Chapter #12

DOES IT ADD UP? DESIGNING ELEMENTARY AND PRESCHOOL TEACHER PROFESSIONAL DEVELOPMENT TO IMPROVE STUDENT ACHIEVEMENT

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ABSTRACT
The quest for effective teacher math professional development that positively influences student achievement is the genesis of this two-year, mixed methods quasi-experimental design research study. The research evaluated the impact of a comprehensive embedded 120-hour professional development initiative on preschool and elementary math teachers' knowledge, beliefs and behaviors and changes in their student's math achievement. An external evaluation from year 1 and year 2 revealed statistically significant changes on measures of teacher math content knowledge for Treatment group vs matched Control group who completed the *Teacher Knowledge Assessment System* (TKAS), an online system for administering the *Learning Mathematics for Teaching* (LMT) assessment. The LMT measures teachers' basic mathematical knowledge and teachers' pedagogical content knowledge in mathematics (Hill, Schilling, & Ball, 2004; Phelps, 2011). Student achievement changes from Treatment teacher classrooms increased in year 1 with significant changes found in year two compared with matched Control teacher classrooms on a variety of grade aligned student achievement measures. Findings from this study demonstrate the potential of effective teacher math professional development on both teacher math content knowledge and on student achievement. Implications for future research that result from this study are presented.

Keywords: professional development, teachers, mathematics instruction, elementary mathematics, *Star Math*, *REMA Short Form*, *DIBELS-Math*, student achievement.

1. INTRODUCTION

The importance of early preschool and elementary mathematics as a predictor of future math achievement is well documented (Aubrey, Godfrey, & Dahl, 2006, Duncan et al., 2007, Claessans & Engel, 2013). Despite the awareness and research related to developing early math skills, student math achievement among United States 4th grade students continue to lag many international peers. Data from the 2015 TIMMS study show American student progress stalled after gains recorded in prior year assessments (National Center for Education Statistics, 2015b). On the 2015 NAEP assessment, only 40% of all 4th graders nationally were proficient in math (National Center for Education Statistics, 2015c). Teaching excellence in elementary school mathematics is urgently needed (D'Ambrosio, Boone, & Harkness, 2004). A review of the 2015 PISA international assessment of fifteen-year old American students reveals a significantly wider gap in achievement compared with more than half of other international students (National Center for Education Statistics, 2015a).

One of the most common strategies for improving student math achievement and teaching effectiveness is teacher professional development. Prior research established the impact of professional development on teachers was established in prior research (Farmer, Gerretson, & Lassak, 2003). Teacher development is the strategy to improve both teacher

content knowledge and pedagogical skill. By one estimate, federal and local agency resources extend more than 18 billion dollars for professional development to improve teacher effectiveness with the hope of positively influencing student achievement across many subject domains (TNTP, 2015).

The purpose of this research is to create a model for teacher professional development that both improves teacher effectiveness and consequently increases student math achievement. The research project was funded by the Ohio Department of Education, Math Science Partnership program.

2. BACKGROUND

Professional development as provided in the *Math Strong* research model is comprised of multiple components that together align with the goals of improving teacher math knowledge for teaching and increasing student math achievement. A more complete description of each component of professional development follows.

2.1. Developing a focus on mathematics for teaching

The goal of increasing teacher's basic mathematical knowledge and teacher's pedagogical content knowledge in mathematics and their understanding of mathematical knowledge in the context of how to explain it to children and to understand and respond to student misconceptions, is the basis for the professional development model used in this research (Hill, Schilling, & Ball, 2004; Phelps, 2011). The identification of specific math content and related instructional content knowledge to better understand student learners and learning as measured on the Teacher Knowledge Assessment System (TKAS), the online system for assessing Learning Mathematics for Teaching (LMT) based on prior research (Hill, Schilling, & Ball, 2004; Phelps, 2011) helps guide professional development.

