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

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Abstract
This comparative study used the latest Trends in International Mathematics and Science Study (TIMSS) data sets and examined the relationship between professional development and student achievement. It found that 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. In addition, teachers' participation in professional development was positively associated with higher student math achievement. This cross-national study provided empirical evidence highlighting the importance of investing in teacher learning for improving national educational quality.

Keywords: comparative study, math achievement, professional development, TIMSS

Introduction

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). Policymakers around the world also recognize the significance of professional learning as a key vehicle and major focus of systemic reform initiatives. For instance, teachers were required to participate in more than 100 hours of PD in Sweden and over 150 hours in the Netherlands each year, and completion of professional learning activities was required for teacher promotion in Australia, England and Wales, Korea, Northern Ireland, and Switzerland (Akiba & LeTendre, 2009; OECD, 2005).

In the United States, the No Child Left Behind (NCLB) act required that school districts use at least five percent of their Title I funds for PD to help teachers become highly qualified, and schools identified for improvement spend at least 10 percent of the funds on professional learning activities for teachers and principal (Birman et al., 2007). By the 2011-12 school year, 39 states had enacted policies on formal PD standards, 23 states on financing PD for all districts, 16 states on requiring districts and/or schools to set aside time for PD, and 31 states on aligning PD with local priorities (Education Week, 2013).

Surprisingly, despite the global consensus on the significance of teachers' participation in professional learning, few large-scale comparative studies investigated the relationship between PD and student math achievement across nations and over time. In addition, we do not know whether this relationship holds true for both elementary and middle school students across PD activities focusing on different areas (e.g., math content versus math curriculum).

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. Specifically, this study addressed the following 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?

This is the first large-scale empirical study from a comparative perspective on the relationship between students' access to teachers with math PD and national levels of math achievement. Findings within the international context provide cross-national evidence and advance our knowledge base on the significance of teachers' participation in high quality PD. It supports policymakers to make evidence-informed decisions and promotes global policies in continuously engaging teachers with professional learning to improve instruction and learning.

Literature Review

Theoretical Framework: The Path Model

The mechanism is straightforward for professional development to improve teaching and learning. According to the path model (Desimone, 2009), teachers' participation in effective professional learning both enhances their knowledge and skills, and changes their attitudes and beliefs. By integrating their improved knowledge, skills, attitudes and beliefs into their daily teaching, teachers improve the content of their instructional practices and pedagogical approaches. The resulted changes in instruction foster improvement in student learning.

The path model presents a succinct and adequate theoretical framework as well as operational guidelines to study how PD brings about positive educational outcomes. It depicts the interactive and non-recursive nature of the relationships between the critical characteristics of PD, teacher knowledge and beliefs, instructional practices, and student achievement. The model allows testing both how PD alters teacher skills, attitudes, or practices, and how improved instruction influences student achievement (Desimone, 2009).

The Impact of Professional Development on Educational Outcomes

The impact of high quality professional learning on teacher instruction and student achievement has been well supported by empirical studies within the U.S. context (Akiba & Liang, 2013; Darling-Hammond et al., 2009; Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001; Slotnik & Smith, 2008). For example, 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.

The significance of teacher PD on student learning has also been broadly documented by researchers around the world such as in England (Wood & Bennett, 2000), Australia (Ingvarson, Meiers, & Beavis, 2005; Kettle & Sellars, 1996), Norway (Kallestad & Olweus, 1998), Pakistan (Warwick & Reimers, 1995), and Israel (Angrist & Lavy, 2001). Despite these empirical studies, the knowledge base on the impact of PD on educational outcomes is still not as strong as it should have been (OECD, 2005; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). In particular, we do not know if the focus area of a PD activity moderates its influence on student learning.

