Early Childhood Educ J (2017) 45:121–131
DOI 10.1007/s10643-013-0605-6

Supporting Kindergarten Teachers' Mathematics Instruction and Student Achievement Through a Curriculum-Based Professional Development Program

Drew Polly · Chuang Wang · Richard Lambert · Christie Martin · Jennifer Richardson McGee · David Pugalee · Amy Lehew

Published online: 28 July 2013

Abstract This study investigates the impacts of a year-long professional development program on Kindergarten teachers' beliefs and practices and the association of these changes with student achievement in mathematics measured by curriculum-based instruments. Although teacher content knowledge was not statistically significantly different before and after participation in the program, changes in teachers' beliefs and practices were both noticed: a trend towards discovery/connectionist orientation and student-centered practices. Teachers' gain scores on a measure of mathematics content knowledge was positively related to the linear growth rate of student achievement.

Keywords Kindergarten · Mathematics education · Professional development · Reform-oriented pedagogies · Common Core

D. Polly (✉)
Department of Reading and Elementary Education, UNC Charlotte, COED 367, 9201 University City Blvd, Charlotte, NC 28213, USA
e-mail: drew.polly@uncc.edu

C. Wang · R. Lambert · C. Martin
Center for Educational Measurement and Evaluation, UNC Charlotte, Charlotte, NC, USA

J. R. McGee
Appalachian State University, Boone, NC, USA

D. Pugalee
Center for Science, Technology, Engineering, and Mathematics (STEM) Education, UNC Charlotte, Charlotte, NC, USA

A. Lehew
Charlotte-Mecklenburg Schools, Charlotte, NC, USA

Overview

The implementation of the Common Core State Standards (NGO/CCSSI 2011) calls for early childhood educators to focus heavily on Kindergarten students' understanding of numbers and quantities, including counting and other basic skills. Research has identified several teacher characteristics that are empirically linked to teachers' effective instruction and their students' achievement (Nye et al. 2004; Polly 2008). Large-scale syntheses of studies concluded that teachers' content knowledge, their beliefs about mathematics teaching and learning, and knowledge of pedagogies and mathematics content are significantly related to teachers' enactment of effective pedagogies (Ball et al. 2001; Hill et al. 2005; Remillard 2005). In this paper, we describe findings from a research study in which we analyze data from Kindergarten teachers and their students about the influence of a year-long professional development project on their content knowledge, beliefs about mathematics, instructional practices, and student achievement.

Supporting Teachers' Mathematics Instruction

Some research studies have found relationships between specific teacher characteristics or behaviors and their students' mathematical understanding (Polly 2008; Carpenter et al. 1996; Fennema et al. 1996; Stigler and Hiebert 1999). Studies on specific mathematics pedagogies have found that these characteristics (knowledge of content and pedagogy and beliefs) also influence of the use of worthwhile mathematical tasks (Henningsen and Stein 1997; Polly 2012), teachers' knowledge about students' mathematical thinking (Carpenter et al. 1989, 1996), knowledge of mathematics content related to topics that they teach (Hill et al. 2005), and ability to foster students' mathematical communication (Huffered-Ackles et al. 2004). These mathematics pedagogies align to recommendations for mathematics education reform that have been advanced by organizations and leaders in mathematics education (Higgins and Parsons 2010; National Council for Teachers of Mathematics (NCTM) 2000; U.S. Department of Education 2008), and are often referred to as reform-based or standards-based pedagogies (McGee et al. 2013).

Remillard's (2005) synthesis of research found that teachers' curricula enactments were linked to teacher characteristics, including mathematics content knowledge, beliefs about mathematics teaching and learning, and contextual factors, such as support from their administrators and colleagues. Drake and Sherin (2002, 2006) concluded that their enacted pedagogies in their classroom were heavily influenced by their beliefs about teaching and learning as well as their perception of their mathematics content knowledge.

In the United States, the implementation of the Common Core State Standards for Mathematics (NGO/CCSS1 2011) calls for teachers to enact more standards-based pedagogies (Polly and Orrill 2012; Russell 2012). One of the ways to support teachers' enactment of these practices is through intensive professional development projects (Polly and Hannafin 2010; Polly et al. 2010; Loucks-Horsley et al. 2009). To that end, there is a need to design and evaluate the impact of teacher professional development programs that simultaneously addresses teachers' knowledge of content and pedagogies; in other words, teachers' beliefs as well as their instructional practices.

Professional Development and Its Impact

Guskey (2000) provided a multi-level framework (Table 1) for evaluating PD, which has been used in prior mathematics studies (Polly and Hannafin 2011; Polly 2012). As mentioned earlier, there is an intuitive relationship among teachers' knowledge and skills, teachers' application of that knowledge, and student learning outcomes. Further, as a result of the research on teachers' beliefs and instruction, evaluations of PD programs must also consider teachers' beliefs when examining how PD impacts both teachers' instruction and students' learning.

Table 1 Levels of evaluating professional development (PD)

Level	Question(s)
Teachers' reactions	What are teachers' reactions during and after PD? Does the PD influence their beliefs about teaching?
Teachers' acquisition of knowledge and skills	What knowledge and skills do teachers develop during PD?
Teachers' use of knowledge and skills	How do teachers apply their new knowledge and skills before, during, and after instruction?
Impact on the organization	What types of organizational changes have been made as a result of the PD? What was the impact of these changes?
Student learning outcomes	What is the impact of teachers' use of new knowledge and skills on their students' learning?

