THE JOURNAL OF EDUCATIONAL RESEARCH
2016, VOL. 21, NO. 1, 1–12
http://dx.doi.org/10.1080/00220671.2014.924470

Effects of teacher professional learning activities on student achievement growth

Motoko Akiba[a] and Guodong Liang[b]

[a]Educational Leadership and Policy Studies, Florida State University, Tallahassee, Florida, USA; [b]Community Training and Assistance Center, Boston, Massachusetts, USA

ABSTRACT
The authors examined the effects of six types of teacher professional learning activities on student achievement growth over 4 years using statewide longitudinal survey data collected from 467 middle school mathematics teachers in 91 schools merged with 11,192 middle school students' mathematics scores in a standardized assessment in Missouri. The data showed that teacher-centered collaborative activities to learn about mathematics teaching and learning (teacher collaboration and informal communication) seem to be more effective in improving student mathematics achievement than learning activities that do not necessarily involve such teacher-centered collaborative opportunities (professional development programs, university courses, individual learning activities). Teacher-driven research activities through professional conference presentation and participation were also found to be associated with student achievement growth in mathematics. The districts and schools may benefit from investing their professional development funds and resources in facilitating teacher-centered collaborative and research-based learning activities in order to improve student learning.

KEYWORDS
Mathematics teachers; student achievement; survey; teacher professional development

Teachers' continuous engagement in professional learning activities is critical for improvement of their knowledge, instruction, and student learning. Previous conceptual studies and case studies of teachers' professional learning activities have documented that teachers engage in various types of learning process beyond formal activities such as professional development programs and university courses (Borko, 2004; Little, 1993; Scribner, 1999, 2003; Smylie, 1995; Wilson & Berne, 1999). Teachers have informal communications with their colleagues and engage in individual learning activities (e.g., reading professional journals, analyzing students' work). To holistically understand teachers' professional learning opportunities, it is important to examine various types and amounts of teachers' professional learning activities and what impacts these activities have on student achievement.

However, only a few studies empirically examined various types of professional learning activities (Akiba, 2012; Scribner, 1999, 2003) and no prior studies have investigated how these various types of professional learning activities influence student achievement growth. To fill this knowledge gap, a longitudinal statewide survey of 467 middle school mathematics teachers in Missouri was conducted in 2009, 2010, and 2011 to examine how six types of professional learning activities focused on mathematics teaching and learning: (a) professional development programs, (b) teacher collaboration, (c) university courses, (d) professional conferences, (e) informal communications, and (f) individual learning activities are associated with student achievement growth in state mathematics assessment over four years.

In this study specifically we asked the following research questions:

Research Question 1: What are the levels of teacher participation in formal and informal professional learning activities from 2009 to 2011?

Research Question 2: How are the levels of teacher participation in formal and informal professional learning activities associated with one another?

Research Question 3: How are school mean levels of teacher participation in formal and informal professional learning activities associated with student achievement growth over four years?

We focused on middle school teachers' professional learning activities on mathematics teaching and learning and their impacts on students' mathematics achievement growth. We decided to focus on middle school teachers because all of their students annually take a state-standardized test and their schools are held accountable for the results under the No Child Left Behind Act of 2001 (2002). Naturally teacher professional development is part of many districts and schools' strategies for improving student achievement and all middle school teachers are under pressure to improve student learning. We focused on mathematics because it is one of the core subject areas that are annually assessed, and the student achievement data were available to the researchers for examining the impacts of teachers' professional learning activities.

An examination of six types of teachers' professional learning and associations among the amounts of these activities over three years will give us a whole picture on how teachers allocate their

CONTACT Motoko Akiba makiba@fsu.edu Educational Leadership and Policy Studies, 1204E Stone Building, 1114 W Call St., Tallahassee, FL 32306-4452.
Color versions of one or more of the figures in this article can be found online at www.tandfonline.com/vjer.

time for these activities, if there is a pattern regarding which learning activities to participate, and how the amounts changed during the time of increasingly stringent financial situation. In addition, by examining the impacts of professional learning activities on student achievement growth over time, we can identify what types of learning activities should be promoted and supported. Such information will be useful for district and school administrators in deciding how professional development resources should be allocated to promote effective teacher learning activities that will lead to improved student learning.

Background

Previous empirical studies on effectiveness of teachers' professional learning activities on student achievement focused on specific types of activities such as professional development programs, teacher collaboration, or professional learning communities. In the field of mathematics professional development, both synthesis studies (Blank, de las Alas, & Smith, 2008; Heck, Banilower, Weiss, & Rosenberg, 2008; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007) and evaluations of individual mathematics professional development programs (Balfanz, Mac Iver, & Byrnes, 2006; Bell, Wilson, Higgins, & McCoach, 2010; Boston & Smith, 2009; Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Hill & Ball, 2004; Jacobs, Franke, Carpenter, Levi, & Battey, 2007; Sherin & van Es, 2009) have identified successful programs that improved teacher knowledge and instructional practice.

However, only a small number of studies have examined the impact of professional development programs on student achievement. While regional experimental studies on programs such as building block professional development (Clements et al., 2011), cognitively guided instruction (Carpenter et al., 1989; Fennema et al., 1996), and talent development (TD) middle school model's mathematics program (Balfanz et al., 2006) were found to be effective in increasing student achievement in mathematics, recent large-scale randomized control trials of professional development programs that are coherent, continuous, and collaborative consistently failed to produce positive results in improving teacher knowledge, instruction, and student achievement (Garet et al., 2011; Newman et al., 2012). Thus, the findings on the effects of professional development programs on student achievement have been inconsistent.

Many empirical studies have been also conducted on the effects of teacher collaboration or professional learning communities on student achievement. Teacher collaboration (Goddard, Goddard, & Tschannen-Moran, 2007), teacher networks (Moolenaar, Sleegers, & Daly, 2012), and grade-level teams (Saunders, Goldenberg, & Gallimore, 2009) were found to be associated with higher student achievement. Professional learning communities, defined as "ongoing groups . . . who meet regularly for the purposes of increasing their own learning and that of their students" (Lieberman & Miller, 2008, p. 2), were also found to be associated with higher student achievement in various sites and subject areas (Berry, Johnson, & Montgomery, 2005; Bolam, McMahon, Stoll, Thomas, & Wallace, 2005; Hollins, McIntyre, DeBose, Hollins, & Towner, 2004; Lomos, Hofman, & Bosker, 2011; Louis & Marks, 1998; McLaughlin & Talbert, 2006; Phillips, 2003; Sigurdardottir, 2010; Strahan, 2003; Supovitz, 2002; Supovitz & Christman, 2003; Vescio, Ross, & Adams, 2008). Most recent research has also pointed out the importance of focusing on the subject matter content and how students learn that content in professional learning communities (Bausmith & Barry, 2011), honest and focused talk among teachers that promotes deep reflection on problems of practice (Horn & Little, 2010; Little & Horn, 2007), and teachers' collective construction and sharing of new knowledge about teaching and student learning (Lieberman & Miller, 2011) to improve student learning.