The Content Focus of Professional Development and Student Achievement

There has been a general consensus that high quality PD activities share the following characteristics: (a) focusing on the content, (b) being coherent, intensive, and ongoing, (c) promoting active learning and collective participation; and (d) connecting to other school initiatives (Darling-Hammond et al., 2009; Desimone, 2009; Desimone et al., 2002; Garet et al., 2001; Slotnik & Smith, 2008). For example, using a national sample of 1,027 math and science teachers, Garet et al. (2001) found that when professional learning activities focused on content knowledge, provided opportunities for active learning, and were coherent with other learning activities, they could have significant, positive effects on teachers' self-reported increases in knowledge and skills and changes in classroom practice. In another longitudinal study of 207 math and science teachers, Desimone and colleagues (2002) found that PD was most effective in changing teachers' practice when it aligned with teachers' professional knowledge and external standards and assessments.

Compared with the other core features of effective PD, the content focus is a most influential one. When PD activities focus on what teachers actually learn, it is most promising to improve classroom practice and enhance student learning (Darling-Hammond et al., 2009; Desimone, 2009). A handful of empirical studies have shown positive relationships between teachers' participation in PD and improved instruction and learning when the PD activities focused on enhancing teacher's mastery of the content (Garet et al., 2001; Saxe, Gearhart, & Nasir, 2001; Smith et al., 2007; Telese, 2008), the pedagogy or instruction (Desimone et al., 2002; Saxe et al., 2001; Wiley & Yoon, 1995), the curriculum (Cohen & Hill, 2001; Telese, 2008; Wiley & Yoon, 1995), the integration of information technology into instruction (Desimone et al., 2002; Power & Thomas, 2007), the assessment (Desimone et al., 2002; Telese, 2008), and improving students' critical thinking or problem solving skills (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Desimone, Smith, Baker, & Ueno, 2005; Wenglinsky, 2002).

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. This study attempts to fill the gap and provide empirical results to inform policy making on teacher PD in the United States and abroad.

Method

Data

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). Conducted every four years, the TIMSS collected rich information on educational background, contexts, curricular content, and instructional practices to provide comparative perspectives on trends in achievement within different educational systems. A study on the factors that have influenced the U.S. education policy during the past decade (Swanson & Barlage, 2006) found that the TIMSS has been highly influential, ranking the second-highest on the overall influence index.

The TIMSS has been a global study as demonstrated by the increasing number of participating countries and regions (for the sake of convenience, they were all called countries in this study). In the 2003 TIMSS cycle, 26 countries were involved in the fourth grade and 48 countries in the eighth grade. Four years later in the 2007 TIMSS study, such numbers increased to 37 and 50, respectively. In the latest TIMSS 2011 administration, 52 countries participated in the fourth grade, and 45 countries in the eighth grade.

The TIMSS used a two-stage stratified cluster sampling design in which schools were first stratified and selected by type of school, region of the country, type of location, and percentage of minority students. A probability-proportional-to-size technique was used so that larger schools had higher probabilities of being selected. Because of its large population sizes, the Russian Federation had a preliminary sampling stage where regions were sampled first and then schools. Singapore also had a third sampling stage, where students were sampled within classes. At the second stage, one or two intact classes of students from the sampled schools are chosen with equal probability of selection using systematic random sampling. The math teachers of these classrooms were selected, and they filled out a teacher questionnaire.

Teachers in the TIMSS did not constitute representative samples of teachers in the participating countries. Rather, they were the teachers of nationally representative samples of students. Therefore, analyses with teacher data should be made with students as the units of analysis and reported in terms of students who were taught by teachers with a particular attribute (Martin & Mullis, 2012; Olson, Martin, & Mullis, 2008). Due to the complex sampling characteristics of TIMSS, this study utilized the International Database Analyzer software (Version 3.0) developed by the IEA Data Processing and Research Center and made use of the Jackknife repeated replication method with appropriate sampling weights and replicate weights.

Measures

Professional development. In the TIMSS teacher questionnaire, math teachers of fourth and eighth graders were asked, "In the past two years, have you participated in professional development in any of the following?" The list of the six focus areas included: (a) math content, (b) math pedagogy/instruction, (c) math curriculum, (d) integrating information technology into math, (e) math assessment, and (f) improving students' critical thinking or problem solving skills. Teachers responded *yes* (coded as 1) or *no* (coded as 0) to the questions. In the 2011 TIMSS cycle, the last answer choice was not available for the fourth grade teachers.