Based on the gap in the literature about the empirical relationship among teachers' knowledge, their beliefs and instructional practices, and student learning outcomes, this study was conducted to examine how a year-long professional development program influenced Kindergarten's teacher characteristics (knowledge, beliefs, and instructional practices) and student learning outcomes. Following the methods and procedures, we discuss our findings and highlight implications related to the development, preparation, and support of early childhood educators.

Methodology

This section describes the methods and procedures of examining the influence of the professional development program on Kindergarten teachers' content knowledge, beliefs, instructional practices, and their students' mathematics achievement.

Description of the Professional Development

This section describes the professional development project that the teacher-participants were engaged in during the year of the study.

Context

The professional development program for this study was a one-year project funded by the United States Department of Education Mathematics Science Partnership (MSP) program. "Content Development for Investigations" (CoDE:I). The data in this study come from the second year of a 3 year grant. While the grant was a multi-year grant, teachers in each cohort participated only for 10 months (August thru June of the following year). The purpose of the MSP grant program was to further the professional development of elementary mathematics teachers by giving teachers the tools to teach with a new standards-based mathematics curriculum, *Investigations in Number, Data, and Space (Investigations).*

The participants in this study were Kindergarten teachers and their students in two school systems located near a large metropolitan city in the southeastern United States. System One is a large, urban school system and System Two is a smaller school system in a neighboring city. In

System One, 57 of the systems' 106 schools receive Title I funding whereas all of five elementary schools in System Two qualify for Title I funding. Title I funding is based on the percentage of students eligible for free/reduced-price lunch program, which is based on students' socio-economic status.

The PD was co-designed by the project team, which consisted of a mathematics professor, 2 mathematics education professors, and leaders from school districts. Each teacher-participant completed 48 h of a summer workshop, 12 h of follow-up workshops during the school year, and approximately 20 h of classroom-embedded professional learning activities. The two school systems conducted PD separately and on different days throughout the grant program, but the overall content and focus of the PD remained consistent. The facilitators worked with both groups of teachers. More information about the professional development activities can be found in an earlier manuscript (Polly and Lehew 2012).

Typical Professional Development Activity

During workshops, teachers completed a variety of activities, including exploring mathematical tasks, examining lessons in their curriculum, and modifying curriculum-based lessons to meet the Common Core Standards as well as the needs of their students. For example, when looking at addition and subtraction, teacher-participants examined the Common Core Standards and solved different types of word problems. They followed that activity by examining where these problems appear in their curriculum, looking for times in which they needed to include more problems or modify them to make the problems easier or more difficult.

Participants

The participants were 15 Kindergarten teachers and their students from the two school systems. Of the 15 participants, 8 were from System One and 7 from System Two. In System One, participants' years of teaching experience ranged from 1 to 32 years, with a mean of 14.29 and a standard deviation of 11.67. In System Two, the participants' years of teaching experiences ranged from 1 to 35 years with a mean of 9.29 and a standard deviation of 11.70. In System One, 7 (87.5 %) of the participants were female and 1 (12.5 %) was male. In System Two, all 7 participants were female. In System One, the ethnicity of the teachers was: 5(62.5 %) Caucasian and 3(37.5 %) African American. In System Two, all teachers were Caucasian.

Participants also included 245 students, of which 145 (59 %) were from System One and 100 (41 %) were from System Two. Gender and ethnicity were reported by teachers for their aggregate classrooms. Of those 245 students, 123 (50 %) were females and 122 (50 %) were males. Of the 245 students, 105 (43 %) were European American, 64 (26 %) were African American, 59 (24 %) were Hispanic, 5 (2 %) were Asian, and 12 (5 %) were identified with other ethnic background.

Data Sources

Four key components of the PD were evaluated: (a) teacher content knowledge in teaching mathematics; (b) teacher beliefs about teaching and learning mathematics, (c) instructional practices in teaching mathematics; and (d) impact of teacher beliefs and practices on student learning outcomes in mathematics.

Long-time engagement and multiple instruments were used to collect data for the formative and summative evaluations. Teacher beliefs, practices and mathematics content knowledge were measured using pre- and post- test instruments. Student achievement was measured using the same assessment from *Investigations* immediately after students had completed 3 different units focused on number sense throughout the year.