What differentiates this model from others is the identification of discrete content math knowledge domains and related pedagogical knowledge associated with student achievement. For example, instead of relating strategies to solve subtraction problems in isolation from student learning, teachers learn the many ways students think about subtraction. This strategy improves teacher's ability to analyze student errors and consequently redirect students to a more successful problem solving strategy. Multiple studies corroborate this approach including a study by the authors that demonstrate a significant correlation with student achievement in both first and third grade (Hill, Rowan, & Ball, 2005). Charalambous' analysis of nine videotaped teaching segments in an elementary setting provides additional evidence that a teacher's mathematic knowledge for teaching was associated with differences in how teachers provided instruction and the level of cognitive demand (Charalambous, 2010). Finally, a state mandated professional development initiative organized to increase teacher learning mathematics for teaching with 4,000 South Dakota teachers successfully increased teachers mathematical knowledge for teaching (MKT), while increasing their sense of self-efficacy (Carney, Brendefur, Thiede, Hughes, & Sutton, 2016).

2.2. Developing a more effective professional development model

Several recent publications highlight the perils of some well-designed rigorous professional development research initiatives. In one recent study, two professional development models, one focused on reading the other on math, provided extensive professional development to teachers as well as offering individualized coaching (Quint,

2011). Despite the extensive opportunities afforded to teachers, each model fails to show significant change in students achievement. Furthermore, the middle school math program did not record significant gains in teacher math content knowledge. The author suggests the professional development may have resulted in more meaningful outcomes if the professional development activities focused on activities that arise in the school context. In other words, effective teacher professional development requires a more in situ focus which may increase relevancy for teachers and alignment with their daily instruction.

A second study focused on teacher math content knowledge as a result of 93 hours of professional development (Garet et al., 2016). The study found improvements in both teacher math content knowledge and use of mathematical explanations. However, student achievement did not demonstrate gains.

The National Council of Teachers of Mathematics (NCTM) identified several factors that promote effective professional development (National Council of Teachers of Mathematics, 2014). These include: 1. Building teachers' mathematical knowledge and their capacity to use it in practice, 2. Building teachers' capacity to notice, analyze, and respond to students' thinking, 3. Building teachers' productive habits of mind, and 4. Building collegial relationships and structures that support continued learning. Building collegial relationships and structures of support appears to standout as either under emphasized or missing in research efforts that do not demonstrate changes in student achievement.

An extensive review and analysis identified 35 professional development programs with strong links between professional development and both teacher practice and student outcomes. The review identified seven critical elements that support change and were incorporated into the design of this research study, which are focused content, incorporated active learning, supported collaboration, use of effective pratice models, coaching and expert support, feedback and reflection and sustained duration (Darling-Hammond, Hyler, & Gardner, 2017).

The results of the current study suggest two additional critical elements that appear to promote successful professional development design: embedded learning and teacher ownership. Embedded professional development that focuses on actual lessons in contrast with model videotape review provides the opportunity to increase the relevancy, alignment and ownership of professional development while supporting teacher collaboration.

2.3. Lesson study model with videotape lesson review

Lesson Study is an integral part of Japanese teaching and professional development although many aspects of traditional lesson study are not faithfully practiced in international adaptations of Japanese practice (Takahashi & McDougal, 2016). Nonetheless, modified lesson study that follows a prescribed cycle of activity that engage teacher learners in planning a "research lesson", direct observation and data collection of the lesson by teachers, review, reflection and revision based on peer feedback and data offers a promising model for review. As a professional learning model, lesson study promotes teacher collaboration based on lesson review with a specific focus on content, pedagogy and student thinking. Lesson study appears to add additional value in professional development with teacher engagement in their own planning and practice within the lesson study cycle resulting in increased teacher motivation and ownership (Lewis, Perry, Friedkin, & Roth, 2012).

A recent national investigation with randomized assignment of teachers to one of two Control groups or lesson study with math resources (Treatment) provided a comparative evaluation of lesson study as a professional development model on teacher and student learning of fractions. (Lewis & Perry, 2017). Compared with both Control conditions, lesson study teachers and their students demonstrated greater fraction knowledge. Assessment of

fraction knowledge was based on a subset of items from the LMT also used in the present study (Hill, Rowan, & Ball, 2005). As significant, lesson study teachers also reported having experienced a higher quality of professional development. In a prior study, it was reported that teacher engagement in their own planning and practice within the lesson study increased teacher motivation and ownership (Lewis et al., 2012).

