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Impact of Online Professional Development on Teacher Quality and Student Achievement in Fifth Grade Mathematics

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Abstract

Despite the ever-increasing number of online professional development (OPD) programs, relatively few studies have been conducted to examine the efficacy of such programs for teachers and students. This manuscript presents findings from an impact study of OPD courses in fractions, algebraic thinking, and measurement on 79 fifth grade teachers' pedagogical content knowledge and pedagogical practices as well as their students' mathematics achievement. The OPD courses were offered one course per semester for three semesters, and each course comprised 1 week of orientation and 6 weeks of course content. Overall, teachers participated in more than approximately 70 hours of OPD. The research findings showed that teachers who had been randomly assigned to the experimental group had significantly greater gains in scores for pedagogical content knowledge and pedagogical practices than teachers in the control group. Nevertheless, the positive changes in teacher outcomes did not translate to any meaningful differences in students' mathematics achievement. (Keywords: teacher quality, online professional development, elementary education, mathematics achievement)

> The single thing that determines how well a child does in math is … an outstanding math teacher.
>
> —*President Barack Obama (Burt-Murray, Robertson, & Gordy, 2010)*

It has been well established in the research literature that highly qualified and highly effective teachers are key to students' academic success (Darling-Hammond & Berry, 2006; Geringer, 2003; Lasley, Siedentop, & Yinger, 2006). In a review of John Hattie's seminal work, Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement, Terhart

(2011) critically analyzed Hattie's (2009) claim that the "teacher" factor was the most significant school predictor of students' academic achievement, particularly in the area of mathematics. Despite criticism of some of Hattie's methods, Terhart (2011) determined that teachers do matter, as only certain teachers with certain practices are highly effective. Indeed teacher quality has been cited as the single most important school factor that explains student achievement (Hanushek, 2007; Haskins & Loeb, 2007; Haycock, 2003; Gordon, Kane, & Staiger, 2006). Still, more than two decades after the publication A Nation at Risk (U.S. Department of Education, 1983), challenges regarding teacher quality continue to be both poignant and relevant (Peterson, 2003; U.S. Department of Education, 2008). Specifically, the National Commission on Excellence in Education highlighted severe shortages of teachers in the areas of mathematics and science in the 1983 publication A Nation at Risk. Moreover, the report indicated that half of the newly employed mathematics teachers were not actually qualified to teach the subject. Some argue that little has changed in the years following the report and education outcomes have shown little improvement since 1970 (Peterson, 2003). Furthermore, there is little evidence to indicate that the highly qualified teacher provisions of the No Child Left Behind (NCLB) Act have led to significant increases in teacher efficacy or to increases in teachers' knowledge in subject areas such as mathematics (U.S. Department of Education, 2008).

Professional development for teachers has been deemed the necessary approach to improving teacher quality, meaning teachers' pedagogical content knowledge and pedagogical practices. Essentially, professional development has been adopted as a policy solution to improving the number of highly qualified teachers as well as helping all students to achieve high academic standards (Colbert, Brown, Choi, & Thomas, 2008). Guided by the mandate that all students should be taught by highly qualified teachers, the NCLB Act stipulates that any local educational agency that receives Title I, Part A, funds must provide their teachers with high-quality professional development (Public Law 107-110-JAN.8, 2002). Support for this policy is based on the premise that teacher knowledge and classroom practices mediate the effects of professional development on student achievement, provided the professional development is conducted within the context of high standards, challenging curricula, systemwide accountability, and high-stakes assessments (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007).

The Wenglinsky (2000) report, *How Teaching Matters: Bringing the Classroom Back into Discussions of Teacher Quality*, documents the positive effects of teacher professional development. Specifically, Wenglinsky (2000) provided evidence that students whose teachers had received professional development in working with special populations outperformed their peers on mathematics assessments by more than a full grade level. Moreover, students whose teachers had received professional development in higher-order thinking skills outperformed their peers on mathematics assessments by 40% of a grade level (Wenglinsky, 2000). Further evidence in the research literature indicates that teachers who receive substantial professional development (an average of 49 hours) can boost their students' academic achievement by approximately 21 percentile points (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). According to Yoon et al. (2007), professional development is most effective if it is characterized by coherence, active learning, sufficient duration, collective participation, a focus on content knowledge, and a reform rather than traditional approach.

Despite these guidelines, the U.S. Department of Education (2007) publication "State and Local Implementation of the No Child Left Behind Act Volume II— Teacher Quality Under NCLB: Interim Report" indicates that few teachers receive content-focused professional development for a sufficient duration. Specifically, although almost all elementary teachers reported participating in content-focused professional development related to teaching mathematics, only 8% of those teachers had received more than 24 hours of professional development on instructional strategies in mathematics (U.S. Department of Education, 2007). The unavailability of professional development opportunities that directly address teachers' individual needs and the rigid schedule associated with traditional professional development programs are some of the obstacles that many teachers face (Kleiman, 2004). Traditional professional development is often offered at times and locations that are not feasible for many teachers, and the reality of having to meet the demands of both work and family life require professional development that can be delivered anytime, anywhere (Vrasidas & Zembylas, 2004).

Online professional development has been championed as the "anytime, anywhere" option that provides flexibility by allowing participants, irrespective of location, to manage educational pursuits with work and personal responsibilities (Davis, 2009; Stanford-Bowers, 2008). Born out of a need for professional development that fits with the busy schedules of teachers, online professional development provides access as well as ongoing support to important resources that might not otherwise be affordable or even available locally (Dede, Breit, Ketelhut, McCloskey, & Whitehouse, 2005). The advent of online courses makes it feasible to connect teachers across schools, districts, and even states, thereby fostering professional learning communities and broadening the professional learning opportunities available to teachers (Russell, Carey, Kleiman, & Venable, 2009). Additionally, online professional development can be offered in various forms: Distance learning classrooms enable individuals to participate in a class via video conferencing with the goal of making the online experience as close as possible to an in-class experience; an online course can be conducted completely through asynchronous interactions, negating the need for all the participants of a course to be available at the same time and allowing participants to complete course requirements according to their individual schedule; and self-paced online courses allow each participant to work through a series of resources and activities at his or her own pace (Russell et al., 2009). Ultimately, online professional development provides the potential means of meeting the ambitious goals of NCLB regarding teacher quality, whereby large numbers of teachers can be provided with high-quality training in mathematical content and pedagogy (Ginsburg, Gray, & Levin, 2004).