Teacher Instruments

All teacher-participants completed three pre-project and post-project instruments: a Teacher Beliefs Questionnaire (TBQ; "Appendix 1"), a Teacher Practices Questionnaire (TPQ; "Appendix 2"), and a Content Knowledge for Teaching Test ("Appendix 3"). Both the TBQ and TPQ have been previously used by the authors to evaluate the impact of PD projects with elementary school teachers (Polly et al. (in press); Polly et al. 2013). The TBQ includes general questions used to examine teachers' espoused beliefs about mathematics, mathematics teaching, and mathematical learning (Swan 2006). For each of those three dimensions, teachers reported the percentage to which their views align to each of the transmission, discovery, and connectionist views. The sum of the three percentages in each section is 100. Since discovery and connectionist both reflect the project staff's views of student-centered teaching, teachers were coded as either discovery/connectionist or transmission. Teachers were coded as discovery/connectionist if they indicated at least 45 % in either discovery or connectionist (Swan 2006). The TPQ examined participants self-report about instructional practices related to their mathematics teaching (Swan 2006). Each of the items reflects either student-centered or teacher-centered pedagogies relevant to mathematics teaching from Kindergarten through the secondary levels. Teachers identified their instructional practices on a 5-point Likert scale, where 0 represents "none of the time" and 4 represents "all of the time." Items that reflect student centered practices (Items 5, 6, 7, 11, 12, 15, 16, 17, 20, 21, 24 and 25) were reversely coded so that teachers with a mean score of 2.00 or less were coded as "student centered" and teachers with a mean score of 2.01 or more were coded as "teacher centered." The Content Knowledge for Teaching Test (see sample in "Appendix 3") measures teachers' knowledge of mathematics content (Hill et al. 2005). The form used for this study examined teachers' knowledge of number sense issues, and included concepts that were aligned to the PD goals and activities. For each teacher, the number of correct items was recorded.

Student Achievement Measures

The student achievement measure was an assessment from the *Investigations* curriculum (Russell and Economopolous 2007). Kindergarten teachers were asked to administer the same assessment at the beginning, middle, and end of the school year. The assessment measured students' ability to count and organize objects, a critical area of the Kindergarten Common Core Standards. The assessment was completed with a teacher and individual students; the teacher gave a student objects to count and manipulate, while the teacher recorded student's performance on the recording sheet. Project staff collected the recording sheet and scored the assessments. One of the project evaluators worked with a mathematics education expert to score a few initial assessments prior to completing the scoring. All scores were converted to a percentage.

Data Analysis

The multiple sources of data listed above were used to triangulate the results. Descriptive and inferential statistical procedures were employed to examine the distribution of the variables and the possible relationships and differences among these variables. Normal distribution is a basic assumption for the statistical tests used in this study, so an alpha level (.05) was used to evaluate the significance of skewness and kurtosis with small samples for teacher participants while histograms were used to check the shape of the distribution with large samples for student participants. This is because the standard errors for both skewness and kurtosis would be small with a large sample size. Box's *M* test was used to check the assumption of homogeneity of variance and covariance. T-tests and analysis of variance (ANOVA) were used to examine group differences and Hierarchical linear modeling (HLM) were used to analyze the student data nested within teacher variables to account for the within- and between-group variances (Raudenbush and Byrk 2002). Normal Q–Q plot and histograms of the residuals at each level of the HLM model were checked the appropriateness of the HLM models such as normal distribution of the residuals and linear relationship between the predictors and the dependent variable. Presence of multivariate outliers was checked with Mahalanobis distance whereas multicollinearity was checked with variance inflation factors (VIF) by running ordinary least squared regressions with residual files. The magnitude of effect, or proportion of variance explained by the complete model for HLM, was calculated by 1 minus the ratio between the estimated variance of the complete conditional model and that of the unconditional model.

Results

The results of this study are organized based on the influence of the professional development on the various data sources that were collected.

Influence on Teacher Beliefs

Of these 15 teachers, 5 changed from transmission to discovery/connectionist orientation, 8 remained unchanged, and 2 changed from discovery/connectionist to transmission orientation with respect to teacher beliefs about mathematics. As for teacher beliefs about learning mathematics, 2 changed from transmission to discovery/connectionist orientation, 12 remained unchanged, and 1 changed from discovery/connectionist to transmission orientation. Finally, 1 changed from transmission to discovery/connectionist orientation, 8 remained unchanged, and 6 changed from discovery/connectionist to transmission orientation with respect to teacher beliefs about teaching mathematics. Of those who remained unchanged, all were originally in the discovery/connectionist orientation.

Influence on Teacher Practices

At the beginning of the study, 9 teachers reported enacting primarily student-centered practices and 6 teachers reported enacting primarily teacher-centered practices. After the PD, 14 teachers reported enacting primarily student-centered practices, while 1 teacher reported enacting primarily teacher-centered practices. All of the teacher-centered teachers prior to PD reported a shift to student-centered practices, and 8 student-centered teachers reported remaining student-centered. One teacher, who was student-centered prior to PD, reported primarily teacher-centered practices at the end of the project. The comparison of mean scores of teacher practices also showed a statistically significant change from pre ($M = 2.70$, $SD = 0.42$) and post ($M = 2.09$, $SD = 0.39$), $t\ (14) = 5.25$, $p < .001$. The skewness of the pre-mean scores was -0.01 with a standard error of 0.58 whereas that of the post-mean scores was −0.21 with a standard error of 0.58. The kurtosis of the pre-mean scores was 0.05 with a standard error of 1.12 whereas that of the post-mean scores was −0.44 with a standard error of 1.12. Neither of the skewness or kurtosis of these measures was statistically significantly different from zero ($p > .05$), therefore, the assumption of normal distribution held for both the pre-mean scores and post-mean scores for teacher practices.

Influence on Mathematical Content Knowledge for Teaching

The Content Knowledge Test was completed by 8 teachers in System One and 7 teachers in System two at the beginning and end of the year. Descriptive statistics of teacher content knowledge are presented in Table 2.