Recent studies also examined the relationship between university course taking and student achievement (Boyd, Grossman, Lankford, Loeb, & Wyckoff, 2009; Harris & Sass, 2007). However, the findings are inconclusive. While Boyd et al. found positive effects of preservice teacher education programs in New York City, especially preparation linked to practice, on the achievement growth of students taught by graduates of these teacher education programs, Harris and Sass (2007) found no statistically significant relationship between preservice training and student outcomes using Florida data.

Despite the availability of many empirical studies on professional development programs, teacher collaboration, professional learning communities and university courses, few empirical studies have been conducted to examine the effects of professional conferences, informal communications, and individual learning activities on student achievement. In addition, most available empirical studies on professional development programs, teacher collaboration, and professional learning communities used cross-sectional data, and even those used experimental or longitudinal survey design collected data for a short term with no more than two years (Boyd et al., 2009; Garet et al., 2011; Newman et al., 2012; Vescio et al., 2008; Yoon et al., 2007).

This study overcame these limitations by using longitudinal statewide survey data collected from 467 mathematics teachers in 91 schools over three years linked with student achievement growth over four years to examine the effects of six types of professional learning activities on student achievement growth. We used three-level hierarchical linear modeling (HLM) to analyze the data at time, student, and school (school data and teacher data aggregated at school level) levels. To isolate the effects of professional learning activities on student achievement growth, we controlled for both student characteristics (poverty level, ethnic minority status, and gender) and school-level background characteristics (poverty level, percentage of ethnic minority students, school size, school location, percentages of teachers with a mathematics certification, master's degree or above, mathematics major, mathematics education major, five or fewer years of teaching experience, and more than 15 years of experience). These methodological approaches allowed the researchers to examine the value-added effects of six types of professional learning activities on student achievement growth independent of other student and school-level predictors of student achievement.

Method

Teacher participation in professional learning activities

The Teachers' Opportunity to Learn (TOTL) survey asked the middle school mathematics teachers about their participation in six types of professional learning activities: Professional development programs, teacher collaboration, university/college courses, professional conferences, informal communication, and individual learning activities. The following definitions of these activities were given on the cover page of the surveys: (a) a professional development program is an organized activity for the purpose of learning and improving mathematics teaching and student learning (e.g., district-sponsored workshop); (b) teacher collaboration is an ongoing activity such as a study group, professional learning community, teacher network, group action research, and any other form of interaction among teachers for the purpose of improving mathematics teaching and learning, and teacher collaboration can be formally organized by professional developers or informally practiced by a group of teachers; (c) university or college courses in mathematics or mathematics education may be taken for a degree or professional development credits; (d) professional conference is an opportunity for a teacher to present his or her practice or research, and learn from presentations about new ideas for mathematics teaching or learning; (e) informal communication refers to planned or unplanned interactions with colleagues or friends for your professional learning of mathematics teaching outside of the previously listed activities; and (f) individual learning activities refer to activities a teacher engages in by him- or herself outside of the previously listed activities such as reading professional journals and analyzing student work.

Data

The TOTL survey was developed for the purpose of understanding: (a) middle school mathematics teachers' participation in various professional learning activities and (b) work contexts that influence teachers' participation in professional learning activities. The TOTL survey was conducted by the research team led by the Motoko Akiba over three years in 2009, 2010, and 2011 in the state of Missouri. To administer the TOTL survey, the research team first obtained a license for using restricted use core data from the Missouri Department of Elementary and Secondary Education. The core data include teachers' names, subject areas of teaching, home address, and school address. The core data also include a large number of variables on school and district characteristics including the percentage of students receiving free or reduced-price lunch (FRL), the percentage of ethnic minority students, school location, and student enrollment.

From the core data, the project team selected only mathematics teachers who were teaching in middle schools with a Grades 6–8 configuration[1] as of January 2009, 2010, and 2011. Middle schools with a Grades 6–8 configuration constitute 80% of all middle-grade schools in Missouri. The populations of 882, 912, and 896 mathematics teachers in Grades 6–8 middle schools in Missouri were selected as the survey participants for the administration of the TOTL survey in 2009, 2010, and 2011, respectively. The survey data were collected from January to May through five waves of mailing each year: (a) the first survey mailing in early January, (b) a postcard reminder three weeks later, 8c) the second survey mailing in February, (d) a postcard reminder three weeks later, and (e) the final survey mailing in late April. Each survey participant was given a $30 gift card in a major retail store as a financial incentive. After five waves of mailing, in 2009, 577 mathematics teachers provided usable surveys with a response rate of 65%. In 2010 and 2011, 633 and 626 teachers responded, producing response rates of 69% and 70%, respectively.

After collecting the TOTL surveys, the project team computed the school level response rates for 2009, 2010, and 2011, and identified 91 schools in which at least 50% of the eligible mathematics teachers participated in the TOTL project across the three years. Using school IDs, the school data were then linked with the student achievement data in the Missouri Assessment Program (MAP) in 2009, 2010, and 2011, a mandatory state assessment in which students in Grades 3–8 participate annually each spring. Then, using student IDs, their 2008 MAP scores as the base-year data before they enter the middle schools were merged with the 2009, 2010, and 2011 data.

To more accurately measure the impact of teachers' participation in professional learning activities on student achievement growth, we selected only the students whose MAP scores in mathematics are available from 2008 to 2011. A total of 11,192 students out of 11,754 students (95.2%) in the database had complete MAP scores across the four years. The final sample includes 44,768 MAP scores in mathematics (four data points for each student) for 11,192 students in 91 middle schools in Missouri.

Measures

The Appendix includes the measures, survey questions, and coding for all variables on teacher participation in professional learning activities.

Professional learning activities

Middle school mathematics teachers were asked if during the previous 12 months they had participated in a list of professional learning activities on mathematics teaching and learning with the answer choices of yes (1) or no (0): (a) professional development program, (b) teacher collaboration, (c) university or college courses, and (d) professional conferences and those answered yes were further asked how many hours in total they spent on each type of the activity. The teachers were also asked if they had someone other than a formally assigned mentor or coach to informally rely on and communicate for professional learning of mathematics teaching (1 = yes, 0 = no) and those who chose yes were further asked the total monthly hours of informal communication with this person. Furthermore, the survey asked the teachers how many hours during a typical month they spent on their own for a series of individual learning activities such as studying and analyzing student work, and reading teachers' manual for adopted textbook. These amounts of professional learning activities were aggregated at school level as the school mean amounts of professional learning activities in order to link with the student data.[2]

Control variables

Three student background characteristics: (a) receiving FRL (1 = yes, 0 = no), (b) being an ethnic minority (1 = yes, 0 = no), and (c) being a female student (1 = yes, 0 = no) were included as control variables for the relationship between teachers' participation in professional learning activities and student achievement.