The advantages associated with online professional development have been linked with a dramatic increase in such programs nationally (Carey, Kleiman, Russell, Venable, & Louie, 2008). However, this increase in the number of online professional development programs has been coupled with increased concerns regarding the efficacy of online professional development as a strategy to improve educational outcomes (Carey et al., 2008). In a review of 40 online professional development sites for teachers of mathematics, Ginsburg, Gray, and Levin (2004) found no independent evidence of program effectiveness. Moreover, the ultimate worth of any teacher professional development initiative is often gauged by whether there is evidence of an impact on teacher practices and student learning (Lawless & Pellegrino, 2007). Previous research studies have documented evidence regarding various designs and methods of delivering online professional development. However, there is currently a void in the research literature regarding the effects of online professional development on teacher quality and student achievement (Ginsburg, Gray, & Levin, 2004; Lawless & Pellegrino, 2007; Whitehouse, Breit, McCloskey, Ketelhut, & Dede, 2006).

Research Purpose

The purpose of this study was to investigate the effects of online professional development in mathematics on fifth grade teachers' pedagogical content knowledge and pedagogical practices as well as their students' mathematics achievement.

We conducted this study as part of a larger research study associated with a specific online professional development program. The online professional development program is a federally funded 10-state collaborative that was founded on the premise that many teachers do not have ready access to high-quality professional development. Thus, the program seeks to create an effective and sustainable model of online professional development for teachers in each of the 10 participating states by removing schedule and location barriers and offering teachers the opportunity to pursue professional development courses online. The ultimate program goal is to improve teachers' pedagogical content knowledge and instructional practices as well as students' academic achievement. As an important part of the initiative, **we** conducted four concurrent experimental studies in fourth grade English language arts (ELA), fifth grade mathematics, seventh grade ELA, and eighth grade mathematics (O'Dwyer, Masters, Dash, Magidin De Kramer, Humez, & Russell, 2010). The focus of this paper is the fifth grade mathematics randomized controlled trial.

Structure of the Fifth Grade Mathematics Online Professional Development Program

The online professional development courses described in this study were three elementary mathematics courses developed by the Education Development Center Inc. (EDC) for use with teachers of grades 3–5. The fifth grade mathematics online professional development program comprised three courses: Using Models to Understand Fractions, Algebraic Thinking in Elementary School, and The Complexities of Measurement. One course was offered each semester for three semesters, and each course comprised 1 week of orientation and 6 weeks of course content. We estimate that each course required 4–6 hours of work per week from each teacher. Therefore, teachers participated in more than approximately 70 hours of online professional development related to teaching specific topics within mathematics.

The online professional development courses were asynchronous, in that, unlike a virtual classroom, course participants were not required to be available at the same time. This asynchronous learning allowed teachers to complete course requirements according to their individual schedules. The courses were also facilitated by individuals who were first trained in online course facilitation by EDC/EdTech Leaders Online (ETLO). ETLO is a capacity-building program administered by EDC that enables state departments of education, school districts, teacher training institutions, and other educational organizations to provide effective online learning programs for teachers. The EDC/ETLO-trained online course facilitators were responsible for monitoring teachers' completion of course activities and issuing certificates of completion to teachers who completed all of the course requirements. Moreover, the courses used a learning community model that included readings, web-based resources, interactive on and offline activities, video, and peer-to-peer discussions. Each course culminated with a project that teachers were required to implement in their classroom. The theoretical underpinning of each course was that teachers would be provided with tools, strategies, and opportunities to explore engaging mathematical activities that could be integrated into their classroom instruction. Furthermore, as teachers improved their knowledge and skills in teaching mathematics, they would be better able to help students improve their own understanding of mathematical concepts.

Interventions

The Fractions Intervention

The fractions course began with an exploration of different ways to think about fractions problems and a review of how fractions are taught in elementary school (see Figure 1 on p. 6). In the second and third sessions, participants departed from using traditional algorithms and investigated how linear measurement models can be used to promote a deeper understanding

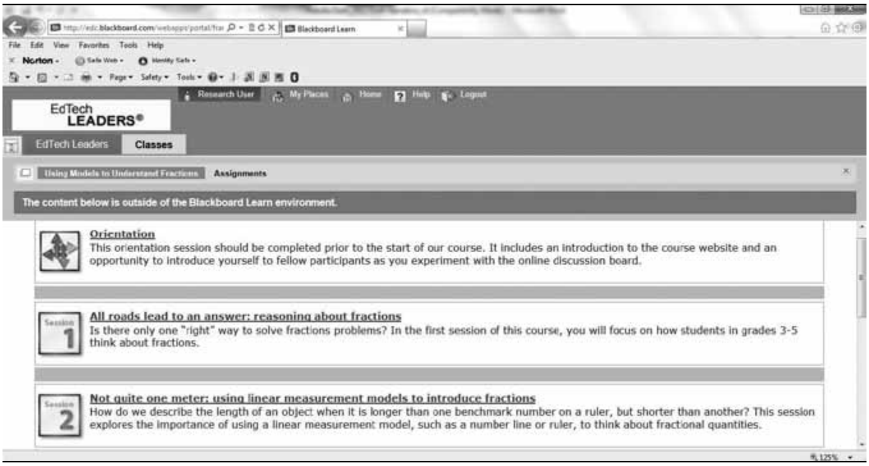

Figure 1. Screen shot of the Assignments page of the Fractions course.

of fractional relationships. During sessions 4 and 5, participants examined area models, specifically pattern blocks. Throughout the course, participants were given opportunities to apply linear and area models to actual fractions problems, use virtual manipulatives, look at student work (to shed light on how young students think about fractions), and discuss their experiences and ideas with their colleagues. By the sixth and final session, participants completed a final project and a student interview. **Examples of a**ctivities in the Fractions course are described below:

> Fractions problems such as the four listed below are often given to students in grades 3–5. In a moment you will be analyzing samples of student work for these problems, so take a few moments to solve each problem first. Think about the following questions as you work through them:
>
> 1. Are you using algorithms (e.g., mathematical procedures for solving the problem) or mental math strategies (e.g., using estimation, rounding, or identifying numerical relationships) to solve these problems?
> 2. Can you solve these problems in more than one way?
> 3. Reflect on the issues depicted in the reading by Carne Barnett. Do these problems extend students' understanding of fractions, or do they illustrate their ability to calculate an answer using an algorithm?

