Multilevel Analysis of PISA 2003 with Influence on Achievement from Education Index of Countries and Time Studying of Students

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Abstract: Starting from 2000, the Programme on International Student Assessment (PISA) is held by the Organization for Economic Co-operation and Development (OECD) for the 15-year-old every three years. The sample includes over 270,000 participants of 41 countries in the PISA 2003 database aimed at evaluating mathematics and problem-solving ability. Most of the studies on the database are analyses of descriptive statistics, however, the database has the characteristics of hierarchical properties. It is necessary to use hierarchical linear model (HLM) of two levels to analyze the relation between the variables of countries and students. The unit in level-1 is students. The variables belonging to the level-1 are the score of mathematics cognition and the time studying mathematics homework outside the regular mathematics classes. As to the level-2, the unit is countries and the variable is Education Index (EI) from Human Development Reports (HDR) of United Nations Development Programme (UNDP). Also, in considering of the differences between OECD countries and non-OECD countries, the database is divided into two groups. Therefore, the purpose of this study is to investigate the PISA 2003 database by HLM of two levels analysis and to provide some suggestions in education and recommendations for future research.

Key-Words: PISA, HLM, mathematics achievement, education index, mathematics homework.

1 Introduction

Under the trend toward globalization, it has been an important education goal to cultivate international manpower. Education is crucial for successful integration in a global world and it should be regarded as a social process to become a world citizen [5]. The former implication has the same idea with PISA 2003 by coincidence. Starting from 2000, the Programme on International Student Assessment (PISA) is held by the Organization for Economic Co-operation and Development (OECD) for the 15-year-old every three years. The sample includes over 270,000 participants of 41 countries in the PISA 2003 database aimed at evaluating mathematics, reading, science and problem-solving knowledge and skills. PISA 2003 seeks to measure how well young adults, at age 15 and at the end of compulsory schooling, are prepared to meet the challenges of today's knowledge societies [7].

Most of the studies on the PISA 2003 database are analyses of descriptive statistics. They are limited to get the advanced information for the comparison of relationships between countries and students.

However, the database has the characteristics of hierarchical properties. It is necessary to use hierarchical linear model (HLM) of two levels to analyze the relation between the variables of countries and students. The models offer an explicit framework in order to combine information across units (such as students or schools) to produce accurate and well-calibrated predictions of observable outcomes [1].

2 Literature Review

2.1 The Related International Assessment

During the past decades, more and more institutions get involved in the international learning achievement and attitude assessment for student. PISA 2003 is also a well-known international assessment, but has different contents from most of the other international assessments. It included an assessment of students' problem-solving skills, providing for the first time a direct assessment of life competencies that apply across different areas of the school curriculum [7]. The basic conception of an overarching idea is a set of phenomena and concepts that make sense and can be encountered within and across a multitude of different situations [8].

There have been already some research outcomes in PISA [3] [9]. Most of them investigate the relationship between student engagement, learning, and mathematics performance as well as the relationship between family characteristics, home environment, and mathematics performance [10]. Williams examines cross-national variation in rural mathematics achievement among 15-year-olds in 24 industrialized nations [4]. To make a survey of these researches, it is obvious that they are nearly analyses of descriptive statistics. Although Kotte, Lietz and Lopez investigate the PISA database with HLM, their study does not include all the nations in the PISA database [2].

Therefore, this study investigates the relationship between nations background and student mathematics cognition by HLM of two levels. The unit in level-1 is students. The variables belonging to the level-1 are the score of mathematics cognition and the time studying mathematics homework outside the regular mathematics classes. The variable of the time studying mathematics homework outside the regular mathematics classes is item 33 selected from the students questionnair of PISA 2003. The more time is spent in studying mathematics homework outside the regular mathematics classes, the higher students get scores of item 33. Homework is reputed to be the extension of learning and one of the influential variables of learing achievement. However, Trautwein and Köller find out that the relationship between homework and achievement remains unclear [13], whereas Hsieh's study indicate that learing outside class has a positive effect on mathematics achievement [6].