In addition, average school level teacher qualifications across the three years were included as control variables based on the previous studies that showed that these teacher qualifications are important predictors of student achievement (Akiba, LeTendre, & Scribner, 2007; Darling-Hammond & Youngs, 2002; Rice, 2003; Wayne & Youngs, 2003; Wilson, Floden, & Ferrini-Mundy, 2002). The six teacher variables are average percentages of (a) teachers with mathematics certification, (b) teachers with education level of master's degree or above, (c) beginning teachers with less than 5 years of teaching experience, (d) experienced teachers with teaching experience of 16 years or more, (e) teachers with mathematics major, and (f) teachers with mathematics education major. Furthermore, five school background characteristics: (a) poverty level (percentage of students receiving FRL), (b) percentage of ethnic minority students, (c) school size, and (d) school location (two dummy variables for urban and rural) were included as the control variables.

Analysis

For the first research question, descriptive statistics and frequencies were computed to present the levels of teacher participation in formal and informal professional learning activities from 2009 to 2011. For the second research question, Pearson's correlation coefficients were calculated to examine the associations among the amounts of six types of teacher participation in these activities. For the third research question, three level HLM analyses were conducted to examine the relationships between the school average amounts of professional learning activities across three years and student achievement growth (slope) in mathematics over four years. The HLM analysis for each teacher professional learning activity (professional development program, teacher collaboration, university or college courses, professional conferences, informal communication, and individual learning activities) was conducted separately. For student achievement in the MAP test, data were collected at four time points in 2008, 2009, 2010, and 2011. Therefore, the level 1 model was time specific and within person. The units at level 2 and level 3 were students and schools, respectively. The HLM equations are specified as follows:

Level 1: Individual Student MAP Score Change

$$Y_{tij} = \pi_{oij} + \pi_{1ij}(TIME)_{tij} + e_{tij}$$

where

Y_{tij} is the MAP score at time t for student i in school j.
π_{oij} is the 2008 MAP score of student ij.
Time = 0 in 2008, Time = 1 in 2009, Time = 2 in 2010, and Time = 3 in 2011
π_{1ij} is the average yearly MAP growth of student ij.

Level 2: Student

$$\pi_{oij} = \beta_{00j} + \beta_{01j}(\text{FRL})_{ij} + \beta_{02j}(\text{MINORITY})_{ij} + \beta_{03j}(\text{FEMALE})_{ij} + r_{0ij}$$

$$\pi_{1ij} = \beta_{10j}$$

Level 3: School

$$\beta_{00j} = \gamma_{000} + u_{00j}$$
$$\beta_{01j} = \gamma_{010}$$
$$\beta_{02j} = \gamma_{020}$$
$$\beta_{03j} = \gamma_{030}$$
$$\begin{aligned}\beta_{10j} = \gamma_{100} &+ \gamma_{101}(\text{PROF. LEARNING ACTIVITY})_j \\ &+ \gamma_{102}(\text{CERTIFICATION})_j + \gamma_{103}(\text{MASTER})_j \\ &+ \gamma_{104}(\text{NEWTEACH})_j + \gamma_{105}(\text{EXPTEACH})_j \\ &+ \gamma_{106}(\text{MATHMAJOR})_j \\ &+ \gamma_{107}(\text{MATHEDMAJOR})_j + \gamma_{108}(\text{SCHLFRL})_j \\ &+ \gamma_{109}(\text{SCHLMINORITY})_j \\ &+ \gamma_{110}(\text{SCHLSIZE})_j + \gamma_{111}(\text{RURAL})_j \\ &+ \gamma_{112}(\text{URBAN})_j\end{aligned}$$

Because changes in the level of student achievement were roughly linear across the four years (as shown in Figure 1 in the result section), linear growth models were applied. In these models, a linear time slope and the intercept were included at level 1. The time variable was coded in such that the intercept represented the expected score for each student in 2008, and the time slope represented the average yearly MAP score growth of the student.

In the level 2 equation, three student background characteristics variables were included as predictors of the level

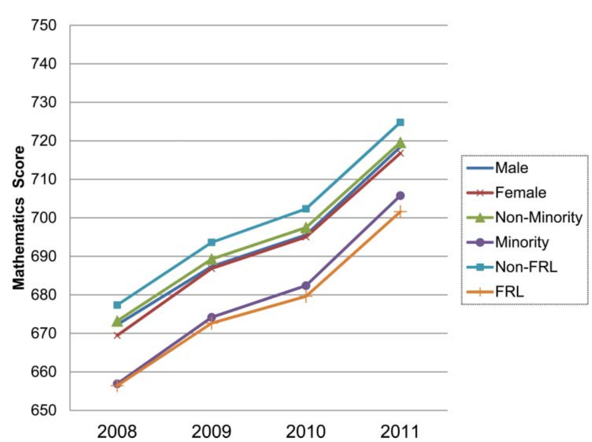

Figure 1. Student achievement growth in mathematics from Grade 5 (2008) through Grade 8 (2011) in Missouri Assessment Program by subgroups.

1 intercept. The level 2 intercept represented the average student achievement in the school in 2008 when the student background variables were equal to zero (i.e., those who did not receive FRL, were not an ethnic minority, and were not female). The level 1 intercept was specified as random and the time slope was specified as fixed at level 2. In the level 3 equation, school mean amount of each type of professional learning activities of all mathematics teachers who participated in the survey across 3 years was entered as the predictor variable, and five school background variables and six school level teacher qualification variables were entered as control variables of the level 2 time slope. The level 3 intercept was specified as random and the slope as fixed. The coefficients of student characteristics were specified as fixed at level 3 to keep the model parsimonious. In the unconditional model, no student or school characteristic variables were included. Those variables were added in the conditional model. Variance components for random effects in both models are reported along with the percentages of variances in the intercept explained at levels 1, 2, and 3.

Results

Teachers' participation in professional learning activities from 2009 to 2011

Before examining the relationship between teachers' participation in professional learning activities and student achievement gains, descriptive statistics and frequency analysis were conducted to describe the changes of student test scores, percentage of teachers who participated in formal and informal professional learning activities, and the average hours they spent on these learning activities across the years. The results are presented in Figure 1.

Figure 1 presents the growth of mean MAP score in mathematics from 2008 to 2011 by student subgroups based on gender, ethnicity, and FRL status. It shows that non-FRL students had the highest average score across four years and FRL students who had the lowest average scores. The achievement gaps between white students and ethnic minority students were also substantial. The gender-based differences, however, were very small. In addition, the six lines are roughly parallel and linear, indicating that the students had the same and constant mean growth rates of MAP scores across the groups and years.