The Algebraic Thinking Intervention

The Algebraic Thinking course began with an exploration of what algebraic reasoning means and exploring activities such as identifying patterns, analyzing change, representing situations, and using mathematics models to understand relationships as algebraic (see Figure 2). During the second session, participants examined types of problems that encourage algebraic thinking and how generalization can help solve some algebraic problems. The third

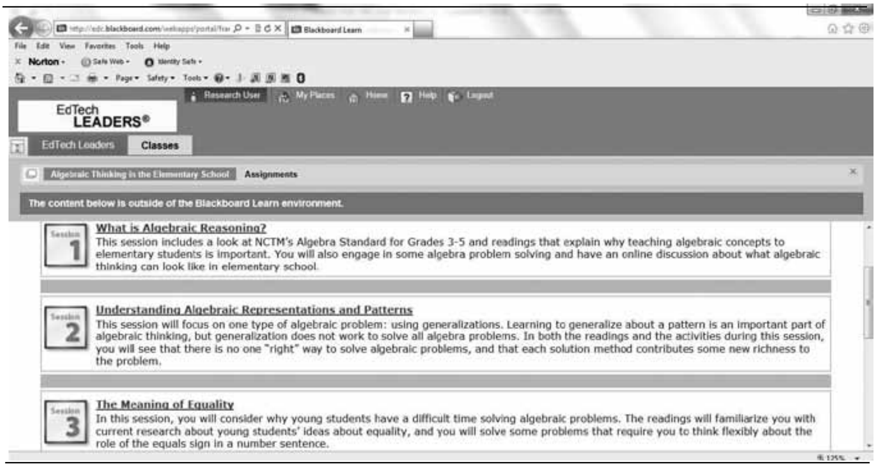

Figure 2. Screen shot of the Assignments page of the Algebraic Thinking course.

session introduced participants to students' misconceptions about the = sign, and participants were taught instructional strategies to help students better understand what the symbol means. Sessions 4 and 5 were designed to show participants that algebraic thinking does not always involve finding a missing quantity and to teach participants how to promote algebraic thinking. By the end of the sixth session, participants explored additional strategies to incorporate algebra into their instruction and completed a final project. Examples of activities in the Algebraic Thinking course are described below:

> The activities that follow present you with some different types of equality problems. There are a number of ways to promote algebraic reasoning about the symbol =, and it is worth noting that none of these problems contain the letter x! As you solve these, think about what assumptions you are making about the symbol =. When does the symbol = indicate that computation can take place, and when is it used as a balance between two sides of an equation? Later on in this session, you will have the chance to watch some videos of students solving missing value problems. You will also examine some student work to see some examples of the types of errors that students make.

The Measurement Intervention

The Measurement course began with an overview of the importance of studying measurement in upper elementary school and investigating some common student misconceptions on measurement (see Figure 3 on page 8). The second and third sessions introduced participants to two-dimensional measurement with linear measurement and area. Additionally, participants investigated the importance of iteration and unitization. Session 4 focused on three-dimensional measurement by looking at student understanding of capacity. During Session 5, instructors asked participants to consider measuring nonstandard

Figure 3. Screen shot of the Assignments page of the Measurement course.

objects and how to help students understand the concepts. During the final session, participants had the opportunity to reflect on what they had learned and to integrate it into their classrooms. Examples of activities in the Measurement course are described below:

> In the video below, teacher Barbara Smith reflects on the way that she teaches measurement in her class. She also discusses the ideas that her students had as they worked on the area and measurement activities earlier in this course. As you watch the video, think about the following questions:
>
> 1. What measurement ideas does she stress in her instruction?
> 2. What implications does that have for student learning?
> 3. To what extent does her instruction include two of the central ideas of this course: using consistent measurement units and learning to iterate?

Theory of Change

The fifth grade mathematics online professional development program was grounded on the principles that professional development in fractions, algebraic thinking, and measurement would lead to improvements in teachers' knowledge of how to teach these subject areas to fifth grade students. Furthermore, improvements in teachers' knowledge would lead to improved instructional practices, which in turn would lead to improved mathematics achievement for students. Specifically, the theoretical underpinnings of each course is that teachers will be provided with tools, strategies, and opportunities to explore engaging activities in mathematics that they could integrate into their classroom instruction. Furthermore, as teachers improve their knowledge and skills in teaching mathematics, they would be better able to help students improve their own understanding and achievement. Consistent with the models of effective professional development described in Yoon, Duncan, Lee, Scarloss, and Shapley (2007), this study is based on the theory that: (a) online professional development will increase teachers' pedagogical content knowledge, (b) increased pedagogical content knowledge will lead to improvements in teachers' instructional practices, and (c) improved instructional practices will result in improved academic achievement for students.

The pedagogical content knowledge construct was first introduced by Shulman (1986), who argued that content knowledge and pedagogical knowledge are not separate and distinct domains because pedagogical content knowledge goes beyond mere knowledge of subject matter. Specifically, pedagogical content knowledge pertains to knowledge of subject matter for teaching—that is, knowledge of ways to represent and formulate the subject matter that make it comprehensible to students. Good teachers know both content and how to teach that content to their students (Hill & Ball, 2009). Pedagogical content knowledge includes an understanding of what makes the learning of specific topics easy or difficult, the conceptions and misconceptions that students might have, and the strategies most likely to be effective in reorganizing the understanding of students (Shulman, 1986). Thames and Ball (2010) further posit that conventional content knowledge is insufficient to effectively teach K–8 mathematics. The mathematics knowledge that teachers need for instruction is not the same mathematics taught and learned in college classes (Ball, Thames, & Phelps, 2008). Rather, teachers require specialized knowledge of how to teach mathematics (Thames & Ball, 2010). Teachers require pedagogical content knowledge in mathematics.