Student achievement. The TIMSS datasets contained the national mean math scores of fourth and eighth graders which represented the overall national level of student performance. For fourth graders, the math achievement ranged from 278 (Yemen) to 594 (Singapore) in 2003, from 224 (Yemen) to 607 (Hong Kong) in 2007, and from 248 (Yemen) to 606 (Singapore) in 2011. For eighth graders, it varied from 264 (South Africa) to 605 (Singapore) in 2003, from 307 (Qatar) to 598 (Chinese Taipei) in 2007, and from 331 (Ghana) to 613 (Korea) in 2011.

Control variables. Gross domestic product (GDP) per capita and educational expenditure as percentage of GDP are two important factors predicting national achievement and commonly used in comparative studies (Akiba et al., 2007; Akiba & Liang, 2014). One measures the financial resources available per person in a country and the other describes national-level educational investment. These indicators were collected from the website of the UNESCO Institute for Statistics by the years of the TIMSS cycles. For the countries without the data for a particular year, the data from the most recent year were used.

The appendix provided the descriptive statistics of the variables by year and grade. For example, among the 26 countries whose data were available for the fourth grade students in the 2003 TIMSS cycle, the GDP per capita ranged from 1.92 ($1,920) to 38.26 ($38,260), with a mean of 20.00 ($20,000) and a standard deviation of 12.59 ($12,590). The educational expenditure as percentage of GDP varied from 2.15 to 9.24, with a mean of 5.27 and a standard deviation of 1.53. On average, 43% of the fourth graders around the world in 2003 were taught by teachers who had participated in PD focusing on math content in 2001 and 2002.

Analysis

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. The regression models took the following basic form:

$$(National\ Math\ Achievement)i = \beta 0 + \beta 1(Percentage\ PD)i + \beta 2(GDP\ PerCapita)i + \beta 3(Educational\ Expenditure\ as\ \%\ of\ GDP)i + \varepsilon i$$

where the dependent variable represents the math achievement of country *i* for a specific grade level and TIMSS cycle. The key independent variable, *Percentage PD*, is a continuous variable indicating the percentage of students whose teachers had PD in one of the six focus areas in country *i* for that grade level and TIMSS cycle. The coefficient $\beta 1$ represents the association between national math achievement and students' access to teachers with PD after accounting for GDP per capita and educational expenditure as percentage of GPD.

Results

Teacher Participation in Professional Development Activities

Table 1 reports the percentages of students whose teachers participated in math PD in the six focus areas from 2003 to 2011 in fourth and eighth grades. As country-specific data have been reported in the TIMSS publications (e.g., Mullis, Martin, Foy, & Arora, 2012), this study focused on the differences between the United State and the international averages of the other TIMSS participating countries. The table also presents refined comparisons with the other high income OECD member countries as classified by the World Bank, and of the other countries economically comparable to the United States in the Group of Eight (G8) industrialized nations, based on the data available in the TIMSS cycles.

As can be seen from the table, the most common areas of math PD for teachers of fourth grade students in the United States have consistently been math content and math curriculum. Take the latest 2011 data as an example, 68% of the fourth graders had teachers with PD in math content, and 68% in math curriculum. It is less common, however, in the other areas including math pedagogy/instruction (55%), math assessment (53%), and integration of information technology (49%). In addition, although the overall variations of the percentages have been generally small, the data show some V-shaped trends from 2003 to 2007 and from 2007 to 2011. For example, the percentage for math content dropped from 65% in 2003 to 60% in 2007, and then increased to 68% in 2011.