Repeated measures analysis of variance revealed no statistically significant interaction effect between school system and time, $F(1, 13) = 0.02$, $p = .96$, partial $\eta^2 < 0.001$, indicating that teachers in the two school systems did not differ with respect to their content knowledge in mathematics at the beginning or the end of the year. The main effect of change was not statistically significant either, $F(1, 13) = 0.53$, $p = .48$, partial $\eta^2 = .04$, indicating that the change of teacher content knowledge after participating in the PD could be possibly due to chance. Box's *M* test showed that the assumption of homogeneity of variance and covariance held for this test ($p = .47$). The skewness of the teacher content knowledge test scores at the beginning of the year was −0.70 with a standard error of 0.58 whereas that at the end of the year was −0.34 with a standard error of 0.58. The kurtosis of the teacher content knowledge test scores at the beginning of the year was −0.38 with a standard error of 1.12 whereas that at the end of the year was −0.55 with a standard error of 1.12. Neither of the skewness or kurtosis of these measures was statistically significantly different from zero ($p > .05$), therefore, the assumption of normal distribution held for the teacher content knowledge test scores both at the beginning and end of the year. Gain scores were completed by subtracting pre-test scores from post-test scores (Table 2). The large standard deviations of the gain scores suggested that the impact of the PD on teachers' content knowledge varied, some experienced large gains, some experienced less gains, and some experienced negative gains In summary, these results suggest it is difficult to conclude if the PD was successful in increasing teachers' content knowledge in teaching mathematics.

Influence on Student Learning Outcomes

Student assessment including gain scores (post-test minus pre-test) were presented in Table 3.

Multivariate analysis of variance (MANOVA) noted statistically significant differences between the two school systems on the combination of all kindergarten student assessments, $F(3, 249) = 3.38$, $p = .02$, partial $\eta^2 = .04$. Histograms for the student assessment scores showed that the data were negatively skewed. This was not surprising because most students had already been exposed to the content knowledge and skills by the time of each assessment. Although significance tests are usually based on the assumption of normal distribution of the dependent variables, MANOVA are robust to normality as long as the sample size is large (Tabachnick and Fidell 2007). The assumption of homogeneity of variance–covariance matrices for MANOVA was violated ($p < .001$) by Box's *M* test, which is a notoriously sensitive test. Based on a Monte Carlo test, robustness of significance tests is expected if the sample sizes are equal (Hakstian et al. 1979). Since the student sample sizes are not the same (100 and 140), the outcome of Box's *M* test was considered and Pillai's criterion instead of Wilks' lambda was used to evaluate multivariate significance. This is because the larger variance was found with the smaller sample (System Two).

Three-level growth curve models were applied because these students were assessed on the same achievement measure three times across the year and because the students are nested within teachers. Since some teachers did not turn in their student assessments for all three points

Table 2 Descriptive statistics of teacher content knowledge in mathematics

	Pre	Post	Gain
System one ($n = 8$)			
M	26.50	27.50	1.00
SD	8.72	10.46	6.63
System two ($n = 7$)			
M	35.29	36.43	1.14
SD	4.96	6.32	4.30

Table 3 Descriptive statistics of student assessment in mathematics

	First round		Second round		Third round	
	M	SD	M	SD	M	SD
System one ($n = 145$)	91.15	20.70	94.48	19.25	96.32	14.23
System two ($n = 100$)	78.50	31.89	94.33	15.75	96.83	11.77

Kindergarten students were given the same assessment three times during the year during the year. Due to the missing data on one of the three assessments, only 15 Kindergarten teachers and their 228 students were used in the growth curve models. Descriptive statistics for the three assessments as well as the plots (Fig. 1) show that the student achievement followed a quadratic trend: Pre-test1 ($M = 85.98$, $SD = 17.88$), Post-test1 ($M = 94.42$, $SD = 17.87$), and Post-test2 ($M = 96.53$, $SD = 13.26$). As a result, a curvilinear model (quadratic) was used. The student performances within the two school systems were: Pre-test ($M = 91.15$, $SD = 20.70$ for System One and $M = 78.50$, $SD = 31.89$ for System Two), Post-test1 ($M = 94.48$, $SD = 19.25$ for System One and $M = 94.33$, $SD = 15.75$ for System Two), and Post-test2 ($M = 96.32$, $SD = 14.23$ for System One and $M = 96.83$, $SD = 11.77$ for System Two). Moreover, independent samples t test suggested statistically significant differences between the two school systems at pre-test, $t(243) = -3.76$, $p < .001$, but not at post-test1, $t(243) = -0.06$, $p = .95$, or post-test2, $t(243) = 0.30$, $p = .77$. Therefore, the school system was dummy coded (0 refers to School System 2 and 1 refers to School System 1) and used as a predictor at Level 2. The influence of teacher content knowledge, practice, and beliefs were assumed to have the same impact on students within two school systems, so these impacts were fixed within school systems and used as predictors at Level 3. The parameter estimates of these models were presented in Table 4.