Methods

Research Design

This study employed a randomized controlled trial that we implemented in three rounds between January 2007 and June 2009. Fifth grade teachers who taught mathematics to a regular-education fifth grade class (for the duration of the research study) qualified to participate in the study. Teachers volunteered to participate in the research study as they typically would for a professional development workshop. Teachers were recruited by each of the eight original participating states as well as through listservs and other online communities. Overall, the sample of teachers represented 12 states.

For each round of implementation, we randomly assigned fifth grade mathematics teachers to either a control or experimental group. Teachers in the experimental group completed a series of three online professional development mathematics courses, offered one course per semester. It is important to note that though teachers assigned to the control group were not allowed to participate in the online professional development courses, they were not restricted from participating in any other professional development that might otherwise have been available to them.

We collected data from both students and teachers over three periods of data collection. Although teachers' participation lasted for three school semesters, the student participants were drawn from only two school semesters, the fall and spring semesters of the teachers' second year of participation. The first round of the randomized trial started in the spring semester of 2007, which meant that we could not measure student achievement over an entire school year for the teachers' first class of students. Therefore, we collected student data from the teachers' second class of students. Prior to the start of any professional development, all teachers were required to complete a background survey as well as a presurvey regarding their pedagogical content knowledge and practices in mathematics.

The second period of data collection occurred in the fall semester after the teachers in the experimental group had completed the first online professional development course. We administered no teacher instruments during the second data collection period, but teachers were required to administer the student background survey and a student mathematics pretest to their new fifth grade class.

The third data collection period occurred at the end of the academic year, after the teachers in the experimental group had completed the remaining two professional development courses. During this period, all teachers were required to complete a postsurvey that focused on their pedagogical content knowledge and pedagogical practices in mathematics. In addition, teachers administered the student posttest measures.

Sample

Teacher participants. We recruited a total of 235 teachers for this study. However, during the course of the study, 143 teachers resigned from participation (61% of recruited sample). It should be noted that distance teaching and learning environments are particularly vulnerable to high attrition, with dropout rates typically ranging from 30% to 50% (O'Brien & Renner, 2002; Stanford-Bowers, 2008). However, the attrition rate for this study was even higher than the norms indicated in the research literature because participants were required to commit to the study for three semesters. Unfortunately, the vast majority of participants did not provide reasons for their withdrawal from the study. However, some participants did indicate that they were no longer able to participate due to personal challenges such as illness in the family. Nevertheless, we conducted chi-square analyses to determine whether there were significant differences between teachers who dropped out of the study and those who remained. The results indicated that significantly more teachers who dropped out of the study (67%) had no previous training with online professional development, compared with teachers who remained in the study (44%), χ^2 (3) = 13.59, p = .004. The effect size associated with this difference as measured by Cramer's V was .261, which, according to Cohen's (1988) criteria, is a medium effect. There were no other significant differences in demographic information between teachers who remained in the study and those who dropped out.

The sample included 13 pairs of teachers who worked at the same school. In an effort to avoid any confounding school effects, we assigned teachers from the same school to the same research group (experimental or control) and randomly selected one teacher from each of the 13 pairs for inclusion in the data analysis. This procedure resulted in the removal of data from 13 teachers (6% of recruited sample) and negated the possibility of teachers from the experimental and control groups working together. It should also be noted that after random assignment, with the exception of one pair of teachers, we assigned all of the duplicate teachers to the control group. Ultimately, the results of the study were based on a sample of 79 teachers, including 34 experimental group teachers and 45 control group teachers.

The teacher sample was predominantly White (89%) and female (90%). More teachers reported that they were in the age groups 26–35 (33%) and 46–55 (30%) than any other age category. The majority of the teachers had regular state certification (91%). Fifty-eight percent of the teacher participants reported having a master's degree as their highest level of education, and 37% indicated that their highest level was a bachelor's degree. Pertaining to teaching experience, 77% of the teachers reported that they had more than 5 years teaching experience overall, and 71% reported that they had been teaching mathematics for more than 5 years. More than half (53%) of the participants indicated that they had received professional development in mathematics during the year prior to participating in the study. Additionally, 73% of the teachers worked at schools that offer Title I services. The largest percentage of teachers (38%) taught in rural schools, followed by city schools (32%), town schools (10%), and suburban schools (9%).[1] The largest group of participating teachers came from the South (43%), followed by the Northeast (39%), the Midwest (15%), and the West (3%).[2] There were no significant differences in teacher demographics between the experimental and control groups.

Student participants. The initial student sample comprised 1,899 fifth grade students taught by the 79 teachers in the final sample. However, we omitted 461 students who had not responded to at least 50% of each of the student pre and post measures from the sample. The final student sample comprised 1,438 students. The experimental-group teachers taught 648 of the students, and the control-group teachers taught 790 of the students.

The sample of students was equally split by gender. Regarding ethnicity, the majority of students identified themselves as White (65%), 12%

1 Locales defined by the National Center for Education Statistics Common Core of Data (http://nces.ed.gov/ccd)
2 Regions defined by the United States Census (http://www.census.gov/geo/www/us_regdiv.pdf)

identified as Black or African-American, and 13% identified as Asian, American Indian, Native Hawaiian, or other. Five percent of the student sample identified as Latino, and English was not the first language for 6% of the students. Eighty-seven percent of the students reported having a computer in their home. Additionally, 74% of the students reported using the computer generally a couple of times a week, 16% a couple of times a month and 7% a couple of times a year. With regard to computer use at school, 65% of the students reported using the computer a couple of times a week, 25% a couple of times a month, and 6% a couple of times a year. There were no significant differences in student demographics between the experimental and control groups.

Instrumentation

Due to the unavailability of measures with demonstrated validity and reliability that were sensitive to and aligned with the online professional development courses in fractions, algebraic thinking, and measurement, we developed research instruments to measure teachers' pedagogical content knowledge and pedagogical practices as well as students' achievement, and to record demographical data for both students and teachers. It should be noted that measures such as the Mathematical Knowledge for Teaching (MKT) instrument (Learning Mathematics for Teaching, 2008), though in development, were not available at the start of this study.