As to the level-2, the unit is countries and the variable is Education Index (EI) of Human Development Reports (HDR) of United Nations Development Programme (UNDP). Based on the definition of HDR, EI is calculated on the basis of data of adult literacy rate and gross enrolment ratio for primary, secondary and tertiary schools. Comparative studies of academic achievement show that the quantity and use of literacy resources influence achievement levels [14]. Literate parents are more likely to support their children in school, ensuring both their higher school retention and higher levels of learing achievement [15]. In the aspect of enrolment ratio, Duraisamy, James, Lanze and Tan find a negtive effect of expanded enrolment on school conditions and learing [11]. Judging from EI, it is easy to know whether there is a good operation of education in the country or not. The operation of education is related to the students achievement.

2.2 Basic Features of Hierarchical Linear Model

The method of this study is HLM of two levels analysis. The equations will be discussed as follows.

Level-1 (e.g. students):

$$Y_{ij} = \beta_{oj} + \beta_{1j} X_{ij} + r_{ij} \quad (1)$$

Y_{ij} is level-1 criterion variable (e.g. student mathematics cognition) and X_{ij} is a level-1 predictive variable (e.g. time studying mathematics homework outside the regular mathemarics classes). β_{oj} and β_{1j} are level-1 coefficients and r_{ij} is a level-1 random effects. Besides, the centering of X_{ij} here is natrual metric. In some cases, grand-mean centering or group-centering are chosen for X_{ij}.

Level-2 (e.g. countries):

$$\beta_{0j} = \gamma_{00} + \gamma_{01} W_j + u_{0j} \quad (2)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} W_j + u_{1j} \quad (3)$$

W_j is a level-2 predictive variable (e.g. countries EI). γ_{00}, γ_{01}, γ_{10} and γ_{11}, are level-2 coefficients and they are also called fixed effects. u_{0j} and u_{1j} are level-2 random effects.

The model in combined form will be as it is in equation (4).

$$Y_{ij} = \gamma_{00} + \gamma_{10} X_{ij} + \gamma_{01} W_j + \gamma_{11} X_{ij} W_j + u_{0j} + u_{1j} X_{ij} + r_{ij} \quad (4)$$

The following assumptions are required for the above combined model [12].

$$E(r_{ij}) = 0 \text{ and } Var(r_{ij}) = \sigma^2$$

$$E\begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \text{ and } Var\begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} = \begin{bmatrix} \tau_{00} & \tau_{01} \\ \tau_{10} & \tau_{11} \end{bmatrix}$$

$$Cov(u_{0j}, r_{ij}) = Cov(u_{1j}, r_{ij}) = 0$$

σ^2 is the level-1 variance and τ_{00}, τ_{01}, τ_{10} and τ_{10} are level-2 variance-covariance components.

3 Method of Data Analysis

3.1 Data Source and Variables of Level-1

There are 41 countries participating in PISA 2003. These countries are depicted in Table 1.

Table 1. The Paticipating Countries of PISA 2003

OECD countries		
Australia	Austria	Belgium
Canada	Czech Republic	France
Denmark	Finland	Germany
Greece	Hungary	Iceland
Ireland	Italy	Japan
Rep. of Korea	Liechtenstein	Luxembourg
Mexico	Netherlands	New Zealand
Norway	Poland	Portugal
Slovakia	Spain	Sweden
Switzerland	Turkey	United Kingdom
United States		
non-OECD counties		
Brazil	Hong Kong (China)	Indonesia
Latvia	Macao (China)	Russian Federation
Thailand	Tunisia	Uruguay
Yugoslavia		

There are over 270,000 students participating in PISA 2003. The original data comes from the internet of OECD (http://www.pisa.oecd.org)

The variables in level-1 are mathematics cognition and the time studying mathematics homework outside the regular mathematics classes. The mathematics cognition is the criterion variable and the time studying mathematics homework outside the regular mathematics classes is the predictive variable.

3.2 Data Source and Variables of Level-2

The unit in level-2 is countries. It is assumed that the development of countries will influence the student mathematics cognition. Besides, it will depend on the development of countries how mathematics cognition is influenced by the time studying mathematics homework outside the regular mathematics classes. There is one index applied to countries development in this study. It is EI (Education Index).

EI is built by HDR of UNDP in 2003 and calculated on the basis of data of adult literacy rate and gross enrolment ratio for primary, secondary and tertiary schools. As to the original data resource of EI, owing to the lack of complete indices for Liechtenstein, Macao and Yugoslavia, only 38 countries are included in the HLM analysis. Also, in considering of the differences between OECD countries and non-OECD countries, the database is divided into two groups.