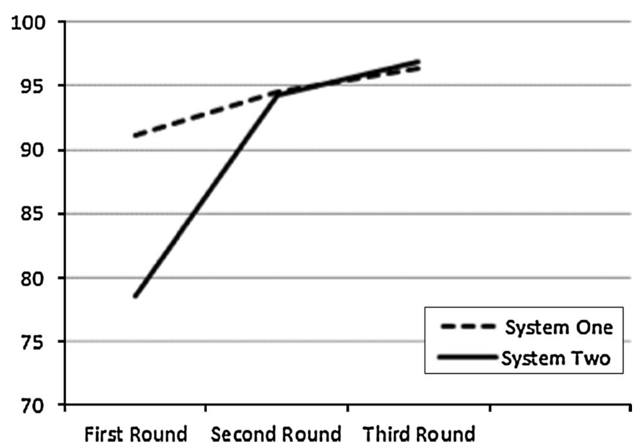

Fig. 1 Linear and curvilinear growth of student assessment across two school districts

Mahalanobis distance values were converted into Chi square values to determine the probability associated with values larger than these values. No multivariate outliers were found as all the probabilities were larger than 0.001. The VIF values ranged from 1.27 to 1.89, so multicollinearity was not a concern either.

As is in the null model (without any predictors), both the linear and quadratic coefficients were statistically significantly different from zero, supporting the curvilinear relationship between student achievement and time of assessment. The negative quadratic coefficient suggests that the growth of student achievement slowed down from the second to the third assessment. Students in System One performed significantly better than students in System Two at pre-test, but students in System Two had significantly higher linear growth rates than students in System One. Furthermore, the positive quadratic coefficient for the difference between System One and System Two indicated that the slowing down trend between the second and third assessment was less observable in System Two than that in System One.

The gain of teacher content knowledge had a strong positive impact on the linear growth rate for all students, but had no statistically significantly impact on the quadratic

Table 4 Parameter estimates of three-level hierarchical liner models for kindergarten students

	Initial status		Linear		Curve linear	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Null model	81.59	1.90***	20.34	3.91***	−6.21	1.88**
System one	9.44	3.18**	−19.74	6.48**	6.81	3.11*
Content_gain	−0.55	0.32	0.49	0.23*	−0.36	0.29
Teacher practice						
T to S	−10.31	3.12**	3.43	2.25	−2.98	3.45
Belief in						
Teaching						
T to DC	−11.74	7.40	8.55	4.79	−9.62	8.18
Learning						
T to DC	−0.45	5.40	1.33	3.37	−1.29	5.76
Mathematics						
T to DC	4.19	4.53	−1.21	2.82	−0.20	4.81

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

growth rate. Students who were taught by teachers who changed their practice from teacher-centered to student-centered had a statistically lower performance at pre-test than students who were taught by teachers who were originally student-centered and remained student-centered from the beginning to the end of the PD program. This change of teacher practice had no statistically significant impact on the linear growth rate or the quadratic growth rate. The change of teacher beliefs in mathematics, learning mathematics, or teaching mathematics, had no statistically significant impact on either the initial status at the pre-test, or the linear growth rate, or the quadratic growth rate. The magnitude of effect of the complete growth curve model was 5.98 %, indicating that these teacher-level variables could only explain less than 6 % of the changes of this kindergarten student achievement.

Discussion and Implications

Numerous findings from this study warrant further discussion, focusing on the positive, statistically significant influence that the PD had on Kindergarten students' mathematics achievement, teachers' mathematical content knowledge, teachers' instructional practices, and teachers' beliefs. Data analysis also indicated statistically significant relationships between gains in teacher content knowledge and student achievement, and also between teachers' instructional practices and student achievement.

Students' Mathematics Achievement

Data analysis showed gains in achievement on the number sense curriculum-based assessment with Kindergarten students from both school systems. The gains were statistically significant from the pre-test (late August, early September) to Post-test1 (January) and Post-test 2 (May). While it is intuitive to expect Kindergarten students to grow in their mathematics achievement and understanding from the beginning of the year through the end of the year, we are most interested in teacher-level variables and other factors related to these noted gains in student learning outcomes.

First, the statistically significant difference that existed between school systems on the Pre-test had been eradicated by the first post-test, 4 months later. This finding provides support to the value of teachers' instruction in Kindergarten and raises the need for further research about the influence of mathematical instruction and the achievement gap that exists for Kindergarten students at the beginning of the school year. This study provides evidence that the use of standards-based instruction helped to close this achievement gap. Other findings related to student learning outcomes and teacher-level variables are discussed below.

Teachers' Content Knowledge

The data from this study indicate that PD focused on number sense concepts and algebraic reasoning positively influenced gains in Kindergarten teachers' mathematical content knowledge and gains in their students' achievement. For the Kindergarten teacher-participants, the gains in mathematical knowledge can likely be attributed to the PD's focus on mathematics content in the elementary grades (Grades K-5), which included content that the teachers either did not know or had not worked with in a few years. The time during workshops spent on fractions and algebraic reasoning, two topics that Kindergarten teachers do not typically work with, may have influenced the increase on the content knowledge measure. The statistically significant positive relationship between gains in teachers' content knowledge and student achievement indicates that the content knowledge either gained or refreshed during the PD is related to student achievement on the curriculum-based measure focused on number sense. Prior research (Hill et al. 2005) found statistically significant relationships between a similar content knowledge measure and student achievement. However, Hill et al.'s work (2005) with first and third graders used the assessment to measure teachers' content knowledge at one point and examined that one data point with gains in student learning, while this present study used the same assessment, but examined teachers' knowledge at two points, while relating their growth to student achievement. Further, the Hill et al. (2005) study focused on all mathematics concepts, while our curriculum-based measure focused only on number sense concepts, which was the focus of the present study.