Measure of Teachers' Pedagogical Content Knowledge

Teachers' pedagogical content knowledge referred specifically to subject matter related to fractions, algebraic thinking, and measurement that formed the curriculum for the series of research courses. We assessed teachers' pedagogical content knowledge using an instrument that was developed to measure the specific content topics covered across the three online professional development courses. We used both multiple-choice and open-response items. We used a scoring rubric to score the open-response items and scored missing items as zero.

The teachers' pedagogical content knowledge measure comprised 31 items. Nine items that assessed knowledge of fractions. These items focused on teachers' knowledge of what fractions are and how they can be operated upon through engagement in mathematics as well as knowledge of specific mathematical models, particularly linear and area models.

Sample items on the fractions subscale included: (a) "Describe both the importance and limitations of fraction algorithms, and when to use/teach them," and (b) "Choose a model for teaching fractions. List one advantage and one disadvantage of teaching fractions with this model."

The algebraic thinking subscale included eight items designed to assess teachers' knowledge of problems that can be used with students to develop their algebraic thinking as well as strategies for solving algebraic problems.

Table 1. Correlation Matrix of Teachers' Pedagogical Content Knowledge Measures

Variables	Pre Fractions Knowledge	Post Fractions Knowledge	Pre Algebraic Knowledge	Post Algebraic Knowledge	Pre Measure Knowledge
Post Fractions Knowledge	.612*				
Pre Algebraic Knowledge	.204	.309**			
Post Algebraic Knowledge	.237***	.467*	.365*		
Pre Measure Knowledge	.316**	.434*	.489*	.295**	
Post Measure Knowledge	.281***	.506*	.196	.503*	.278***

Note: N = 79 . * $p < .001$, ** $p < .01$, *** $p < .05$

Sample items on the algebraic thinking subscale included: (a) "Give one example of a problem that encourages algebraic thinking," and (b) "Give one example of a problem that highlights generalization as a way to solve algebraic problems."

The measure included 14 items assessing teachers' knowledge of measurement. These items focused on teachers' knowledge of tasks that encourage students' understanding of what measurement is and why it is necessary, in addition to knowledge of how elementary students think about linear measurement, area, and capacity. Sample measurement items included: (a) "How would you explain differences between area and capacity to your students?" and (b) "Explain how the use of nonstandard objects can facilitate students' understanding of measurement."

We calculated an overall knowledge score as well as three subscale scores for each teacher participant. We calculated scores using a weighted scale whereby all pedagogical content knowledge items were equally weighted with a maximum possible score of 1. We then calculated mean scores by summing the scores of all items within a scale and dividing by the total number of items for that scale. Higher scores were indicative of higher pedagogical content knowledge. The internal consistency reliability coefficient, as estimated by Cronbach's alpha, for scores on the overall knowledge scale was .72 on the presurvey and .80 on the postsurvey. Cronbach's alpha for scores on the subscale measures was significantly lower on the pre- and postsurveys respectively: fractions .54 and .48; algebraic thinking .55 and .60; and measurement .55 and .67. We performed Pearson's product-moment correlation analyses to determine the relationships among the pedagogical content knowledge subscales. The correlation analyses confirmed statistically significant and positive relationships among the postsurvey pedagogical content knowledge subscales that ranged from .47 to .51. The presurvey subscales were also positive and statistically significant, with the exception of algebraic thinking and fractions, $r(79) = .20$, $p = .072$. Due to the lower reliability estimates of the individual subscales and the significant intercorrelations, we conducted analyses with the total scale scores. Table 1 presents the correlation matrix for measures of teachers' pedagogical content knowledge.

Measure of Teachers' Pedagogical Practices

Teachers' pedagogical practices in mathematics pertained to specific teaching practices in Fractions, Algebraic Thinking and Measurement that were promoted as best practices in the online professional development courses. A researcher-developed instrument was utilized to assess teachers' pedagogical practices, and the course developers reviewed the instrument to confirm the accuracy of the content. All of the pedagogical practice items were measured on 4-point Likert scales that were anchored at: 1 = at least once a week and 4 = never; 1 = strongly agree and 4 = strongly disagree; or 1 = always and 4 = rarely. The scores were summed and an average taken to yield three separate subscale scores (one for each subject area). Higher scores were indicative of better pedagogical practices. Less than 1% (0.73%) of data for the teachers' pedagogical practices items were missing. A stochastic linear regression model was employed to impute this missing data for teacher practices.

The pedagogical practices measure was composed of 38 items that assessed teachers' self-reported pedagogical practices. Four items focused on Fractions, and sample items included "When teaching fractions to students, how often do you use area models?" and "When teaching fractions to students, how often do you use real world examples or situations of fractions?" Eight items measured pedagogical practices in Algebraic Thinking, and sample items included "How often do you apply ideas from the NCTM Algebra strand in your classroom practice?" and "How often do you use student interviewing techniques to explore student thinking?" Twenty-six items assessed teachers' pedagogical practices in Measurement, and sample items included "When teaching measurement, how often do you teach your students how to measure the area of non-standard shapes?" and "When teaching measurement, how often do you teach your students how to use different tools and methods to measure capacity?"

Cronbach's alpha for scores on the overall pedagogical practices scale was .87 on the pre-survey and .90 on the post-survey. The reliability coefficient for scores on the Measurement Practices subscale was .82 for the presurvey and .88 for the postsurvey. Additionally, the Algebraic Thinking Practices subscale was .82 for both the pre- and postsurveys, but Cronbach's alpha was lower for scores on the Fractions Practices subscale: .61on the presurvey and .60 on the postsurvey. We also conducted Pearson's product-moment correlation analyses to investigate the intercorrelations among the pedagogical practices subscales. Pearson's r was statistically significant and positive among the postsurvey pedagogical practices subscales and ranged from .28 to .55. The correlation analyses also confirmed statistically significant and positive relationships among the presurvey subscales, with the exception of Algebraic Thinking and Fractions, $r(79) = .16$, $p = .150$. Due to the significant relationships and lower estimates of Cronbach's alpha among the individual subscales, analyses were conducted with the total scale scores. Table 2 presents the correlation matrix for measures of teachers' pedagogical practices.

