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Title: **Professional Development and Student Achievement: International Evidence from the TIMSS Data**

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Background: Teachers' sustained engagement in high quality professional development (PD) is a vital contributing factor in deepening teachers' knowledge and skills, changing attitudes and beliefs, improving instructional practices, and bolstering student achievement and growth (Akiba & Liang, 2013; Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Desimone, 2009). In a most recent study with longitudinal data on middle school math teachers and students in a mid-western state, a recent study (Akiba, Wang, & Liang, 2015) found that one hour increase in school average amount of teacher participation in professional conference and informal communication was associated with on average a .15 point increase and .23 point increase in the annual growth rate in students' math scores.

It was worth noting, however, that cross-national studies were still rare on the topic of PD focus areas. The existing comparative research on educational characteristics and student achievement has primarily focused on such topics as teacher quality (e.g., Akiba, LeTendre, & Scribner, 2007; Akiba & Liang, 2014), classroom instruction (e.g., Hiebert et al., 2005), class size (e.g., Pong & Pallas, 2001), and teacher compensation (e.g., Akiba, Chiu, Shimizu, & Liang, 2012; Woessmann, 2011). To our knowledge, little cross-national research exists that used nationally representative datasets to examine the association between national math achievement and students' access to teachers with PD in various focus areas.

To fill the knowledge gap, this study used the latest administrations of the Trends in International Mathematics and Science Study (TIMSS) data across the years (i.e., 2003, 2007, and 2011) and grade levels (i.e., students and teachers in both fourth and eighth grades), and examined the relationship between students' access to teachers who participated in PD and national math achievement. It focused on the PD activities in the following areas which share a relatively common meaning across the various national and cultural contexts: (a) math content, (b) math pedagogy or instruction, (c) math curriculum, (d) integrating information technology into math, (e) math assessment, and (f) improving students' critical thinking or problem solving skills.

Research Questions: (1) How does the percentage of students whose teachers participated in math professional development in the United States compare with the other countries around the world from 2003 to 2011? (2) How are the national levels of students' access to teachers who participated in professional development associated with national math achievement?

Materials and Methods: This study used secondary data from the fourth and eighth graders and their math teachers in the latest 2003, 2007, and 2011 administrations of the Trends in International Mathematics and Science Study (TIMSS). For the first research question, this study reported the percentages of students in the United States whose math teachers participated in professional learning by grade level, PD focus area, and TIMSS cycle. The average percentages were also reported for the other countries. To address the second question, Pearson's correlation coefficients were first calculated on the association between national mean math achievement and students' access to teachers with PD. Based on the findings of the correlations, a series of multiple regression models were conducted for each grade, PD focus area, and TIMSS cycle. The data were also pooled across the TIMSS cycles by PD focus area and grade level.

Results: (1) Although the national levels of access for students at the fourth and eighth grade levels to teachers who participated in professional learning in the United States were higher than the other countries, one third to one half of the fourth grades were taught by teachers who had no professional learning focusing on math instruction or curriculum; (2) In addition, teachers' participation in professional development was positively associated with higher student math achievement. Holding GPD per capita and educational expenditure as percentage of GPD constant, an average of a .96 point increase in national math achievement is associated with a one percentage point increase in the proportion of fourth graders whose teachers had PD focusing on math content, a .78 point increase on math pedagogy or instruction, a .70 point increase on math curriculum, a 1.58 points increase on integrating information technology into math, and a .94 point increase on improving critical thinking or problem solving skills. For the eighth graders, when the proportion of students increases by one percentage point on their access to teachers with PD on math content, math pedagogy/instruction, math curriculum, and integration of information technology, the associated national math achievement increases on average by 1.04, 1.24, .93, and 1.07 points, respectively.

Conclusions: Educators and policymakers around the world strive to improve student learning with various reform initiatives such as compensation (Akiba et al., 2012) and performance-related pay (e.g., Liang, 2013a; Liang & Akiba, 2011). Educational reform efforts to improve student achievement, however, can only succeed by building the capacity of teachers to improve their instructional practices and the capacity of school systems to promote teacher learning (Darling-Hammond et al., 2009). Building on the findings of the previous studies, this study provides cross-national evidence that enhancing students' access to teachers who participated in PD is promising in increasing student learning. It suggests that when coupled with high quality teacher evaluation (Liang, 2013b; Liang & Akiba, 2013), content specific professional learning activities can be an effective tool for strengthening the capacity of frontline educators and ensuring adequate access and opportunities for students to a teaching workforce with continuous learning.