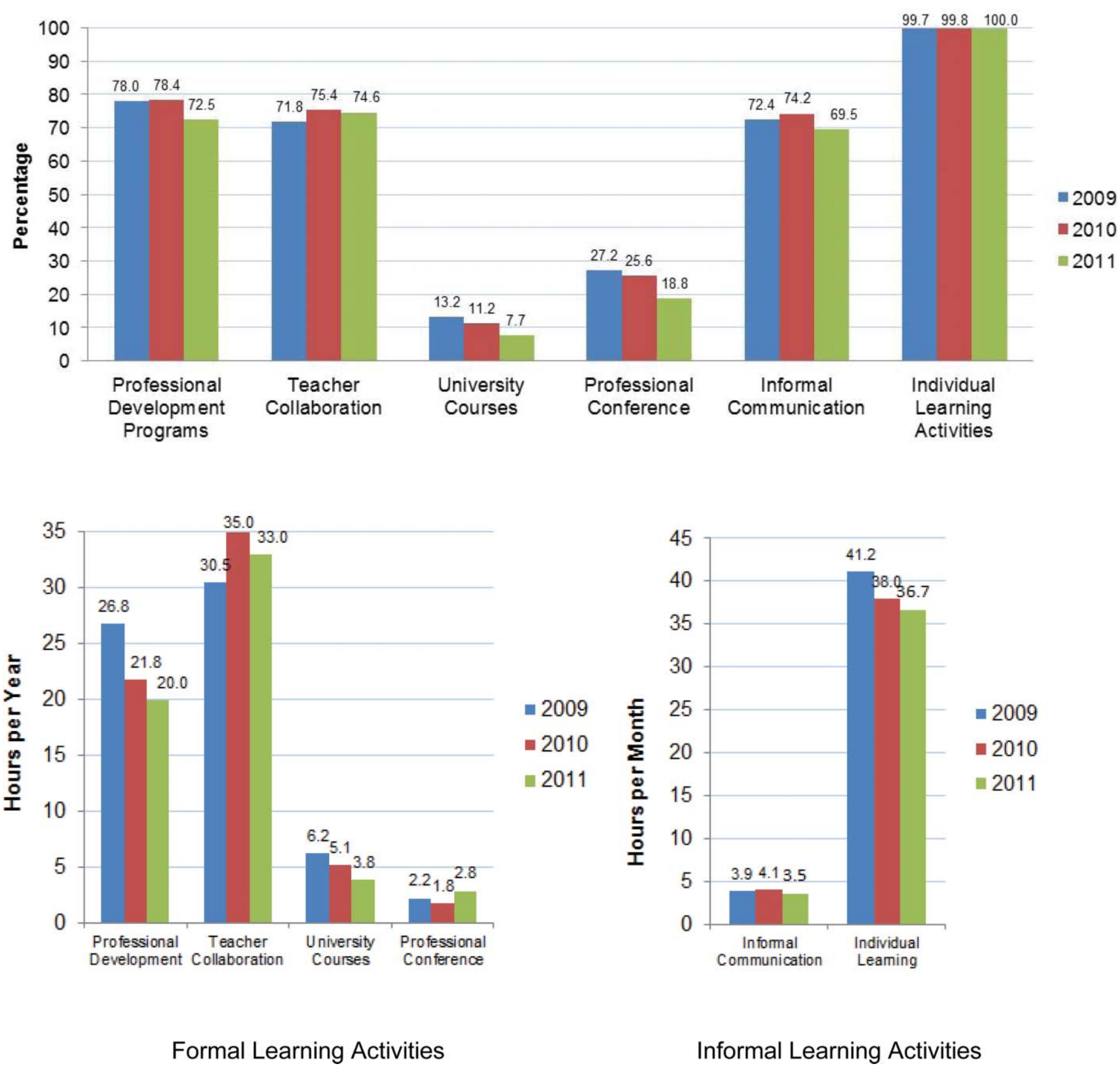

Figure 2. Teacher participation (percentage and amount) in six types of professional learning activities.

Table 1. Impacts of professional learning activities on student achievement growth from 2008 to 2011.

	Professional development	Teacher collaboration	University courses	Professional conference	Informal communication
Teacher collaboration	.28** (2009) .20** (2010) .13** (2011)				
University courses	.15* (2009) .19** (2010) .05 (2011)	.08 (2009) .06 (2010) .03 (2011)			
Professional conference	.29** (2009) .28** (2010) .21** (2011)	.09* (2009) .12** (2010) .05 (2011)	.23** (2009) .05 (2010) .09* (2011)		
Informal communication	.06 (2009) .09* (2010) .04 (2011)	.29**(2009) .26** (2010) .31** (2011)	.04 (2009) .02 (2010) .07 (2011)	.05 (2009) .07 (2010) .01 (2011)	
Individual learning	.15** (2009) .21** (2010) .13** (2011)	.10* (2009) .16** (2010) .15** (2011)	.15** (2009) .13** (2010) .20** (2011)	.12** (2009) .13** (2010) .13** (2011)	.15** (2009) .13** (2010) .13** (2011)

Note. The sample sizes are 577 in 2009, 633 in 2010, and 626 in 2011.
*$p < .05$. **$p < .01$.

Figure 2 presents the percentages of middle school mathematics teachers who participated in the six types of professional learning activities and the average number of hours middle school mathematics teachers spent in these six types of professional learning activities from 2009 to 2011. The percentages during the previous 12 months were reported for professional development programs, teacher collaboration, university courses, and professional conferences, and the percentages during a typical school month were reported for informal communication, and individual activities. We can see that teachers' participation in professional development programs, teacher collaboration, informal communication, and individual learning activities is common because over 70% of teachers participated in these activities in all three years. The most common type of activities that almost all teachers (99.7% in 2009, 99.8% in 2010, and 100.0% in 2011) engaged in is individual learning activities. Participation in professional development programs is also common; 78.0%, 78.4%, and 72.5% of teachers participated in one or more professional development programs in 2009, 2010, and 2011, respectively. In addition, 71.8%, 75.4%, and 74.6% of teachers participated in teacher collaboration in these three years. Over 70% of teachers also communicate informally with their colleagues to discuss mathematics teaching and learning (72.4% in 2009, 74.2% in 2010, and 69.5% in 2011). These percentages show that a majority of teachers participate in both formal and informal learning activities.

The other two types of learning activities are less common among middle school mathematics teachers. No more than 30% of mathematics teachers attended a professional conference(s) as a presenter or an audience (27.2% in 2009, 25.6% in 2010, and 18.8% in 2011). The least common activity was taking university courses. In 2009, 13.2% of teachers took a university course and the percentage changed to 11.2% in 2010 and 7.7% in 2011. Unlike the other four types of professional learning activities, the percentages of teachers who participated in a professional conference and who took a university course decreased from 2009 to 2011.

Figure 2 presents the average amounts of teacher participation in six types of professional learning activities. The average amounts in hours during the previous 12 months were reported for formal learning activities: professional development programs, teacher collaboration, university courses, and professional conferences, and the average amounts in hours during a typical school month were reported for informal learning activities: informal communications and individual activities. Among the formal professional learning activities, on average, teachers spent the most time for teacher collaboration (30.5 hr in 2009, 35.0 hr in 2010, and 33.0 hr in 2011). Teachers also spent a relatively large but decreasing amount of time (26.8 hr in 2009, 21.8 hr in 2010, and 20.0 hr in 2011) participating in professional development programs. Teachers spent significantly fewer hours taking university courses (6.2 hr in 2009, 5.1 hr in 2010, and 3.8 hr in 2011), or attending professional conferences (2.2 hr in 2009, 1.8 hr in 2010, and 2.8 hr in 2011).