Relative to the fourth graders, students in the eighth grade had teachers who reported higher levels of participation in math PD. As shown in the 2011 data, the majority of the eighth grade students were taught by math teachers who had PD in math curriculum (78%), math content (73%), math pedagogy or instruction (73%), and integrating information technology into math (68%). About three fifths of the students had teachers with PD in math assessment (61%), and improving students' critical thinking or problem solving skills (61%). However, the table suggests that the percentages have been decreasing for eighth graders from 2003 to 2011. For example, 83% of the eighth grade students had teachers who had PD focusing on math content in 2003, but in 2011, the percentage decreased by 10 percentage points to 73%. Similar trends can be seen in math assessment (74% in 2003 and 61%

in 2011), and in improving students' critical thinking or problem solving skills (76% to 61%).

Compared with their peers around the world, students at both the fourth and eighth grade levels in the United States had more access to teachers with PD in different focus areas. Still take the 2011 data as an example, two thirds of the fourth graders in the United States (68%) were taught by teachers with PD in math curriculum.

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.

The corresponding mean percentage was 41% for all the other countries that participated in the TIMSS 2011 cycle at the fourth grade level, 34% for the other high income OECD countries, and 41% for the other G8 nations (41%). Similarly, three fourths of the eighth graders in the United States (78%) had teachers with math PD in curriculum, compared with 51% for the other countries, 50% for the other high income OECD members, and 49% for the other G8 nations.

Professional Development and Student Math Achievement

To address the second research question of how the levels of students' access to teachers with PD are associated with student math achievement, a series of correlation analyses were first conducted based on the 2003, 2007, and 2011 TIMSS data for both fourth and eighth grade students. Tables 2 and 3 present the Pearson correlation coefficients.

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.

In general, national math achievement is moderately associated with four PD focus areas of math content, math pedagogy or instruction, math curriculum, and integrating information technology into math. The relationship is weaker for math assessment and improving students' critical thinking or problem solving skills. At the fourth grade level, out of the 23 correlation coefficients, 22 (95.7%) are positive, and 9 (39.1%) are both positive and statistically significant. At the eighth grade level, 17 out of the 24 coefficients are positive (70.8%), and 10 are both positive and significant (41.7%). When combined, 39 out of the 47 correlation coefficients are positive (83.0%), and 19 are both positive and significant (40.4%). This suggests positive associations between math achievement and teacher PD and supports conducting multiple regression models.

Based on the findings in tables 2 and 3, a series of multiple regression models were conducted. Table 4 reports the coefficients of interest on the relationship between students' access to teachers with PD and the national level of fourth graders' math achievement by the focus area of the PD and the TIMSS cycle.

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.

As shown in the table, after controlling for GDP per capita and educational expenditure as percentage of GDP in 2003, one percentage point increase in the share of students whose teachers had PD on math content is positively associated with a .76 point increase in national level of math achievement. This relationship, however, is not statistically significant at the 90 percent confidence level. So are the other PD coefficients based on the 2003 data. The relationships are much stronger in the 2007 data. An increase of 1.90 points of national mean math score is associated with a one percentage point increase in the proportion of fourth graders whose teachers had PD on math content, 1.59 points on math pedagogy or instruction, 1.35 points on math curriculum, 2.39 points on integrating information technology into math, and 1.58 points on improving students' critical thinking or problem solving skills. The coefficient for math assessment is also positive. The associations based on the 2011 data appear less strong, but again, most of the coefficients are positive. In addition, it is statistically significant for integrating information technology into math. The fourth column of the table reports the findings on the simple pooled OLS models. It shows mostly positive and significant associations between teacher PD and student achievement for fourth graders. 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.

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.

Table 5 shows a similar pattern for the eighth graders. The associations are strongest based on the 2007 data and relatively less strong one the 2003 and 2011 data. Again, most of the PD coefficients are positive. The pooled OLS models show that 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. It is interesting to note that the coefficient is negative for PD focusing on improving students' critical thinking or problem solving skills.

Discussion

It is a universal consensus that professional learning matters in improving teaching and learning. However, few cross-national studies evidenced the association between teachers' participation in PD and student achievement. Using the latest administrations of the largest international TIMSS data sets across multiple years and grades, this study attempts to fill in this gap by examining the relationship from a comparative perspective. It concentrates on the focus area of the PD, a key feature affecting the effectiveness of the learning activities in improving teachers' instructional practices. Findings of this study provide policymakers in the United States and abroad with up-to-date, cross-national evidence for the future directions of supporting teacher professional growth and improving student learning.