While PD researchers espouse the value of developing teachers' content knowledge (Borko 2004; Darling-Hammond et al. 2009; Heck et al. 2008), few studies have been disseminated looking at the influence of mathematics PD projects on teachers' content knowledge. While some research studies (Hill and Ball 2004) have found positive impacts of PD on mathematical content knowledge, little is known on the interplay between PD, mathematical content knowledge, and students' achievement. This study contributes to that body of research.

Teachers' Instructional Practices

The PD influenced a statistically significant shift from teacher-centered instructional practices toward primarily enacting student-centered instructional practices. This aligns to prior research where PD projects have found that mathematics PD can positively influence teachers' enactments of student-centered and standards-based mathematics pedagogies (Carpenter et al. 1996; Heck et al. 2008; Polly and Hannafin 2011). The shift towards student-centered practices was large; 8 of 15 (53.33 %) were student-centered prior to the workshops, while 14 teachers (93.33 %) reported enacting primarily student-centered practices at the end of the study.

While these data were self-reported by participants, classroom observations conducted as a separate part of the evaluation indicated that teachers' enacted practices were student-centered. During observations, teachers posed mathematical tasks and supported students with a variety of questions that encouraged students to reason about mathematics and communicate their mathematical thinking orally (McGee et al. 2013).

Kindergarten students in classrooms taught by teachers who used primarily student-centered practices scored statistically significantly higher on the curriculum-based achievement measure than Kindergarten students who were in classroom taught by teachers who reported using primarily teacher-centered practices at the beginning of the year. There was a statistically significant difference between these groups of students throughout the year, indicating that while the teacher-centered teachers shifted their practices during the year, their students consistently scored statistically significantly lower than teachers who enacted primarily student-centered practices throughout the entire year.

Teachers who were enacting student-centered practices may have been more apt to report this in Kindergarten due to the number of math centers, games, and hands-on activities that the curriculum included during the year. Simply by following and implementing the activities in the curriculum, teachers' instructional practices may have been influenced to be more student-centered.

Teachers' Beliefs

In this present study, participants demonstrated statistically significant changes from transmission to discovery/connectionist about participants' beliefs about mathematics as a subject, and a statistically significant change from discovery/connectionists to transmission about participants' beliefs about mathematics teaching. There was no statistically significant change regarding the learning of mathematics, and there was no statistically significant relationship between teachers' beliefs and student achievement.

The PD included numerous experiences for participants to solve mathematical tasks. Through this, teachers explored many connections between mathematical concepts and also discovered how mathematics was embedded in these cognitively-demanding tasks. These reasons likely led to the shift towards discovery/connectionist beliefs about mathematics as a subject.

The shift towards transmission-oriented beliefs regarding teaching mathematics contradicts the professional developers intended shift for participating teachers. The item regarding beliefs about teaching mathematics refers to transmission teaching as a "linear curriculum" and "a lot of practice," two facets of teaching with *Investigations* that were frequently discussed in the workshops. First, teachers asked frequently if there was freedom to use the 7 Kindergarten units in any order that they wanted, and the project staff told participants that the curriculum should be kept intact with the books taught in their order. This aspect alone could have attributed for participants' high rating for transmission beliefs about teaching. Further, Kindergarten teachers discussed the critical idea of practicing essential skills, such as counting objects, and working with representations, such as a 5-frame. While the authors expected participants to rate themselves as discovery/connectionist at the end of the project, the survey items' referral to linear curriculum and practice likely caused teachers to report themselves in line with transmission beliefs about teaching.

The lack of a statistically significant shift for teachers' beliefs about learning mathematics could be explained by the fact that a majority (53 %) of the participating teachers were discovery/connectionist at the beginning of the study.

The lack of a relationship between any of the measured aspects of teachers' beliefs and student learning outcomes, while there was an increased shift from teacher-centered to student-centered instructional practices indicates that while teachers' beliefs did not favor discovery/connectionist beliefs about teaching, their instructional practices were reported to be student-centered. One possible explanation for this could be that teachers in this present study, like some teachers in Fennema et al.'s (1996) cognitively guided instruction study, used their classroom as a laboratory to test these instructional practices, and were willing to do that before changing their beliefs about mathematics teaching. Another possible explanation is that the Kindergarten teachers, as stated earlier, viewed the *Investigations* curriculum to be aligned to transmission orientations to teaching mathematics with the linear curriculum and amount of practice for certain skills.

Limitations

As repeated measures ANOVA does not tolerate missing data, only students with complete information on all variables were used in inferential statistical analyses. This reduced the student sample size from 245 to 228. Although the pattern of missing data was random and the concern of missing data as a result of the study itself was ruled out, the loss of 17 student participants might have reduced the statistical power.

The sample size for teachers is small ($n = 15$). This limited the representativeness of these teacher participants in the school districts and might have also reduced the statistical power of the teacher-level data analyses, The student performance data on the assessments were not normally distributed. Although ANOVA and MANOVA are both robust to non normality with large sample sizes, means are not the best indicator for central tendency in the dependent variables used in this study. The two school systems are not identical; one is a large urban district with 106 elementary schools, while the other is a small suburban district with only 5 schools. Although the teacher average years of experience in teaching is not significantly different between the two school districts, the teacher participants in System Two scored significantly higher (an average of 10 out of 45 points).