Among informal learning activities, teachers spent a larger amount of time per month in individual learning activities (41.2 hr in 2009, 38.0 hr in 2010, and 36.7 hr in 2011). In contrast, they spent much less time (3.9 hr in 2009, 4.1 hr in 2010, and 3.5 hr in 2011) for informal communications with their colleagues to learn about mathematics teaching or learning. The amount of learning activities decreased over the years in professional development programs, university courses, and individual learning activities unlike the other learning activities.

Associations between teachers' participation in professional learning activities

To answer the second research question of how the levels of teacher participations in formal and information professional learning activities are associated with one another, we conducted three sets of correlation analyses among the average hours middle school mathematics teachers in Missouri spent in six professional learning activities based on the 2009, 2010, and 2011 data. Table 1 presents Pearson r correlation coefficients.

In general, four types of formal learning activities: professional development program, teacher collaboration, university courses, and professional conference were significantly associated with one another. One exception is the relationship between teacher collaboration and university courses; those teachers who collaborate more often are not necessarily taking more university courses, or vice versa. Informal communications with colleagues were significantly associated with only with teacher collaboration and individual learning. Individual learning, on the other hand, was significantly associated with all the other five types of professional learning activities. It seems that those teachers who spent more time engaging in individual learning activities such as reading journals and

Table 2. Impacts of professional learning activities on student achievement growth from 2008 to 2011.

	Professional development		Teacher collaboration		University courses	
	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Level 1: Time ($n = 44{,}768$)						
Intercept	688.71 (.96)***	678.01 (.88)***	668.71 (.96)***	678.03 (.88)***	668.71 (.96)***	678.02 (.88)***
Time	14.84 (.07)***	14.86 (.11)***	14.84 (.07)***	14.83 (.11)***	14.84 (.07)***	14.85 (.11)***
Level 2 intercept: Student ($n = 11{,}192$)						
Free or reduced-price lunch (FRL)		−17.93 (.71)***		−17.93 (.71)***		−17.93 (.71)***
Ethnic minority		−11.91 (.92)***		−11.91 (.92)***		−11.91 (.92)***
Female		−1.00 (.61)		−1.00 (.61)		−1.00 (.61)
Level 3 slope: School ($n = 91$)						
Professional learning activity		−.01 (.01)		.01 (.00)**		.00 (.01)
Teacher qualifications						
% Math certification		.34 (.51)		.15 (.49)		.10 (.49)
% Master's or above		−.45 (.41)		−.54 (.41)		−.43 (.41)
% Beginning teachers		−2.39 (.48)***		−2.42 (.48)***		−2.31 (.49)***
% Experienced teachers		−1.26 (.32)***		−1.24 (.32)***		−1.24 (.32)***
% Mathematics major		.98 (.49)*		1.11 (.49)*		1.02 (.49)*
% Mathematics education major		1.29 (.43)**		1.13 (.43)**		1.31 (.43)**
School background						
% FRL		−.02 (.01)**		−.02 (.01)**		−.02 (.01)***
% Ethnic minority		.01 (.01)		−.00 (.01)		.00 (.01)
School size		.00 (.00)		.00 (.00)		.00 (.00)
Urban school		−2.15 (.33)***		−1.99 (.33)***		−2.13 (.33)***
Rural school		−.64 (.20)**		−.64 (.20)**		−.63 (.20)**
Variance component						
Level 1: Temporal variation	260.42 (19.0%)	258.55 (20.6%)	260.42 (19.0%)	258.50 (20.6%)	260.42 (19.0%)	258.57 (20.6%)
Level 2: Intercept	1044.29 (76.0%)	955.38 (76.0%)	1044.29 (76.0%)	955.39 (76.1%)	1044.29 (76.0%)	955.38 (76.1%)
Level 3: School mean intercept	69.39 (5.0%)	42.46 (3.4%)	69.39 (5.0%)	42.37 (3.4%)	69.39 (5.0%)	42.30 (3.4%)
% Variance explained						
Level 1: Temporal variation		.72		.74		.71
Level 2: Intercept		8.52		8.51		8.51
Level 3: School mean intercept		38.81		39.02		39.04

	Professional conferences		Informal communication		Individual learning	
	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Level 1: Time ($n = 44{,}768$)						
Intercept	668.71 (.96)***	678.00 (.88)***	668.71 (.96)***	678.04 (.88)***	668.71 (.96)***	678.02 (.87)***
Time	14.84 (.07)***	14.81 (.11)***	14.84 (.07)***	14.83 (.11)***	14.84 (.07)***	14.83 (.11)***
Level 2 intercept: Student (N = 11,192)						
FRL		−17.93 (.71)***		−17.93 (.71)***		−17.93 (.71)***
Ethnic minority		−11.92 (.92)***		−11.91 (.92)***		−11.91 (.92)***
Female		−1.00 (.61)		−1.00 (.61)		−1.00 (.61)
Level 3 slope: School ($n = 91$)						
Professional learning activity		.15 (.03)***		.23 (.04)***		−.01 (.01)
Teacher qualifications						
% Math certification		.19 (.49)		.34 (.50)		.11 (.49)
% Master's or above		−.31 (.41)		−.43 (.41)		−.42 (.41)
% Beginning teachers		−2.24 (.48)***		−2.15 (.48)***		−2.28 (.48)***
% Experienced teachers		−1.54 (.33)***		−1.17 (.32)***		−1.26 (.32)***
% Mathematics major		1.18 (.49)*		.57 (.50)		1.14 (.50)*
% Mathematics education major		1.07 (.43)*		1.27 (.43)**		1.24 (.43)**
School background						
% FRL		−.02 (.01)***		−.02 (.01)***		−.02 (.01)***
% Ethnic minority		.01 (.01)		−.00 (.01)		.00 (.01)
School size		.00 (.00)*		.00 (.00)		.00 (.00)
Urban school		−2.10 (.33)***		−1.69 (.34)***		−2.12 (.33)***
Rural school		−.49 (.20)*		−.72 (.20)***		−.59 (.20)**
Variance component						
Level 1: Temporal variation	260.42 (19.0%)	258.29 (20.5%)	260.42 (19.0%)	258.34 (20.6%)	260.42 (19.0%)	258.57 (20.6%)
Level 2: Intercept	1044.29 (76.0%)	955.50 (76.0%)	1044.29 (76.0%)	955.46 (76.1%)	1044.29 (76.0%)	955.37 (76.1%)
Level 3: School mean intercept	69.39 (5.0%)	43.55 (3.5%)	69.39 (5.0%)	42.56 (3.4%)	69.39 (5.0%)	42.16 (3.4%)
% Variance explained						
Level 1: Temporal variation		.82		.80		.71
Level 2: Intercept		8.50		8.51		8.52
Level 3: School mean intercept		37.24		38.67		39.25

*$p < .05$. **$p < .01$. ***$p < .001$.

analyzing students' work are also more likely to engage in various types of formal and informal learning activities.