This study finds that the percentages of students in the United States whose teachers had math content-, math instruction-, or math curriculum-focused PD have been consistently higher than their peers around the world across the years. However, still one third to one half of the fourth grade students in the United States are being taught by teachers who have not participated in these professional learning activities, and that the percentages of eighth grade students whose teachers had PD have been decreasing from 2003 to 2011, especially in the focus areas of math content, math assessment, and improving students' critical thinking or problem solving skills. Research has shown that compared with teachers in other high achieving countries, teachers in the United States have less time to develop high quality curriculum and instruction, and had little professional collaboration in designing curriculum and sharing practices (Darling-Hammond et al., 2009). Therefore, these findings may still be of concern.

Consistent with the literature (Akiba & Liang, 2013; Garet et al., 2001), this study finds generally positive associations at both the fourth and eighth grade levels across the years between national math achievement and students' access to teachers who had PD in various focus areas. This suggests that teacher knowledge of subject matter, teaching methods, student learning and development, technology, and assessment are all important elements of teacher effectiveness and students benefit from their teachers' participation in continuous learning. As over one third of math teachers around the world do not have a major in math or math education (Akiba et al., 2007; Akiba & Liang, 2014), it is crucial to provide math teachers with sufficient and high quality learning opportunities so that they can continuously improve their classroom instruction and produce higher student achievement.

Although this study provides evidence from a comparative perspective on the positive relationship between students' access to teachers with PD and national math achievement, the relationships are not always strong or consistent across the years or PD focus areas. For example, the findings on the PD activities focusing on improving students' critical thinking or problem solving skills are mixed. The relationship tends to be positive for the fourth graders but negative for the eighth graders. This complexity highlights the importance of exploring cross-national differences in mediators and processes with further research (Akiba et al., 2007). It also suggests that focusing on providing more professional learning opportunities alone is unlikely to be sufficient to enhance student achievement. A more comprehensive and systematic approach in educational reform such as improving teacher quality and providing additional resources to better support teachers may bear more promise.

Before discussing the implications, it is important to acknowledge the limitations of this study. In the first place, this study measured teachers' participation in PD based on self-reported survey data. As the survey instruments provided no common definitions, teachers across the national and cultural contexts interpreted the PD items based on their own understandings. A previous study found that activities labeled as PD are actually very diverse around the world and the outcomes are dependent on the particular circumstances (OECD, 2005). In addition, prior research suggests that high quality professional learning needs to be sustained, consistent, and intensive (Yoon and colleagues, 2007). However, the TIMSS surveys did not query teachers about the time they spent on these PD activities or the training materials they receive. Therefore, this study could not examine how the quality of the PD (e.g., the dosage of participation) moderates the association between PD participation and math achievement. Meanwhile, it should be reiterated that there are significant variations in country-specific structural, cultural, and social differences. Such variations are important to be considered when adapting cross-national practices (Desimone, Smith, Baker, and Ueno, 2005). Furthermore, it is interesting to see some negative coefficients, especially for the 2011 data. Although most of them are not statistically significant, future studies using disaggregated data may still be warranted. In particular, the pooled data in Table 5 indicate a statistically significantly negative relationship between student achievement and teachers' participation in PD focusing on improving students' critical thinking skills. As this will be a most important skill for students in the 21st century, this finding warrants attention to examining the contents of PD programs and identifying potential areas of improvement.

Despite of these limitations, this comparative study used the latest multiple cycles of the nationally representative TIMSS data sets and addressed one important policy issue of the focus area of professional learning activities for teachers. The findings have important implications.

Policy and Leadership Implications

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.

Despite the significance of engaging teachers in high quality professional learning, professional development often turns out to be a major target for budget cut. 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.