A recent study used longitudinal data from middle school math teachers in a mid-western state found that teachers who received an increased amount of organizational resources were more likely to increasingly participate in high quality PD activities (Akiba et al., 2015). Therefore, it is important for districts and schools to continuously provide adequate resources for professional learning in order to support and encourage their teachers' participation in high quality learning activities.

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Table 1

Percentage of students by their teachers' participation in math PD in the past 2 years

PD Focus Area	Country/Country Group	Grade 4			Grade 8		
		2003	2007	2011	2003	2007	2011
Math Content	United States	65	60	68	83	81	73
	TIMSS Countries*	42	42	43	55	56	54
	OECD Countries**	44	40	40	58	56	52
	G8 Countries***	48	47	49	58	64	54
Math Pedagogy / Instruction	United States	54	50	55	75	76	73
	TIMSS Countries*	45	47	46	56	58	58
	OECD Countries**	44	43	42	61	61	57
	G8 Countries***	54	53	54	65	71	64
Math Curriculum	United States	66	63	68	83	80	78
	TIMSS Countries*	37	40	41	50	51	51
	OECD Countries**	34	34	34	51	49	50
	G8 Countries***	45	41	41	52	51	49
Integrating Information Technology into Math	United States	41	39	49	74	61	68
	TIMSS Countries*	30	29	33	42	44	47
	OECD Countries**	30	26	25	48	44	41
	G8 Countries***	38	34	29	55	56	47
Math Assessment	United States	54	47	53	74	69	61
	TIMSS Countries*	39	37	37	48	48	47
	OECD Countries**	33	28	30	47	45	38
	G8 Countries***	34	32	39	46	49	37
Improving Students' Critical Thinking or Problem Solving Skills	United States	58	51	NA	76	65	61
	TIMSS Countries*	44	40	NA	46	45	43
	OECD Countries**	37	31	NA	38	34	34
	G8 Countries***	42	42	NA	38	41	35

Notes. * Excludes the United States. ** Excludes the United States. *** Excludes the United States. The G8 countries refer to France, Germany, Italy, the United Kingdom, Japan, the United States, Canada, and Russia. Not all of the G8 countries participated in all administrations (by year and grade levels) of the TIMSS.

Table 2

Correlation coefficients between math achievement and % of 4th graders whose teachers had PD

	2003	2007	2011	Pooled
Math Content	.457*	.437**	.082	.298**
Math Pedagogy / Instruction	.468*	.312	.023	.225*
Math Curriculum	.250	.295	.042	.187*
Integrating Info Tech into Math	.532**	.429**	.210	.365**
Math Assessment	.004	.106	-.013	.037
Improving Critical Thinking Skills	.044	.210	NA	.150
N	26	37	50	113

Note. *p<.05, **p<.01.

Table 3

Correlation coefficients between math achievement and % of 8th graders whose teachers had PD

	2003	2007	2011	Pooled
Math Content	.230	.495**	.198	.310**
Math Pedagogy / Instruction	.272	.453**	.340*	.350**
Math Curriculum	.243	.408**	.185	.281**
Integrating Info Tech into Math	.551**	.426**	.192	.409**
Math Assessment	-.196	.211	-.072	-.020
Improving Critical Thinking Skills	-.258	-.117	-.265	-.206
N	47	50	42	139

Note. *p<.05, **p<.01.

Table 4
Relationship between math achievement and % of 4th graders whose teachers had PD

	2003	2007	2011	Pooled OLS
Math Content	.76 (.61)	1.90** (.72)	.17 (.51)	.96** (.37)
Math Pedagogy / Instruction	.90 (.65)	1.59* (.79)	-.03 (.56)	.78* (.40)
Math Curriculum	.33 (.55)	1.35** (.64)	.24 (.50)	.70** (.34)
Integrating Info Tech into Math	.85 (.71)	2.39*** (.85)	1.08* (.60)	1.58*** (.42)
Math Assessment	.65 (.62)	1.06 (.85)	.19 (.56)	.44 (.40)
Improving Critical Thinking Skills	.46 (.56)	1.58* (.86)	N/A	.94* (.55)
N	26	37	50	113

Note. Standard errors were in parentheses. All of the 23 models controlled for GDP per capita and educational expenditure as % of GDP.
*p<.10, **p<.05, ***p<.01.