Although a majority of the correlation coefficients (i.e., 31 of 45, or 68.9%) were statistically significant, they were generally small in size, ranging from .01 between informal communication and professional conferences in 2011, to .31 between informal communication and teacher collaboration in 2011. Therefore, the amounts of teachers' participation in formal and information professional learning activities were only weakly associated with one another. In summary, these correlations show that middle school mathematics teachers who actively participate in professional learning activities engage in both formal and informal activities, and those who spend more time in teacher collaboration tend to also informally communicate with their colleagues about mathematics teaching and learning more frequently than others.

Professional learning activities and student achievement growth from 2008 to 2011

Table 2 presents the results of three-level HLM analyses on the relationships between school average amount of teachers' participation in six types of professional learning activities (number of hours) and student achievement growth from 2008 to 2011, controlling for six teacher qualification variables and five school background variables. For each dependent variable, both unconditional and fully conditional models are presented with variance components and percentages of variance explained at three levels. The variance component for time (level 1), students (level 2), and schools (level 3) are presented for fully unconditional models without any independent variables and conditional models after entering all the independent variables.

Based on statistical significance, we can see modest yet positive associations between student achievement growth rates in MAP scores and school average amounts of participation in teacher collaboration, professional conferences, and informal communications with colleagues. Controlling for individual student poverty level, ethnic minority status, and gender, and teacher qualification and school background characteristics, one hour increase in school average amount of teacher participation in teacher collaboration results in a .01-point increase in the annual growth rate in student mathematics achievement from 2008 to 2011. One hour increase in school average amount of teacher participation in professional conference and informal communication results in a .15-point increase and a .23-point increase in the annual growth rate in students' mathematics scores. School average amounts of teacher participation in professional development, university courses, and individual learning activities, however, were not significantly associated with student achievement growth.

Four teacher qualification variables were significantly associated with student achievement growth rates: percentages of beginning teachers with teaching experience of less than five years, experienced teachers with at least 16 years of teaching experience, teachers who majored in mathematics, and teachers who majored in mathematics education. Students in the schools with a higher percentage of midcareer teachers (i.e., 5–15 years of teaching experience) with mathematics or mathematics education major improved their achievement more than the other students in the schools with a higher percentage of beginning or experienced teachers without a major in mathematics or mathematics education.

Both poverty level and school location were also significantly associated with student achievement growth rate after controlling for individual student's poverty level, ethnic minority status, and gender. High-poverty schools as measured by the percentage of students receiving FRL had a smaller student achievement growth rate than low-poverty schools. The student achievement growth rates of both urban schools and rural schools were smaller than that of suburban schools.

Discussion

This study used longitudinal statewide survey data to examine the effects of both formal and informal learning activities of mathematics teachers on student achievement growth over four years. No previous studies have examined the long-term effects of multiple types of teacher professional learning activities on student achievement growth. This study identified value-added effects of teacher participation in six types of professional learning activities on student achievement growth over four years, controlling for teacher and school background characteristics.

The findings have important policy implications for school and district administrators who are striving to improve student achievement through investment in teacher professional development. The data showed that teacher-centered collaborative learning activities on mathematics teaching and learning (teacher collaboration and informal communication) seem to be more effective in improving student achievement than learning activities that do not necessarily involve such communications (professional development programs, university courses, individual learning activities). These positive effects of informal communications and teacher collaboration are consistent with prior empirical findings on teacher collaboration and professional learning community (e.g., Goddard et al., 2007; Vescio et al., 2008). These collaborative learning opportunities focused on mathematics teaching and learning allow teachers to have honest and focused talk about their beliefs and teaching approaches, promoting collective teacher reflection and construction of new knowledge that lead to changes in teaching practice and student learning (Horn & Little, 2010; Lieberman & Miller, 2011; Little & Horn, 2007).

Our data further showed that the effect of the amount of informal communications among colleagues on student achievement growth was larger than the effect of formal teacher collaboration activities. When a teacher informally communicates with his or her colleagues about mathematics teaching and learning, the intent is often to share specific teaching or learning issues the teacher is facing and to seek information or input from colleagues on these issues. The communications are specific to his or her daily classroom teaching and student learning, and this type of communications may not be always possible in formal collaboration activities with meeting agendas. This indicates the importance of organizing formal collaborative activities around the problems of practice experienced by teachers (Horn & Little, 2010; Little & Horn, 2007).

The focus on the teacher-driven research activities around mathematics teaching or student mathematics learning through professional conference presentation and participation also seems to be beneficial for improving student achievement. Mathematics teachers' participation in professional conferences may be beneficial for two reasons. First, conferences have multiple presentations in which teachers can choose based on their learning needs and interests. Such flexibility and autonomy in choosing the topics for their professional learning may lead to instructional improvement by trying out new ideas and approaches they learned through conferences, which could in turn lead to student achievement growth. Second, the focus on teacher research in these conferences may contribute to enhancement of teacher knowledge of mathematical content knowledge and pedagogical knowledge. This effect may be even greater if the teacher is presenting his or her own practice-based research findings at a conference and receiving feedback on their teaching experience and knowledge from the other teachers. Such opportunities promote knowledge sharing and reflection on own beliefs and perspectives on teaching and student learning.

Based on these findings, the districts and schools are likely to improve student achievement when they focus on promoting teacher-centered collaborative and research-based learning activities. The data were derived from middle school mathematics teachers and thus directly applicable to mathematics-focused professional learning activities at middle grade level. However, the importance of promoting teacher-centered collaborative and research-based learning activities likely applies to all teachers in various subject areas and grade levels. Teacher collaborations and communications that involve in-depth teacher discussions of teaching approaches and student understanding based on actual classroom situations, and learning from practice-based research findings through conference participation and receiving feedback on their research-based presentations seem to be beneficial in improving teacher knowledge and instruction, which in turn leads to improved student achievement. These findings also suggest that professional development programs and university courses may become more effective in promoting improvement of instruction and student learning if they integrate the principles of teacher-centered collaborative and research-based learning activities.

A significant amount of funds and resources have been devoted to teacher professional development over the past decade with major initiatives promoted under the No Child Left Behind Act of 2001 and the Race to the Top program. State departments of education and school districts often contract with outside professional development providers to offer a short-term program to a large number of teachers. This type of one-size-fits-all programs do not allow teachers to engage in in-depth communications and discussions about teaching approaches and student learning in specific contexts where teachers work within, and collaboratively develop lessons that make a difference in student learning. The funds and resources will be better used for facilitating teacher-centered collaborative and research-based learning activities led by teacher leaders with strong content and pedagogical content knowledge. Through a collaborative and research-based learning process promoting in-depth discussions and reflections on specific teaching approaches and student learning, it is likely that these investments in promoting teachers' professional learning activities will result in improved student learning.