4 Results

In this study, the unit in level-1 is students and the unit in level-2 is countries. HLM 6 software is used in analyze the structural data. Four submodels will be the exploratory models. These submodels, running from simpler to the more complex, include the one-way ANOVA model with random effects, means-as-outcome regression, random coefficients regression model and model with non-randomly varying slopes [12].

4.1 One-way ANOVA Model with Random Effects

The level-1 and level-2 equations are as follows.

Level-1:

$$Y_{ij} = \beta_{0j} + r_{ij} \ , \ r_{ij} \sim N(0, \sigma^2) \quad (5)$$

Level-2:

$$\beta_{0j} = \gamma_{00} + u_{0j} \quad (6)$$

Y_{ij} is the mathematics cognition. The results are depicted in Table 2 and Table 3. It shows that there is significant mean difference among countries. In

OECD countries, the intraclass correlation coefficient is $\rho = 3.447/(3.447 + 74.174) = 4.44\%$. In non-OECD countries, the intraclass correlation is $\rho = 15.126/(15.126 + 51.934) = 22.56\%$. Therefore, the explained variance from OECD countries is 4.44%, while the explained variance from non-OECD countries is 22.56%, which means that certain predictive variables may exist so that the difference of means among countries could be explained. Thus, the following submodel, means-as-outcome regression, will be investigated further.

Table 2. The Analysis of One-way ANOVA Model with Random Effects (OECD countries)

Fixed Effect	Coefficient		Standard Error	
γ_{00}	13.466		.334	
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	3.447	29	17770.469	.000
r_{ij}	74.174			

Table 3. The Analysis of One-way ANOVA Model with Random Effects (non-OECD countries)

Fixed Effect	Coefficient		Standard Error	
γ_{00}	9.572		1.286	
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	15.126	7	11209.677	.000
r_{ij}	51.934			

4.2 Means-as Outcomes Regression

As to the predictive variable EI in level-2, the level-1 and level-2 equations are as follows.

Level-1:

$$Y_{ij} = \beta_{0j} + r_{ij}\ ,\ r_{ij} \sim N(0, \sigma^2) \tag{7}$$

Level-2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} W_j + u_{0j} \tag{8}$$

Y_{ij} is the mathematics cognition of students and W_j is EI of countries. The analysis results are depicted in Table 4 and Table 5. In OECD countries, the coefficient is significant and it shows that predictive variable EI can explain the mathematics cognition means of countries, and so is in non-OECD countries. Making a comparison between Table 2 and Table 4, EI can explain 42.38% of mathematics cognition means of OECD countries because of $(3.477 - 1.986)/3.477 = 42.38\%$. With a comparison between Table 3 and Table 5, EI can explain 15.13% of mathematics cognition means of non-OECD countries because of $(15.126 - 12.838)/15.126 = 15.13\%$. Besides, in OECD countries, the conditional intraclass correlation is $\rho = 1.986/(1.986 + 74.174) = 2.61\%$. In other words, the EI variable reduces the intraclass correlation from 4.44% to 2.61%. And in non-OECD countries, $\rho = 12.838/(12.838 + 51.934) = 19.82\%$, it means that EI variable reduces the intraclass correlation from 22.56% to 19.82%. Hence, certain predictive variables except EI may exist so that the difference of means among countries could be explained.

Table 4. The Analysis of Means-as-Outcomes Regression (OECD countries)

Fixed Effect	Coefficient		Standard Error	p-value
γ_{00}	-16.649		6.063	.011
γ_{01}	31.371		6.245	.000
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	1.986	28	5631.371	.000
r_{ij}	74.174			

Table 5. The Analysis of Means-as-Outcomes Regression (non-OECD counties)

Fixed Effect	Coefficient		Standard Error	p-value
γ_{00}	-13.621		5.138	.038
γ_{01}	26.383		5.631	.003
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	12.838	6	7298.842	.000
r_{ij}	51.934			

4.3 Random Coefficient Regression Model

In this model, there are some predictive variables in level-1, but not in level-2. The time studying mathematics homework outside the regular mathematics classes is a possible factor which may influence mathematics cognition, so it is a predictive variable in level-1. The equations are as follows.