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

References

Akiba, M., Chiu, Y.-L., Shimizu, K., & Liang, G. (2012). Teacher salary and national achievement: A cross-national analysis of 30 countries. International Journal of Educational Research, 53, 171-181. http://dx.doi.org/10.1016/j.ijer.2012.03.007

Akiba, M., & LeTendre, G. K. (2009). Improving teacher quality: The U.S. teaching force in global context. New York: Teachers College Press.

Akiba, M., LeTendre, G. K., & Scribner, J. P. (2007). Teacher quality, opportunity gap, and national achievement in 46 countries. Educational Researcher, 36(7), 369-387. http://dx.doi.org/10.3102/0013189X07308739

Akiba, M., & Liang, G. (2013). Effects of teacher professional learning activities on student achievement growth. Paper presented at the Association for Education Finance and Policy Annual Conference.

Akiba, M., & Liang, G. (2014). Teacher qualification and the achievement gap: A cross-national analysis of 50 countries. In J. V. Clark (Ed.), Closing the achievement gap from an international perspective: Transforming STEM for effective education. New York, NY: Springer. http://dx.doi.org/10.1007/978-94-007-4357-1_3

Akiba, M., Wang, Z., & Liang, G. (2015). Organizational resources for professional development: A statewide longitudinal survey of middle school mathematics teachers. Journal of School Leadership, 25(2), 252-285.

Angrist, J. D., & Lavy, V. (2001). Does teacher training affect pupil learning? Evidence from matched comparisons in Jerusalem public schools. Journal of Labor Economics, 19(2), 343-369. http://dx.doi.org/10.1086/319564

Birman, B. F., Floch, K. C. L., Klekotka, A., Ludwig, M., Taylor, J., Walters, K., et al. (2007). State and local implementation of the No Child Left Behind Act volume II—Teacher quality under NCLB: Interim report. Washington, DC: U.S. Department of Education.

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C.-P., & Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. American Educational Research Journal, 26(4), 499-531. http://dx.doi.org/10.3102/00028312026004499

Cohen, D. K., & Hill, H. C. (2001). Learning policy: When state education reform works. New Haven, CT: Yale University Press. http://dx.doi.org/10.12987/yale/9780300089479.001.0001

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). Professional Learning in the Learning Profession: A Status Report on Teacher Development in the United States and Abroad. Dallas, TX: National Staff Development Council.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. Educational Researcher, 38(3), 181-199. http://dx.doi.org/10.3102/0013189X08331140

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. Educational Evaluation and Policy Analysis, 24(2), 81-112. http://dx.doi.org/10.3102/01623737024002081

Desimone, L. M., Smith, T., Baker, D., & Ueno, K. (2005). Assessing barriers to the reform of U.S. mathematics instruction from an international perspective. American Educational Research Journal, 42(3), 501-535. http://dx.doi.org/10.3102/00028312042003501

EducationWeek. (2013). Quality Counts 2013. Bethesda, MD: Editorial Projects in Education.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. American Educational Research Journal, 38(4), 915-945. http://dx.doi.org/10.3102/00028312038004915

Hiebert, J., Stigler, J. W., Jacobs, J. K., Givvin, K. B., Garnier, H., Smith, M., et al. (2005). Mathematics teaching in the United States today (and tomorrow): Results from the TIMSS 1999 video study. Educational Evaluation and Policy Analysis, 27(2), 111-132. http://dx.doi.org/10.3102/01623737027002111

Ingvarson, L., Meiers, M., & Beavis, A. (2005). Factors affecting the impact of professional development programs on teachers' knowledge, practice, student outcomes & efficacy. Education Policy Analysis Archives, 13(10). Retrieved May 24, 2012, from http://epaa.asu.edu/epaa/v13n10/

Kallestad, J. H., & Olweus, D. (1998). Teachers' emphases on general educational goals: A study of Norwegian teachers. Scandinavian Journal of Educational Research, 42(3), 257-279. http://dx.doi.org/10.1080/0031383980420302

Kettle, B., & Sellars, N. (1996). The development of student teachers' practical theory of teaching. Teaching and Teacher Education, 12(1), 1-24. http://dx.doi.org/10.1016/0742-051X(95)00016-D

Liang, G. (2013a). Performance-related pay for teachers: An updated review. Journal of Postdoctoral Research, 1(1), 99-117.