Notes

1. We chose mathematics teachers in these Grades 6–8 middle schools, not in other middle-grade schools with different grade configuration (e.g., Grades 5–6, 6–7, 7–8, or 5–8) for the purpose of isolating the effect of student mobility from one school to another on student achievement. This focus on teachers in Grades 6–8 middle schools allowed us to control for school transition effects.
2. The teacher IDs that can be linkable to individual students were not available to the researchers at the time of this study. Therefore, we decided to examine the collective school effects measured by the average amounts of professional learning activities among all the mathematics teachers who participated in the survey on student achievement growth in mathematics.

Acknowledgments

This material is based on work supported by the National Science Foundation under Grant No. 0746936. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

References

Akiba, M. (2012). Professional learning activities in context: A statewide survey of middle school mathematics teachers. *Education Policy Analysis Archives, 20*(14). Retrieved from http://epaa.asu.edu/ojs/article/download/838/1407

Akiba, M., LeTendre, G. K., & Scribner, J. P. (2007). Teacher quality, opportunity gap, and achievement gap in 47 countries. *Educational Researcher, 36,* 369–387.

Balfanz, R., Mac Iver, D. J., & Byrnes, V. (2006). The implementation and impact of evidence-based mathematics reforms in high-poverty middle schools: A multi-site, multi-year study. *Journal for Research in Mathematics Education, 37,* 33–64.

Bausmith, J. M., & Barry, C. (2011). Revisiting professional learning communities to increase college readiness: The importance of pedagogical content knowledge. *Educational Researcher, 40,* 175–178.

Bell, C. A., Wilson, S. M., Higgins, T., & McCoach, D. B. (2010). Measuring the effects of professional development on teacher knowledge: The case of developing mathematical ideas. *Journal for Research in Mathematics Education, 41,* 479–512.

Berry, B., Johnson, D., & Montgomery, D. (2005). The power of teacher leadership. *Educational Leadership, 62*(5), 56–60.

Blank, R. K., de las Alas, N., & Smith, C. (2008). *Does teacher professional development have effects on teaching and learning? Analysis of evaluation findings from programs for mathematics and science teachers in 14 states*. Washington, DC: Council of Chief State School Officers.

Bolam, R., McMahon, A., Stoll, L., Thomas, S., & Wallace, M. (2005). *Creating and sustaining professional learning communities*. Research Report Number 637. London, England: General Teaching Council for England, Department for Education and Skills.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15.

Boston, M. D., & Smith, M. S. (2009). Transforming secondary mathematics teaching: Increasing the cognitive demands of instructional tasks used in teachers' classrooms. *Journal for Research in Mathematics Education, 40,* 119–156.

Boyd, D. J., Grossman, P. L., Lankford, H., Loeb, S., & Wyckoff, J. (2009). Teacher preparation and student achievement. *Educational Evaluation and Policy Analysis, 31,* 416–440.

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,* 499–531.

Clements, D. H., Sarama, J., Spitler, M. E., Lange, A. A., & Wolfe, C. B. (2011). Mathematics learned by young children in an intervention based on learning trajectories: A large-scale cluster randomized trial. *Journal for Research in Mathematics Education, 42,* 127–166.

Darling-Hammond, L., & Youngs, P. (2002). Defining "highly qualified teachers": What does "scientifically-based research" actually tell us? *Educational Researcher, 31*(9), 13–25.

Fennema, E., Carpenter, T. S., Franke, M. L., Levi, L., Jacobs, V., & Empson, S. B. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education, 27,* 403–434.

Garet, M., Wayne, A., Stancavage, F., Taylor, J., Eaton, M., Walters, K., & Doolittle, F. (2011). *Middle school mathematics professional development impact study: Findings after the second year of implementation*. Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education.

Goddard, Y. L., Goddard, R. D., & Tschannen-Moran, M. (2007). A theoretical and empirical investigation of teacher collaboration for school improvement and student achievement in public elementary schools. *Teachers College Record, 109,* 877–896.

Harris, D. N., & Sass, T. (2007). *Teacher training, teacher quality and student achievement: CALDER Working Paper 3*. Washington, DC: The Urban Institute.

Heck, D. J., Banilower, E. R., Weiss, I. R., & Rosenberg, S. L. (2008). Studying the effects of professional development: The case of the NSF's local systemic change through teacher enhancement initiative. *Journal for Research in Mathematics Education, 39,* 113–152.

Hill, H. C., & Ball, D. L. (2004). Learning mathematics for teaching: Results from California's mathematics professional development institutes. *Journal for Research in Mathematics Education, 35,* 330–351.

Hollins, E., McIntyre, L., DeBose, C., Hollins, K., & Towner, A. (2004). Promoting a self-sustaining learning community: Investigating an internal model for teacher development. *International Journal of Qualitative Studies in Education, 17,* 247–264.

Horn, I. S., & Little, J. W. (2010). Attending to problems of practice: Routines and resources for professional learning in teachers' workplace interactions. *American Educational Research Journal, 47,* 181–217.

Jacobs, V. R., Franke, M. L., Carpenter, T. P., Levi, L., & Battey, D. (2007). Professional development focused on children's algebraic reasoning in elementary school. *Journal for Research in Mathematics Education, 38,* 258–288.

Lieberman, A., & Miller, L. (2008). *Teachers in professional communities: Improving teaching and learning*. New York, NY: Teachers College Press.

Lieberman, A., & Miller, L. (2011). Learning communities: The starting point for professional learning is in schools and classrooms. *Journal of Staff Development, 32*(4), 16–20.

Little, J. W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis, 15,* 129–151.

Little, J. W., & Horn, I. S. (2007). "Normalizing" problems of practice: Converting routine conversation into a resource for learning in professional communities. In L. Stoll & K. S. Louis (Eds.), *Professional learning communities: Divergence, depth, and dilemmas* (pp. 29–42). Maidenhead, England: Open University Press.

Lomos, C., Hofman, R. H., & Bosker, R. J. (2011). The relationship between departments as professional communities and student achievement in secondary schools. *Teaching and Teacher Education, 27,* 722–731.

Louis, K. S., & Marks, H. M. (1998). Does professional development affect the classroom? Teachers' work and student experiences in restructuring schools. *American Journal of Education, 106,* 532–575.

McLaughlin, M. W., & Talbert, J. E. (2006). *Building school-based teacher learning communities: Professional strategies to improve student achievement*. New York and London: Teachers College Press.

Moolenaar, N. M., Sleegers, P. J. C., & Daly, A. J. (2012). Teaming up: Linking collaboration networks, collective efficacy, and student achievement. *Teaching and Teacher Education, 28,* 251–262.

Newman, D., Finney, P. B., Bell, S., Turner, H., Jaciw, A. P., Zacamy, J. L., & Feagans Gould, L. (2012). *Evaluation of the effectiveness of the Alabama Math, Science, and Technology Initiative (AMSTI). Final Report.* NCEE 2012-4008. Washington, DC: National Center for Education Evaluation and Regional Assistance.

No Child Left Behind Act of 2001, Pub. L. No. 107–110, § 115, Stat. 1425 (2002).