Table 2. Correlation Matrix of Teachers' Pedagogical Practices Measures

Variables	Pre Fractions Practices	Post Fractions Practices	Pre Algebraic Practices	Post Algebraic Practices	Pre Measure Practices
Post Fractions Practices	.438*				
Pre Algebraic Practices	.163	.150			
Post Algebraic Practices	.013	.276***	.328**		
Pre Measure Practices	.461*	.158	.542*	.245***	
Post Measure Practices	.288**	.421*	.304**	.550*	.564*

Note: N = 79 . * $p < .001$, ** $p < .01$, *** $p < .05$

Measure of Students' Mathematics Achievement

To measure students' achievement in fractions, algebraic thinking, and measurement, we developed tests that focused on these three subcontent areas specifically for this study. We constructed parallel pre and post measures with the use of released test items from national and state standardized tests, as well as with test items that we created and piloted for this study. The selected test items targeted the specific student outcomes that were outlined in the research courses. We anticipated that teachers who completed the Fractions course would be better able to prepare students to: (a) understand the process of computations rather than simply use algorithms, (b) use models to solve problems related to fractions, (c) find fractions of nonstandard shapes, and (d) solve traditional fractions problems.

After completing the Algebraic Thinking course, teachers were expected to be better prepared to teach students to: (a) use representations such as graphs to draw conclusions, (b) solve missing value problems, (c) use generalization strategies such as finding a mathematical rule, (d) solve "unknown quantity" problems without solving for a variable, and (e) identify the equal sign as a balance point in an equation.

The Measurement course was designed to prepare teachers to help students to: (a) understand the concepts of length and width; (b) differentiate area from capacity; (c) and use both standard and nonstandard units to determine length, area, and capacity.

In an effort to minimize familiarity effects, we designed the pre- and posttests as parallel forms that comprised isomorphic items. Specifically, both instruments included the same balance of content areas and specific outcomes (skills) within those content areas. The parallel pre- and posttests each comprised 29 items. Specifically, each test included 8 fractions items, 10 algebraic thinking items, and 11 measurement items. Each item had a maximum possible score of 1. The scores summed across items and averages calculated to determine an overall knowledge score as well as a subscale score for each of the three content areas. Higher scores were indicative of higher pedagogical content knowledge.

Regarding the overall mathematics achievement scale, Cronbach's alpha was .73 on the pretest and .85 on the posttest. The reliability estimates,

Table 3. Correlation Matrix of Students' Mathematics Knowledge Measures

Variables	Pre Fractions Practices	Post Fractions Practices	Pre Algebraic Practices	Post Algebraic Practices	Pre Measure Practices
Post Fractions Practices	.359*				
Pre Algebraic Practices	.415*	.434*			
Post Algebraic Practices	.403*	.575*	.538*		
Pre Measure Practices	.403*	.427*	.502*	.532*	
Post Measure Practices	.386*	.538*	.465*	.635*	.553*

Note. $N = 1438$. * $p < .001$

however, were lower for the subscales. Specifically, Cronbach's alpha for scores on the fractions subscale was .49 on the pretest and .68 on the posttest. The algebraic thinking subscale yielded a Cronbach's alpha of .60 on the pretest and .73 on the posttest. Cronbach's alpha for scores on the measurement subscale was .48 on the pretest and .59 on the posttest. Pearson's product-moment correlation analyses confirmed statistically significant relationships among the pretest subscales that ranged from .40 to .50. Regarding the posttest subscales, the correlations were also statistically significant and positive and ranged from .54 to .64. Due to the positive relationships and lower reliability estimates of the individual subscales, we conducted analyses with the total scale scores. Table 3 presents the correlation matrix for measures of students' mathematics achievement.

Research Procedures

We administered all of the research instruments online. Specifically, we designed a webpage for the research study that required teachers to sign in to a teacher management page to complete the teacher instruments. Teachers were allowed to complete their surveys in multiple sittings. However, once a teacher clicked the Submit button on any survey page, he or she was not allowed to return to that page to revise those answers. For example, if a teacher clicked Submit on page 3, he or she would have been taken to page 4. If the teacher exited the survey at that time, no answers from page 4 would have been submitted. The next time that teacher signed in, he or she would have been directed to page 4 and would not be able to revise any of the answers provided on pages 1 through 3.

Teachers also used the teacher management page to administer the student instruments online. The student instruments were designed to be completed in a single class period, but students were allowed to finish a test in more than one sitting if necessary. Additionally, students were permitted to use calculators or pencil and paper during the tests. Upon completion of the students' tests, teachers could immediately access each student's results. The rationale was that teachers could use the students' test results as a formative assessment.

In addition to instant feedback regarding students' performance on the mathematics tests, we also offered teachers other incentives. Specifically, both experimental- and control-group teachers who completed all of the study requirements were paid a stipend of $300. Teachers in the experimental group were also able to receive graduate credit or continuing education units for the courses that they completed, and teachers in the control group were given the opportunity to complete a series of three online professional development courses after the research study ended.

Results

Online Professional Development and Teachers' Pedagogical Content Knowledge

We employed a repeated measures analysis of variance (RM-ANOVA) technique to ascertain whether there were significant differences in participants' pedagogical content knowledge (pre/post) as a function of group membership (experimental or control). The results of the RM-ANOVA confirmed a significant interaction between group membership (experimental or control) and total pedagogical content knowledge, $F(1, 77) = 22.36$, $p < .001$. This significant interaction suggests there was variability by group membership regarding pre to post gains in teachers' pedagogical content knowledge. Specifically, whereas there was an increase in knowledge scores for the experimental-group teachers from pre ($M = .46$, $SD = .14$) to post ($M = .58$, $SD = .14$), there was a slight decline for the control group from pre ($M = .45$, $SD = .11$) to post ($M = .44$, $SD = .12$). The effect size associated with this interaction as measured by ηp^2 was .23. Using Keppel and Wickens (2004) guidelines, which suggest that .01–.05 is indicative of a small effect size, .06–.14 a medium effect size, and greater than .14 a large effect size, this coefficient was indicative of a large effect.