Liang, G. (2013b). Teacher evaluation policies in the United States: Implementation and impact on constructivist instruction. In M. Akiba (Ed.), Teacher reforms around the world: Implementations and outcomes (pp. 179-206). Bingley, UK: Emerald Publishing. http://dx.doi.org/10.1108/S1479-3679(2013)0000019013

Liang, G., & Akiba, M. (2011). Performance-related pay: District and teacher characteristics. Journal of School Leadership, 21(6), 844-869.

Liang, G., & Akiba, M. (2013). Teacher evaluation, performance-related pay, and constructivist instruction. Educational Policy, DOI: 10.1177/0895904813492379. http://dx.doi.org/10.1177/0895904813492379

Martin, M. O., & Mullis, I. V. S. (2012). Methods and procedures in TIMSS and PIRLS 2011. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Mullis, I. V. S., Martin, M. O., Foy, P., & Arora, A. (2012). TIMSS 2011 International Results in Mathematics. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

OECD. (2005). Attracting, developing and retaining effective teachers. Paris: Author. http://dx.doi.org/10.1787/9789264018044-en

Olson, J. F., Martin, M. O., & Mullis, I. V. S. (2008). TIMSS 2007 technical report. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Pong, S.-L., & Pallas, A. (2001). Class size and eighth-grade math achievement in the United States and abroad. Educational Evaluation and Policy Analysis, 23(3), 251-273. http://dx.doi.org/10.3102/01623737023003251

Power, T., & Thomas, R. (2007). The classroom in your pocket? Curriculum Journal, 18(3), 373-388. http://dx.doi.org/10.1080/09585170701590031

Saxe, G. B., Gearhart, M., & Nasir, N. S. (2001). Enhancing students' understanding of mathematics: A study of three contrasting approaches to professional support. Journal of Mathematics Teacher Education, 4(1), 55-79. http://dx.doi.org/10.1023/A:1009935100676

Slotnik, W. J., & Smith, M. D. (2008). Focus on literacy: Professional development audit. Boston, MA: Community Training and Assistance Center.

Smith, T. M., Desimone, L. M., Zeidner, T. L., Dunn, A. C., Bhatt, M., & Rumyantseva, N. L. (2007). Inquiry-oriented instruction in science: Who teaches that way? Educational Evaluation and Policy Analysis, 29(3), 169-199. http://dx.doi.org/10.3102/0162373707306025

Swanson, C. B., & Barlage, J. (2006). Influence: A Study of the Factors Shaping Education Policy. Bethesda, MD: Editorial Projects in Education.

Telese, J. A. (2008). Teacher professional development in mathematics and student achievement: A NAEP 2005 analysis. Paper presented at the Annual Meeting of the School Science and Mathematics Association.

Warwick, D. P., & Reimers, F. (1995). Hope or despair? Learning in Pakistan's primary schools. Westport, CT: Praeger.

Wenglinsky, H. (2002). How schools matter: The link between teacher classroom practices and student academic performance. Education Policy Analysis Archives, 10(2).

Wiley, D. E., & Yoon, B. (1995). Teacher reports on opportunity to learn: Analyses of the 1993 California learning assessment system. Educational Evaluation and Policy Analysis, 17(3), 355-370. http://dx.doi.org/10.3102/01623737017003355

Woessmann, L. (2011). Cross-country evidence on teacher performance pay. Economics of Education Review, 30, 404-418. http://dx.doi.org/10.1016/j.econedurev.2010.12.008

Wood, E., & Bennett, N. (2000). Changing theories, changing practice: Exploring early childhood teachers' professional learning. Teaching and Teacher Education, 16(5), 635-647. http://dx.doi.org/10.1016/S0742-051X(00)00011-1

Yoon, K. S., Duncan, T., Lee, S. W.-Y., Scarloss, B., & Shapley, K. L. (2007). Reviewing the evidence on how teacher professional development affects student achievement. Washington, DC: U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southwest.