An essential part of lesson study is the direct observation of the research lesson by teachers participating in lesson study. Limitations on common planning schedules, budget and substitute teachers makes direct observation more challenging in most schools. One strategy developed for this research project is the remote videotape of the research lesson using the SWIVL robot. The SWIVL device is a commercially produced robot that tracks target teacher while simultaneously recording teacher and student audio. Coupled with the Swivl Cloud, teachers can collaborate and provide feedback on the research lesson by typing annotated remarks matched to specific events in the video recorded lesson. Using this system, teachers have the ability to review a lesson at a convenient time while also accessing all team member feedback recorded during the lesson. Unlike traditional lesson study sessions organized around one public research lesson, teachers in this project will gain understanding from review of their own and other teacher's classroom video while retaining the traditional focus on a group planned lesson.

The use of classroom video as a feedback tool for teacher improvement in math and science is supported by several recent studies (Allen, Pianta, Gregory, Mikami, & Lun, 2011; Brantlinger, Sherin, & Linsenmeier, 2011; Roth et al., 2011, Schoenfeld, 2017), and is consistent with earlier reports about the value of feedback as part of professional development. In this project, teachers will reflect and evaluate audio and video obtained through the new Swivl robot within the TRU Math framework (Teaching for Robust Understanding) to provide a lens to focus on teacher and student math content understanding within the lesson study cycle (Schoenfeld,Floden, & the Algebra Teaching Study and Mathematics Assessment Project, 2014).

3. DESIGN AND RESEARCH METHODOLOGY

Math Strong was a two-year, quasi-experimental mixed methods research project to evaluate the effect of 120-hour non-traditional professional development on preschool and elementary teachers' knowledge/beliefs and behaviors related to mathematics instruction and the resultant impact on student math achievement. This chapter reports on year two of the study.

The central research question for this study was, "What is the effectiveness of a (120+ hours) of math professional development integrated with bi-weekly lesson study using video and math coaches to increase teacher and student math content knowledge in preschool and elementary classrooms?" Specific objectives paired with outcome measures include the following:

1. Improve PK- 5 teachers' math content knowledge as measured by the LMT because of 120+ hours of PROFESSIONAL DEVELOPMENT with video-assisted lesson study and math coaching.
2. Increase student math achievement as measured by grade appropriate assessments including the REMA-Short Version (preschool), DIBELS-Math (grades 1-5) and STAR Math (2-5).

The research design was organized to answer three essential questions:

1. Does professional development increase teacher mathematical knowledge?

2. Does professional development improve teacher's classroom mathematical teaching?
3. Does the professional development lead to increases in student mathematical achievement?

The research design for this study used a quasi-experimental mixed methods design. Treatment and Control schools were selected based on the schools qualifying as a "high need school district" a designation reflecting parent income and agreement of teachers to participate in professional development or in the Control group through a signed informed consent form approved by the university institutional review board. Two schools assigned as Controls were matched with two Treatment schools. The study was a mixed methods design since it combined formal quantitative measures with qualitative reports by teachers.

Full time teachers employed by the Treatment and Control schools from preschool through fifth grade were invited to participate. In year 2 of this study, 29 Control and 27 Treatment teachers participated in *Math Strong* and completed all pretest and post-test assessments. Teachers in both conditions were compensated for completion of all assessments. In addition, Treatment teachers received a stipend for participation in summer and after school professional development activities.

The research design was organized to answer three essential questions:

1. Did the professional development increase teacher mathematical knowledge?

The TKAS (Teacher Knowledge Assessment System (TKAS) is an online computer adapted testing system for administering the Learning Mathematics for Teaching (LMT) assessment questions. This was the primary assessment measure of teacher mathematical knowledge administered to Treatment and Control teachers. The LMT was designed to assess basic mathematical knowledge and teachers' pedagogical content knowledge in mathematics, their understanding of mathematical knowledge in the context of how to explain it to students, and to understand and respond to student misconceptions (Hill, Schilling, & Ball, 2004; Phelps, 2011). The adaptive nature of the TKAS allows adjustment of assessment items according to a teacher's correct or incorrect response on prior items. Two subscales from the TKAS were selected for the study that best matched the content of the professional development: Number Concepts and Operations (TKAS-NCOP) and Patterns, Functions, and Algebra (TKAS-PFAS). Teachers in the Treatment condition also completed a confidential online Qualtrics questionnaire to provide a qualitative self-assessment of the professional development and changes in their math content understanding.