Group membership (experimental or control) emerged as a significant main effect, $F(1, 77) = 8.73$, $p = .004$, confirming that teachers in the experimental group received significantly higher overall pedagogical content knowledge scores ($M = .52$, $SE = .02$) than did teachers in the control group ($M = .44$, $SE = .02$). The effect size associated with this difference as measured by ηp2 was .10 and is indicative of a medium effect. Total pedagogical content knowledge (pre/post) also emerged as a significant main effect, $F(1, 77) = 16.31$, $p < .001$, indicating that across all teachers, the overall mean score in total knowledge increased between administration of the pretest ($M = .45$, SD = .13) and the posttest ($M = .50$, $SD = .15$). The effect size associated with this difference as measured by ηp^2 was .18, which is large. However, it should be noted that this main effect shows differences pre to post for all teachers and therefore masks differences between the experimental and control groups. Table 4 (p. 18) presents the means and standard deviations for scores on the teacher pedagogical content knowledge scales by group membership (experimental or control). Table 5 (p. 18) presents the summary statistics for the effects of online professional development on teachers' pedagogical content knowledge by group membership (experimental or control).

Table 4. Means and Standard Deviations for Scores on the Teachers' Pedagogical Content Knowledge and Pedagogical Practices Scales by Group Membership

	Experimental Group (n = 34)				Control Group (n = 45)			
	Pre-Intervention		Postintervention		Pre-Intervention		Postintervention	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Overall Pedagogical Content Knowledge	.46	.14	.58	.14	.45	.11	.44	.12
Overall Pedagogical Practices	2.52	.35	3.05	.37	2.71	.37	2.79	.34

Table 5. Summary Statistics for the Effects of Online Professional Development on Teachers' Pedagogical Content Knowledge by Group Membership (Control or Experimental)

Source	*df*	Sum of Squares	Mean Square	*F*	ηp^2
Within					
Time (Pre/Post)	1	.115	.115	16.314*	.175
Time x Group Membership	1	.158	.158	22.362*	.225
Error (Time)	77	.544	.007		
Between					
Group	1	.229	.229	8.729**	.102
Error	77	2.018	.026		

* $p < .001$, ** $p < .01$

Online Professional Development and Teachers' Pedagogical Practices

We also conduced repeated measures analysis of variance (RM-ANOVA) to determine whether there were significant differences by group membership (control or experimental) with respect to participants' pedagogical practices (pre/post). The results of the analyses revealed a significant interaction between group membership (control or experimental) and pedagogical practices, $F(1, 77) = 46.10$, $p < .001$. The significant interaction is indicative of variability by group membership. Notably, participants in the experimental group showed significantly greater gains in scores for overall pedagogical practices from pre ($M = 2.52$, $SD = .35$) to post ($M = 3.05$, $SD = .37$), compared with control group teachers' pre ($M = 2.71$, $SD = .37$) to post scores ($M = 2.79$, $SD = .34$). The effect size associated with this interaction as measured by ηp^2 was .38, which is quite large.

Group membership (control or experimental) did not emerge as a significant main effect, $F(1, 77) = .230$, $p = .633$, indicating that experimental-group teachers' overall mean scores in pedagogical practices ($M = 2.78$, $SE = .06$) were not statistically significantly higher than overall mean scores for teachers in the control group ($M = 2.75$, $SE = .05$). However, the results indicated a significant main effect for overall pedagogical practices (pre/post), $F(1, 77) = 84.53$, $p <.001$, indicating that mean scores for teachers across both experimental and control groups increased from pre ($M = 2.62$, $SD = .37$) to post ($M = 2.90$, $SD = .38$). The effect size associated with this difference as measured by ηp2 was .52 and is indicative of a large effect. It should

Table 6. Summary Statistics for the Effects of Online Professional Development on Teachers' Pedagogical Practices by Group Membership (Control or Experimental)

Source	*df*	Sum of Squares	Mean Square	*F*	ηp^2
Within					
Time (pre/post)	1	3.607	3.607	84.529*	.523
Time x Group Membership	1	1.967	1.967	46.103*	.375
Error (Time)	77	3.286	.043		
Between					
Group Membership	1	.049	.049	.230	
Error	77	16.483	.214		

* $p < .001$

Table 7. Means and Standard Deviations for Scores on the Students' Mathematics Knowledge Scales

Experimental Group ($n = 648$)				Control Group ($n = 790$)			
Pre-Intervention		Postintervention		Pre-Intervention		Postintervention	
M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
.42	.16	.54	.21	.44	.16	.53	.20

be noted that this significant main effect for overall pedagogical practices (pre/post) masks differences between the experimental and control groups. Table 6 presents the summary statistics for the effects of online professional development on teachers' pedagogical practices by group membership (experimental or control).

Online Professional Development and Students' Mathematics Achievement

Table 7 shows the means and standard deviations for students' scores on the mathematics knowledge subscales and overall scale. We applied hierarchical linear models to determine whether teachers' assignment to the experimental or control group was a significant predictor of students' posttest scores after controlling for students' pretest scores. We used this type of analysis to account for the nesting of students within randomly assigned teachers and allowed for the estimation of the impact of teachers' assignment to the experimental or control conditions on students' mathematics achievement. Students' posttest scores were modeled as a function of their pretest scores (Level 1) and as a function of teachers' group membership (Level 2).

The results of the unconditional model indicated significant variation in students' posttest knowledge scores among teachers. Specifically, the unconditional intraclass correlation coefficient (ICC) was .32 for the overall mathematics posttest scores. This indicates that 26–32% of the total variability on the posttest scores could be attributed to between-teacher differences. These nonzero ICCs, in addition to the modest sample size, support the need for the use of hierarchical linear regression models to estimate unbiased treatment effects.

Table 8. HLM Results for the Effects of Teachers' Group Membership (Control or Experimental) on Students' Mathematics Achievement

	Students' Overall Mathematics Scores		
Unconditional Model			
Fixed Components	Coefficient	s.e.	Sig.
	.537	.014	< .001
Random Components	Within School	Between School	ICC
	.029	.014	.32
Conditional Model	Coefficient	s.e.	Sig.
Intercept	.523	.009	< .001
Student Measures			
Pretest Scores	.806	.028	< .001
Teacher Measures			
Group membership (0 = Control, 1 = Treatment)	.027	.014	.062
Random Components	Residual Variance		
Within Schools	.019		
Between Schools	.003	$p < .001$	
Total Residual	.022		
Total Variance Explained by the Model	48.13%		

The results of the HLM analyses reported in Table 8 indicated that after controlling for students' pretest scores, teachers' participation in the online professional development treatment did not predict students' achievement in mathematics ($b = .027$, $t = 1.89$, $df = 77$, $p = .062$). Essentially, there were no significant differences in students' mathematics achievement, as a function of teachers' group membership (control or experimental).