Phillips, J. (2003). Powerful learning: Creating learning communities in urban school reform. *Journal of Curriculum and Supervision, 18,* 240–258.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning. *Educational Researcher, 29,* 4–15.

Rice, J. K. (2003). *Teacher quality: Understanding the effectiveness of teacher attributes*. Washington, DC: Economic Policy Institute.

Saunders, W. M., Goldenberg, C. N., & Gallimore, R. (2009). Increasing achievement by focusing grade-level teams on improving classroom learning: A prospective, quasi-experimental student of Title I schools. *American Education Research Journal, 46,* 1006–1033.

Scribner, J. P. (1999). Professional development: Untangling the influence of work context on teacher learning. *Educational Administration Quarterly, 35,* 238–266.

Scribner, J. P. (2003). Teacher learning in context: the special case of rural high school teachers. *Educational Policy Analysis Archives, 11*(12), Retrieved from http://epaa.asu.edu/ojs/article/download/240/366

Sherin, M. G., & van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education, 60,* 20–37.

Sigurdardottir, A. K. (2010). Professional Learning Community in relation to school effectiveness. *Scandinavian Journal of Educational Research, 54,* 395–412.

Smylie, M. A. (1995). Teacher learning in the workplace: Implications for school reform. In T. R. Guskey & M. Huberman (Eds.), *New paradigms and practices in professional development* (pp. 92–113). New York, NY: Teachers College Press.

Strahan, D. (2003). Promoting a collaborative professional culture in three elementary schools that have beaten the odds. *The Elementary School Journal, 104,* 127–146.

Supovitz, J. A. (2002). Developing communities of instructional practice. *Teachers College Record, 104,* 1591–1626.

Supovitz, J. A., & Christman, J. B. (2003). *Developing communities of instructional practice: Lessons for Cincinnati and Philadelphia*. CPRE Policy Briefs. Philadelphia, PA: University of Pennsylvania.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education, 24,* 80–91.

Wayne, A. J., & Youngs, P. (2003). Teacher characteristics and student achievement gains: A review. *Review of Educational Research, 73,* 89–122.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education, 24,* 173–209.

Wilson, S. M., Floden, R., & Ferrini-Mundy, J. (2002). Teacher preparation research: An insider's view from the outside. *Journal of Teacher Education, 53,* 190–204.

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* (Issues & Answers Report, REL 2007–No. 033). Washington, DC: U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southwest.

Appendix: Survey items on professional learning activities

Definition	Survey items	Final coding
Professional development program is an organized activity for the purpose of learning and improving mathematics teaching and student learning (E.g., school- , district- , or Regional Professional Development Center (RPDC)-sponsored workshop).	**Professional development program**	
	1A. During the past 12 months, have you participated in a professional development program related to mathematics teaching or learning?	1 = Yes 0 = No
	1B. How many hours of professional development programs on mathematics teaching or learning in total have you participated in during the past 12 months? Please include hours spent for a take-home task or a project required by the professional development programs. *Choose one response.*	0 = None (No in 1A) 1.5 = 1-2 hr 4 = 3-5 hr 8 = 6-10 hr 15 = 11-20 hr 30 = 21-40 hr 50 = 41-60 hr 70 = 61-80 hr 90 = > 80 hr
Teacher collaboration is an ongoing activity such as a study group, Professional Learning Community, teacher network, group action research, and any other form of interaction among teachers for the purpose of improving mathematics teaching and learning. Mentoring or coaching is <u>not</u> teacher collaboration. Teacher collaboration can be formally organized by professional developers <u>or</u> informally practiced by a group of teachers.	**Teacher collaboration**	
	2A. Have you participated in an ongoing teacher collaboration on mathematics teaching and learning during the past 12 months?	1 = Yes 0 = No
	2B. How many hours in total did you spend in teacher collaboration(s) during the past 12 months? *Choose one response.*	0 = None (No in 2A) 5 = 1-10 hr 15 = 11-20 hr 30 = 21-40 hr 50 = 41-60 hr 70 = 61-80 hr 90 = 81-100 hr110 = 101-120 hr 130 = >120 hr
University/college courses may be taken for a degree or professional development credits.	**University/college courses**	
	3A. Have you taken university or college courses in mathematics or mathematics education for credit during the previous 12 months?	1 = Yes 0 = No
	3B. How many actual hours (not credit hours) have you spent attending university courses on the following topics during the past 12 months? *Choose one response for each item*. a. Mathematics contents b. Mathematics instruction/pedagogy c. Foundations (e.g., diversity, social contexts of schools) d. Research on mathematics education e. Other	<u>Sum of 5 items</u> 0 = None (or No in 3A) 3 = 1-5 hr 8 = 6-10 hr 15 = 11-20 hr 30 = 21-40 hr 50 = > 40 hr
Professional conference is an opportunity to present your practice or research, and learn from presentations about new ideas for mathematics teaching or learning.	**Professional conference**	
	4A. Have you attended a local, regional, state, or national conference(s) on mathematics teaching or learning during the previous 12 months?	1 = Yes 0 = No
	4B. How many hours have you spent for each of the following activities at a conference(s) on mathematics teaching or learning during the past 12 months? *Choose one response for each item.* a. Conference audience member b. Conference presenter	<u>Sum of 2 items</u> 0 = None (or No in 4A) 1.5 = 1-2 hr 4 = 3-5 hr 8 = 6-10 hr 15 = 11-20 hr 30 = 21-40 hr 50 = > 40 hr
Informal communication refers to planned or unplanned interactions with colleagues or friends outside of the above-listed activities.	**Informal communication**	
	5A. Do you have someone other than a formal mentor or coach whom you informally rely on and communicate with for your professional learning of mathematics teaching?	1 = Yes 0 = No
	The following questions are about this person. If you have multiple persons on whom you communicate with for your professional learning of mathematics teaching, please choose the person who most influenced your mathematics teaching.	

(*Continued*)

Definition	Survey items	Final coding
	5B. How many hours do you spend communicating with this person during a typical month? Please include both the face-to-face time and the communication through phone or email. *Choose one response.*	0 = No in 5A 0.5 = Less than 1 2 = 1-3 4.5 = 4-5 8 = 6-10 12 = More than 10
Individual learning activities refer to activities you engage in by yourself outside of the above-listed activities such as reading professional journals and analyzing student work.	**Individual learning activities** 6A. How many hours during a typical month do you usually spend on your own for … *Choose one response for each item.* a. Studying and analyzing student work (e.g., homework, worksheet, student responses to your questions in class) b. Reading teachers' manual for adopted textbook c. Studying and developing student assessment tools and materials d. Searching web-based resources for curriculum and instruction e. Reading professional journals or books on mathematics teaching and learning (e.g., *Mathematics Teaching in the Middle School, Mathematics Teacher*) f. Other (please specify)	Sum of 6 items 0 = Never 1.5 = 1-2 hr 4 = 3-5 hr 8 = 6-10 hr 15 = 11-20 hr 25 = 21-30 hr 35 = >30 hr