Level-1:

$$Y_{ij} = \beta_{0j} + \beta_{1j} X_{ij} + r_{ij}\ ,\ r_{ij} \sim N(0, \sigma^2) \tag{9}$$

Level-2:

$$\beta_{0j} = \gamma_{00} + u_{0j} \quad (10)$$

$$\beta_{1j} = \gamma_{10} + u_{1j} \quad (11)$$

X_{ij} is the time studying mathematics homework outsides the regular mathematics classes. The analysis results are depicted in Table 6 and Table 7. In OECD countries and non-OECD countries, γ_{10} is not statistically significant, which implies that the predictive variable can not influence mathematics cognition well. u_{0j} is statistically significant in OECD countries and non-OECD countries, which shows that there is significant difference of means among countries. And in OECD countries and non-OECD countries, u_{1j} is statistically significant, which indicates that there is still difference of means among countries when taking off the influence of the time studying mathematics outside the regular mathematics classes on mathematics cognition. In consequence, certain predictive variable may exist to inflence the mathematics cognition.

Table 6. The Analysis of Random Coefficients Regression Model (OECD countries)

Fixed Effect	Coefficient	Standard Error		p-value
γ_{00}	14.398	.378		.000
γ_{10}	-.086	.042		.050
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	4.241	28	1401.552	.000
u_{1j}	.050	28	745.123	.000
r_{ij}	81.270			

Table 7. The Analysis of Random Coefficients Regression Model (non-OECD countries)

Fixed Effect	Coefficient	Standard Error		p-value
γ_{00}	11.960	1.217		.000
γ_{10}	.002	.071		.979
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	10.619	5	1169.844	.000
u_{1j}	.034	5	157.689	.000
r_{ij}	68.918			

4.4 Model with Non-randomly Varying Slopes

EI in level-2 is considered to be the pridictor for the advanced model. The level-1 and level-2 equations are as follows.

Level-1:

$$Y_{ij} = \beta_{0j} + \beta_{1j} X_{ij} + r_{ij}\ ,\ r_{ij} \sim N\left(0, \sigma^2\right) \quad (12)$$

Level-2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} W_j + u_{0j} \quad (13)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} W_j \quad (14)$$

X_{ij} is the time studying mathematics homework outsides the regular mathematics classes and Y_{ij} is the mathematics cognition. The analysis results are depicted in Table 8 and Table 9. In OECD countries and non-OECD countries, u_{0j} is statistically significant, which indicates the time studying mathematics homework outside the regular mathematics classes can influence mathematics cognition. In OECD countries, the coefficient γ_{11} shows that EI can not explain the influence of the time studying mathematics homework outside the regular mathematics classes on mathematics cognition, whereas in non-OECD countries, γ_{11} shows that the influence of the time studying mathematics homework outside the regular classes on mathematics cognition varies with EI. Moreover, as EI increases, it will reduce that mathematics cognition is influenced by the time studying mathematics homework outside the regular classes. Futhermore, in OECD and non-OECD countries, EI can not explain all the variance of varying slopes across countries because u_{0j} is statistically significant.

Table 8. The Analysis of Model with Non-randomly Varying Slopes (OECD countries)

Fixed Effect	Coefficient	Standard Error		p-value
γ_{00}	-13.348	13.052		.316
γ_{01}	28.848	13.434		.040
γ_{10}	-.602	.522		.249
γ_{11}	.606	.559		.279
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	2.637	27	2359.913	.000
r_{ij}	81.675			

Table 9. The Analysis of Model with Non-randomly Varying Slopes (non-OECD countries)

Fixed Effect	Coefficient		Standard Error	p-value
γ_{00}	-8.993		28.440	.762
γ_{01}	22.808		29.969	.475
γ_{10}	2.409		.584	.000
γ_{11}	-2.580		.653	.000
Random Effect	Variance Component	df	χ^2	p-value
u_{0j}	13.955	4	2335.342	.000
r_{ij}	69.113			

5 Conclusions

Based on the findings of this research, it shows that mathematics cognition among countries is different. In non-OECD countries, EI can explain the influence of the time studying mathematics homework outside the regular mathematics classes on mathematics cognition, but in OECD countries EI can not do so, which is worth investigating further.

In this study, HLM analysis of the PISA 2003 database demonstrates basic information about international assessment. With simpler to the more complex submodels, it can suitably clarify the structural relationship of students and countries. It may be an approach to use other students variables and countries variables in advanced research. Also, HLM of three levels for PISA 2000,PISA 2003 and PISA 2006 is a potential study.

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