Discussion

Key Findings

This research study examined the impact of online professional development courses in fractions, algebraic thinking, and measurement on fifth grade teachers' pedagogical content knowledge and pedagogical practices as well as their students' mathematics achievement. The results of the study showed that teachers assigned to the experimental group had significant gains in scores of overall pedagogical content knowledge, whereas these knowledge scores for the control group actually declined slightly. Additionally, the experimental group teachers had significantly greater gains in scores for pedagogical practices related to overall mathematics, compared with teachers in the control group. Moreover, the effect sizes associated with these differences were large for gains in both knowledge and practices. These findings provide evidence and support for the research literature, which indicates that professional development for teachers can be effective if it is intensive, sustained, and content focused (Yoon et al, 2007). Teachers in this study participated in a minimum of approximately 24 hours of professional development for each course, which equates to more than approximately 70 hours of professional development across the three online professional development courses. Furthermore, the online professional development courses were based on a learning community model that allowed teachers to actively explore students' conceptions and misconceptions about mathematics through various activities, such as student interviews, analyses of students' work, and peer-to-peer discussions. Moreover, consistent with the tenets of Shulman (1986), teachers were provided with strategies for representing and formulating mathematical concepts in a way to make the subject matter more comprehensible to upper elementary students. Overall, the results of the study indicate that intensive, sustained, content-focused online professional development in mathematics can effect positive change in teachers' pedagogical content knowledge and pedagogical practices.

Limitations of the Study

One significant limitation of this study is the high attrition rate. Despite providing teachers with a moderate stipend and free access to online professional development (teachers in the control group were allowed to take each course free of charge upon completion of the study), a large number of participants did not persist through the full study. However, it should be noted that, unlike typical professional development programs, teachers in this study were required to commit to three semesters of participation. In a "real world" context, teachers complete individual courses and are not usually required to complete a series of three professional development courses. Therefore, the high attrition rate associated with this research study should not generalize to a standard online professional development program. Nevertheless, although the number of teachers who completed the study was sufficient for data analyses, it is possible that effects might have differed for teachers who dropped out versus those who persisted. Such differences may bias the estimates reported herein. Chi-square analyses revealed that the only significant difference in teacher demographics between teachers who dropped out and those who remained in the study was previous experience with online professional development. Specifically, teachers who dropped out of the study had less experience with online professional development. Yukselturk and Inan (2006) suggest that participants sometimes underestimate the time and effort required for successful completion of online courses and can experience anxiety regarding their technology proficiency. It should be noted that for this study, the first session (the first week of each of the online professional development courses) was an orientation session. However, the results suggest that the orientation session of online professional development programs ought to be as carefully planned as the content sessions to allay participants' anxieties and help set realistic expectations.

Regarding students' mathematics achievement, the results of the HLM analyses indicated that positive changes in teachers' pedagogical content knowledge and practices did not translate to any meaningful differences for students. Specifically, there were no statistically significant differences in students' overall mathematics achievement as a function of teachers' group membership (control or experimental). It would be easy to conclude that teacher professional development has no impact on student achievement, especially given the findings of other large-scale studies, such as those conducted by the American Institutes for Research on the impact of professional development in middle school mathematics and early reading instruction (Garet, Cronen, Eaton, Kurki, Ludwig, Jones, Uekawa, Falk, Bloom, Doolittle, Zhu, & Sztejnberg, 2008; Garet, Wayne, Stancavage, Taylor, Walters, Song, Brown, Hurlburt, Zhu, Sepanik, & Doolittle, 2010). However, it should be noted that the true effects of professional development on student achievement cannot be ascertained without first considering teachers' opportunity to implement course material.

It should be noted that for this study, we administered the student measures in a relatively short period after the professional development ended. Therefore, teachers would have had a limited opportunity to implement the content from the online professional development courses in their classrooms. Additionally, the sample of teachers was drawn from multiple states, and as there is no national curriculum, the schedule of the online professional development courses could not be aligned with the mathematics syllabi of individual teachers. Therefore, it is possible, for example, that a teacher might have participated in the Fractions course after that subject matter had already been taught to students. Consequently, the teacher would not be able to implement the new knowledge, skills, and strategies he or she would have learned from that Fractions with that group of students. In specifying the link between professional development and student achievement, Yoon et al. (2007) indicated that if a teacher fails to apply new ideas from professional development to classroom instruction or arguably has limited opportunity to fully implement those new ideas, improved student learning cannot be expected.

Recommendations for Future Research

The implications regarding the implementation of course material, coupled with the research literature that indicates change in teacher practices takes time, underscore the need for a follow-up study to determine whether teacher gains persist over time and affect student learning. Future research should consider the follow-up support system needed as well as teachers' motivation to apply professional development to classroom teaching. Additionally, future research studies can be strengthened by adding a face-to-face component, thereby offering a hybrid intervention that includes both online and face-to-face professional development. Such a research design might allow comparisons to be made between online professional development and face-to-face professional development.

Indeed, a complete depiction of what teachers actually do in their classrooms requires data collection methods such as classroom observations, which were not feasible for this study. However, Hamilton and Guarino (2004) argue that it is possible to gain accurate information regarding teachers' instructional practices through self-reported questionnaires. Still, self-reported measures of teachers' pedagogical practices, as were used in this study, have the limitation of providing information regarding teachers' reports of their instructional practices rather than their actual practices.

Implications for Practice

Despite the shortcomings, the findings of this study add to the growing body of research regarding the impact of professional development in general and online professional development in particular. The results of this study hold promise that online professional development can be an effective strategy to improve teachers' pedagogical content knowledge and pedagogical practices. However, the impact of online professional development on students' academic achievement, though null for this study, requires further investigation if a more contextualized picture regarding the efficacy of online professional development is to be depicted.

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