Finally, this is not an experimental study and there was no control group. Therefore, cautions should be taken when generalizing the results. The model only suggested relationships between teacher content knowledge gain and student achievement growth whereas student growth in mathematics skills could be related to many other factors not included in the model.

Appendix 1: Teacher Beliefs Questionnaire

Teacher name: _______________________ Grade(s) taught: ________

Indicate the degree to which you agree with each statement below by giving each statement a percentage so that the sum of the three percentages in each section is 100.

A. *Mathematics is:* Percents

1. A given body of knowledge and standard procedures; a set of universal truths and rules which need to be conveyed to students: _____
2. A creative subject in which the teacher should take a facilitating role, allowing students to create their own concepts and methods: _____
3. An interconnected body of ideas which the teacher and the student create together through discussion: _____

B. *Learning is:* Percents

1. An individual activity based on watching, listening and imitating until fluency is attained: ______
2. An individual activity based on practical exploration and reflection: ______
3. An interpersonal activity in which students are challenged and arrive at understanding through discussion: ______

C. *Teaching is:* Percents

1. Structuring a linear curriculum for the students; giving verbal explanations and checking that these have been understood through practice questions; correcting misunderstandings when students fail to grasp what is taught: ______
2. Assessing when a student is ready to learn; providing a stimulating environment to facilitate exploration; avoiding misunderstandings by the careful sequencing of experiences: ______
3. A non-linear dialogue between teacher and students in which meanings and connections are explored verbally where misunderstandings are made explicit and worked on: ______

This questionnaire was adapted from Swan, M. (2006). Designing and using research instruments to describe the beliefs and practices of mathematics teachers. *Research in Education, 75*, 58-70. Permit for use was obtained on May 29, 2009.

Appendix 2: Teacher Practices Questionnaire

Indicate the frequency with which you utilize each of the following practices in your teaching by *circling* the number that corresponds with your response.

Practice	Almost never	Sometimes	Half the time	Most of the time	Almost always
1. Students learn through doing exercises	0	1	2	3	4
2. Students work on their own, consulting a neighbor from time to time	0	1	2	3	4
3. Students use only the methods I teach them	0	1	2	3	4
4. Students start with easy questions and work up to harder questions	0	1	2	3	4
5. Students choose which questions they tackle	0	1	2	3	4
6. I encourage students to work more slowly	0	1	2	3	4
7. Students compare different methods for doing questions	0	1	2	3	4
8. I teach each topic from the beginning, assuming they don't have any prior knowledge of the topic	0	1	2	3	4
9. I teach the whole class at once	0	1	2	3	4
10. I try to cover everything in a topic	0	1	2	3	4
11. I draw links between topics and move back and forth between topics	0	1	2	3	4
12. I am surprised by the ideas that come up in a lesson	0	1	2	3	4
13. I avoid students making mistakes by explaining things carefully first	0	1	2	3	4
14. I tend to follow the textbook or worksheets closely	0	1	2	3	4
15. Students learn through discussing their ideas	0	1	2	3	4
16. Students work collaboratively in pairs or small groups	0	1	2	3	4
17. Students invent their own methods	0	1	2	3	4
18. I tell students which questions to tackle	0	1	2	3	4
19. I only go through one method for doing each question	0	1	2	3	4
20. I find out which parts students already understand and don't teach those parts	0	1	2	3	4
21. I teach each student differently according to individual needs	0	1	2	3	4
22. I tend to teach each topic separately	0	1	2	3	4
23. I know exactly which topics each lesson will contain	0	1	2	3	4
24. I encourage students to make and discuss mistakes	0	1	2	3	4
25. I jump between topics as the need arises	0	1	2	3	4

This questionnaire was adapted from Swan (2006). Designing and using research instruments to describe the beliefs and practices of mathematics teachers. *Research in Education*, *75*, 58–70. Permit for use was obtained on May 29, 2009.

Appendix 3: Sample of Content Knowledge for Teaching Mathematics (CKT-M)

Ms. Dominguez was working with a new textbook and she noticed that it gave more attention to the number 0 than her old book. She came across a page that asked students to determine if a few statements about 0 were true or false. Intrigued, she showed them to her sister who is also a teacher, and asked her what she thought.

Which statement(s) should the sisters select as being true? (Mark YES, NO, or I'M NOT SURE for each item below.)

	Yes	No	I'm not sure
0 is an even number	1	2	3
0 is not really a number. It is a placeholder in writing big numbers	1	2	3
The number 8 can be written as 008	1	2	3

References

Ball, D. L., Lubienski, S. T., & Mewborn, D. S. (2001). Research on teaching mathematics: The unsolved problem of teachers' mathematical knowledge. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed., pp. 433–456). Washington, DC: American Educational Research Association.

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

Carpenter, T. P., Fennema, E., & Franke, M. L. (1996). Cognitively guided instruction: A knowledge base for reform in primary mathematics instruction. *Elementary School Journal, 97*(1), 1–20.

Carpenter, S. R., Frost, T. M., Heisey, D., & Kratz, T. (1989). Randomized intervention analysis and the interpretation of whole ecosystem experiments. *Ecology, 70*, 1142–1152.

