1.97	11.64	4.51	12.14	5.36
Educational Resources	0.38	1.07	-0.2	0.82	0.44	1.02	0.13	1.24
LEADPD	0.59	0.94	-0.14	0.8	-0.66	0.91	-0.22	0.88
LEADINST	0.9	0.97	-0.24	0.86	0.67	0.98	-0.2	0.76
LEADCOM	0.84	0.96	-0.38	0.93	-1.05	0.9	-0.35	0.7
LEADTCH	0.54	0.99	0.03	0.85	-0.42	1	-0.79	0.77

Table 4 shows the estimated variance across and within school among the four countries/regions. The Intraclass Correlation Coefficient (ICC) represents the degree of similarity within the group. Cohen (1988) considered that when ICC is greater than 0.059, then it could not ignore the existence of similarity within the group, it should consider use of multilevel analysis. Bryk & Raudenbush (1992) and Verbek & Molenberghs (2000) also believed that if we still use the traditional multiple regression under this condition, the occurrence of Type I error probability will increase substantially. The ICC of the United States, Finland, Japan and Shanghai area have 0.25, 0.12, 0.54 and 0.47, respectively. As can be seen in the table, Japan and Shanghai have the larger proportion of variation across schools, whereas Finland and the United States have the larger proportion of variation within schools, which indicates that that Finland and the United States have a better equity of education.

From the Table 5, the results shown: with students' background controlled, the effect of school educational resources on students' mathematical literacy demonstrated some cultural differences among the four countries. Specifically, class size had a significantly positive effect on students' mathematical literacy in Finland and Japan. There was a negative relationship between student achievement and lack of educational resources. Social, economic, and cultural status showed a positive relationship with mathematical literacy under each of the four different cultural contexts. Results also indicated that students are likely to achieve better if principals perceive that there are no shortages of personnel and equipment.

Table 4.Variance Estimated across and within school.

Variance Estimate	Country							
	United States		Finland		Japan		Shanghai-China	
	M	SE	M	SE	M	SE	M	SE
Variance Across Schools	2062(25%)	45.41	866(12%)	29.43	4721(54%)	68.72	4823(47%)	69.45
Variance Within Schools	6121(75%)	78.24	6329(88%)	79.56	4047(46%)	63.62	5382(53%)	73.36

Table 5. Descriptive Statistics of Explanatory and Outcome Variables.

Variable	Country							
	United States		Finland		Japan		Shanghai-China	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Fixed Effect								
Intercept	504.51***	11.7	516.65***	4.45	563.59***	10.69	592.76***	12.4

Gender	7.90**	2.61	0.45	2.61	16.45***	2.19	14.08***	2.41
ESCS	24.08***	1.99	29.86***	1.53	3.92*	1.74	9.27***	1.75
School Type	-29.94**	9.39	-9.9	7.99	-42.37***	7.96	-3.19	10.31
School Size	0.005	0.004	0.02	0.01	0.02	0.01	-0.005	0.003
Class Size	-0.75	0.68	2.34**	0.77	1.37**	0.43	0.19	0.48
Student-Teacher Ratio	-0.14	0.29	-1.65	1.68	-0.29	0.98	-1.32	0.91
Educational Resources	3.42	2.29	1.21	2.11	-2.76	2.64	1.25	2.68
LEADCOM	-7.38	5.37	5.84	4.25	1.82	5.04	6.89	6.1
LEADINST	3.13	6.45	-4.27	3.56	1.07	5.37	-2.71	6.54
LEADPD	-7.28	4.99	-5.54	4.34	-4	3.7	1.59	5.17
LEADTCH	7.23	4.15	-4.22	2.56	-2.84	4	3.32	5.39
Random Effect								
Variance Across Schools	712.99***	26.7	469.40***	21.67	1166.48***	34.15	1612.11***	43.15
Variance Within Schools	5695.19**	75.47	5821.52***	76.3	3989.85***	63.17	5279.13***	72.66

*** P<0.001

CONCLUSION

The findings indicated that: Class size had a significantly positive effect on students' mathematical literacy in Finland and Japan. There was a negative relationship between student achievement and lack of educational resources. Social, economic, and cultural status showed a positive relationship with mathematical literacy under each of the four different cultural contexts. Results also indicated that students are likely to achieve better if principals perceive that there are no shortages of personnel and equipment.

With students' background controlled, principals' perceptions of leadership have no significant predictive effect on student's mathematical literacy. The possible reasons are: each country has an unique education systems and their principals, teachers, and students behave differently from each other in certain circumstances. In additional, the PISA questionnaire also has limitations to measure the same educational construct across different countries.

The data from PISA school questionnaire are self -reported data. Perceptions do not necessarily equal reality, and maintaining a level of honesty and accuracy with survey data can be difficult. Regarding to principal leadership, the school principal may not be the appropriate information provider. Previous studies indicated that the data of principal's leadership collected from the teacher' perspective provided the most effective result. For instance, the Principal Instructional Leadership questionnaires developed by Hallinger were divided into three parallel versions, the principal self-assessment version, teacher's version and supervisor's version. These three versions are identical and only were filled out by three different groups. Earlier studies found that there was a significant difference between the views of the three different groups towards principal's leadership (Hallinger & Murphy, 1985; Krug, 1986). Validation studies also conducted in the US shown that, teachers' version provided the most effective and convincing data among the three parallel versions (Hallinger, 2011). Because Teachers tend to answer questions based on to what extent they perceive their respective principal actually performed behavior, whereas the principal self-assessment scores tend to be less objective. Therefore, regarding to principal's leadership, the teacher may be the most appropriate information provider.

Moreover, there is a distance between principals' perceptions of leadership and students' learning, which is mediated by teachers' professional activities. Although principal behaviors have influence on teacher's activities, in the end, teacher's professional activities will have a huge impact on student achievement. In addition, according to the OECD report (OECD, 2013), it has presented that the four types of leadership defined by PISA2012 were highly correlated, which may lead to collinearity issues, resulting in the inflation of Type II error rate.

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