Table 5
Relationship between national math achievement and percentage of eighth grade students whose teachers had PD in the past 2 years

	2003	2007	2011	Pooled OLS
Math Content	.48 (.43)	1.74*** (.47)	.78 (.52)	1.04*** (.28)
Math Pedagogy / Instruction	.50 (.50)	1.65*** (.56)	1.58** (.65)	1.24*** (.33)
Math Curriculum	.65 (.41)	1.46*** (.48)	.57 (.46)	.93*** (.27)
Integrating Info Tech into Math	.91* (.48)	1.23** (.49)	.70 (.53)	1.07*** (.28)
Math Assessment	-.56 (.51)	.96 (.62)	.02 (.60)	.06 (.35)
Improving Critical Thinking Skills	-.38 (.55)	-.53 (.63)	-1.09 (.77)	-.74** (.36)
N	46	48	41	135

Note. Standard errors were in parentheses. All of the 24 models controlled for GDP per capita and educational expenditure as % of GDP.
*p<.10, **p<.05, ***p<.01.

Appendix

Descriptive Statistics of the 2003, 2007, and 2011 TIMSS Data

Year	Grade	National Characteristics and PD Area	N	Mean	Min	Max	SD
2003	4	GDP per capita (in US$1,000)	26	20.00	1.92	38.26	12.59
		Educational expenditure as % of GDP	26	5.27	2.15	9.24	1.53
		Math content	26	0.43	0.05	0.76	0.20
		Math pedagogy / instruction	26	0.45	0.04	0.88	0.18
		Math curriculum	26	0.38	0.03	0.78	0.22
		Integration of information technology	26	0.30	0.00	0.68	0.18
		Math assessment	26	0.40	0.03	0.69	0.19
		Improving students' critical thinking skills	26	0.45	0.03	0.73	0.20
	8	GDP per capita (in US$1,000)	46	16.38	1.07	38.26	11.49
		Educational expenditure as % of GDP	46	5.15	2.15	9.52	1.54
		Math content	47	0.56	0.12	0.86	0.21
		Math pedagogy / instruction	47	0.56	0.09	0.89	0.19
		Math curriculum	47	0.51	0.15	0.85	0.22
		Integration of information technology	47	0.42	0.12	0.88	0.22
		Math assessment	47	0.49	0.10	0.79	0.18
		Improving students' critical thinking skills	47	0.47	0.09	0.80	0.17
2007	4	GDP per capita (in US$1,000)	37	26.54	2.38	72.00	17.79
		Educational expenditure as % of GDP	37	4.63	2.45	7.81	1.25
		Math content	37	0.42	0.11	0.83	0.20
		Math pedagogy / instruction	37	0.47	0.11	0.82	0.19
		Math curriculum	37	0.41	0.06	0.78	0.23
		Integration of information technology	37	0.29	0.03	0.64	0.17
		Math assessment	37	0.37	0.05	0.81	0.19
		Improving students' critical thinking skills	37	0.41	0.09	0.82	0.19
	8	GDP per capita (in US$1,000)	49	21.39	1.38	72.00	16.66
		Educational expenditure as % of GDP	48	4.57	2.45	7.96	1.29
		Math content	50	0.56	0.13	0.85	0.20
		Math pedagogy / instruction	50	0.58	0.12	0.93	0.18
		Math curriculum	50	0.51	0.11	0.84	0.20
		Integration of information technology	50	0.45	0.09	0.83	0.21
		Math assessment	50	0.48	0.17	0.83	0.17
		Improving students' critical thinking skills	50	0.45	0.09	0.82	0.17
2011	4	GDP per capita (in US$1,000)	50	30.07	2.35	88.92	17.23
		Educational expenditure as % of GDP	50	4.82	1.10	8.72	1.48
		Math content	50	0.44	0.09	0.79	0.20
		Math pedagogy / instruction	50	0.46	0.11	0.82	0.19
		Math curriculum	50	0.41	0.03	0.81	0.21
		Integration of information technology	50	0.33	0.05	0.77	0.18
		Math assessment	50	0.37	0.03	0.77	0.19
	8	GDP per capita (in US$1,000)	41	25.90	1.88	88.92	19.15
		Educational expenditure as % of GDP	41	4.55	1.10	7.32	1.51
		Math content	42	0.55	0.09	0.79	0.19
		Math pedagogy / instruction	42	0.58	0.21	0.85	0.14

Math curriculum	42	0.52	0.06	0.88	0.22
Integration of information technology	42	0.48	0.11	0.90	0.19
Math assessment	42	0.47	0.05	0.90	0.17
Improving students’ critical thinking skills	42	0.43	0.08	0.66	0.14