Darling-Hammond, L., Wei, R. C., Andree, A., Richardson, N., & Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher professional development in the United States and abroad*. Washington, DC: National Staff Development Council.

Drake, C. & Sherin, M. G. (2002, April). Changing models of curriculum use. In *Paper presented at the annual meeting of the American Educational Research Association*, New Orleans, LA.

Drake, C., & Sherin, M. G. (2006). Practicing change: Curriculum adaptation and teacher narrative in the context of mathematics education reform. *Curriculum Inquiry, 36*(2), 153–187.

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

Guskey, T. R. (2000). Professional development that works: What makes professional development effective? *Phi Delta Kappan, 84*, 748–750.

Hakstian, A. R., Roed, J. C., & Lind, J. C. (1979). Two-sample T^2 procedure and the assumption of homogeneous covariance matrices. *Psychological Bulletin, 86*, 1255–1263.

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*(2), 113–152.

Henningsen, M., & Stein, M. K. (1997). Mathematical tasks and student cognition: Classroom-based factors that support and inhibit high-level mathematical thinking and reasoning. *Journal for Research in Mathematics Education, 28*(5), 524–549.

Higgins, J. & Parsons, R. M. (2010). Designing a successful system-wide professional development initiative in mathematics: The New Zealand numeracy development project. In *Paper presented at the annual meeting of the American Educational Research Association,* Denver, CO.

Hill, H. C., & Ball, D. L. (2004). Learning mathematics for teaching: Results from California's mathematics professional development institutes. *Journal of Research in Mathematics Education, 55*, 330–351.

Hill, H., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal, 42*, 371–406.

Huffered-Ackles, K., Fuson, K. C., & Sherin, M. G. (2004). Describing levels and components of a math-talk learning community. *Journal for Research in Mathematics Education, 35*(2), 81–116.

Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N., & Hewson, P. W. (2009). *Designing professional development for teachers of science and mathematics* (3rd ed.). Thousand Oaks, CA: Corwin Press.

McGee, J. R., Wang, C., & Polly, D. (2013). Guiding teachers in the use of a standards-based mathematics curriculum: Perceptions and subsequent instructional practices after an intensive professional development program. *School Science and Mathematics, 113*(1), 16–28.

National Council for Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

NGO/CCSSI. (2011). Common Core State Standards: Mathematics. Retrieved from http://www.corestandards.org/Math.

Nye, B., Konstantopoulos, S., & Hedges, L. (2004). How large are teacher effects? *Educational Evaluation and Policy Analysis, 26*, 237–257.

Polly, D. (2008). Modeling the influence of calculator use and teacher effects on first grade students' mathematics achievement. *Journal of Technology in Mathematics and Science Teaching, 27*(3), 245–263.

Polly, D. (2012). Supporting mathematics instruction with an expert coaching model. *Mathematics Teacher Education and Development, 14*(1), 78–93.

Polly, D., & Hannafin, M. J. (2010). Reexamining technology's role in learner-centered professional development. *Educational Technology Research and Development, 58*(5), 557–571. doi:10.1007/s11423-009-9146-5.

Polly, D., & Hannafin, M. J. (2011). Examining how learner-centered professional development influences teachers' espoused and enacted practices. *Journal of Educational Research, 104*, 120–130.

Polly, D. & LeHew, A. J. (2012). Supporting elementary teachers' retention through professional development: Developing teachers' understanding of the Common Core State Standards in Mathematics. In California Mathematics Project Monograph: Mathematics Teacher Retention. Los Angeles, CA: California Mathematics Project. Retrieved from: http://cmpstir.cmpso.org/monograph.

Polly, D., McGee, J. R., & Martin, C. S. (2010). Employing technology-rich mathematical tasks to develop teachers' technological, pedagogical, and content knowledge (TPACK). *Journal of Computers in Mathematics and Science Teaching, 29*(4), 455–472.

Polly, D., McGee, J. R., Wang, C., Lambert, R. G., Pugalee, D. K., & Johnson, S. (2013). The association between teachers' beliefs, enacted practices, and student learning in mathematics. *The Mathematics Educator, 22*(2), 11–30.

Polly, D., & Orrill, C.H. (2012). CCSSM: Examining the critical areas in grades 5–6. *Teaching Children Mathematics*, *18*(9), 566–573.

Polly, D., Wang, C., McGee, J.R., Lambert, R.G., Martin, C.S., Pugalee, D.K. (in press). Examining the influence of a curriculum-based elementary mathematics professional development program. *Journal of Research in Childhood Education*.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*(2), 211–246.

Russell, S. J. (2012). CCSSM: Keeping teaching and learning strong. *Teaching Children Mathematics, 19*(1), 50–56.

Russell, S. J., & Economopolous, K. (2007). *Investigations in number, data, and space* (2nd ed.). Boston: TERC.

Stigler, J. W., & Hiebert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. New York: Free Press.

Swan, M. (2006). Designing and using research instruments to describe the beliefs and practices of mathematics teachers. *Research in Education, 75*, 58–70.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics*. Upper Saddle River, NJ: Pearson.

U.S. Department of Education. (2008). The Final Report of the National Mathematics Advisory Panel. Retrieved from http://www2.ed.gov/about/bdscomm/list/mathpanel/report/final-report.pdf.