2. Did the professional development improve teacher's classroom mathematical teaching?

Objective assessment of teacher's math instruction is incomplete at the time of publication. Future analysis based on coded assessment of video clips recorded from SWIVL may provide future data for analysis. Teachers in the Treatment condition completed a confidential online Qualtrics questionnaire to provide a qualitative self-assessment of the professional development and changes in their math instruction.

3. Did the professional development lead to increases in student mathematical achievement?

Students took valid and reliable grade aligned measures of student mathematical competence and achievement. First, Weiland et al. (2012) developed a short form of the 125 item research-based Research Early Mathematics Assessment (REMA) validated earlier by Clements, Sarama, and Liu (2008). This 19-item validated measure of preschool mathematics achievement was administered one on one to preschool students. While the original form included both number and geometric/spatial competency areas, only the number domain assessed alignment with professional development content.

Second, *DIBELS-Math (Dynamic Measurement Group, 2016) DIBELS® Math* is a commercial product that was selected based on the assessment of ease of measurement, long history of successful school assessment and alignment with professional development goals. *DIBELS Math* is designed to measure early numeracy, computation and problem solving skills specific to each tested grade level. *DIBELS Math* assessed student math competence both at pre-test and post-test conditions in grades K – 5. For kindergarten and first grade students, *Math Strong* staff provided one-on-one assessment. Grades 2-5 teachers following assessment protocols assessed students at pre-test and post-test periods.

Third, *STAR Math* was selected as an additional measure of student math mastery in grades 2-5. *STAR Math* is an online computer adaptive assessment of student math skills developed by Renaissance Learning. *STAR Math* was a "bonus" assessment since students in both Treatment and Control schools assessed students as part of their ongoing progress monitoring. While not ideally aligned with professional development goals, *STAR Math* provides a gross measure of classroom math achievement and progress between Treatment teacher and Control classrooms.

Last, one hundred-twenty hours of professional development was provided independently to two different Treatment schools by the research team. In addition, two math coaches were helped to manage lesson study sessions and provide individual coaching aligned with the professional development goals. Professional development was provided at different times of the calendar year and in different settings by the coaches.

For each of the two Treatment schools, four days (28 hours) of professional development were provided prior to the start of the school year in August and an additional four days (28 hours) following the last day of school. These more formalized sessions focused on both generalized math knowledge for teaching and grade specific content aligned with math standards from the state of Ohio. The primary content area focus for the before school year professional development was on building number sense through Operations and Algebraic Thinking (OA), Number and Operations-Base 10 (NBT). In addition, teachers were introduced to the TRU Math Framework. Each session included time for teachers to review prior year assessment data and identify grade level math needs. The after school year professional development was organized around Geometry & Measurement Standards, a review of Operations and Algebraic Thinking (OA) and Number and Operations-Base 10 (NBT).

Professional development was designed to engage teachers as learners of mathematics. Every professional development session included hands-on tasks and games that teachers could adapt to their classroom that provided opportunities to discuss content knowledge and student math understanding. Working together in large group and grade level teams, teachers developed professional learning communities organized around student math learning and math instruction.

A unique feature of the *Math Strong* professional development was the time devoted to a modified lesson study. Teachers were organized in grade level groups often incorporating adjacent grade level teachers. Guided by a math coach or *Math Strong* co-investigator, lesson study groups met at least once per month (often twice monthly after school). Due to time constraints, lesson study teacher groups loosely followed the activities proscribed by the lesson study cycle. Working together, teachers created a common research lesson plan with full discussion of the math content and predicted student math thinking. Teachers were also guided to consider possible student conceptual errors and strategies to scaffold learning for lower performing students. Teachers were also encouraged to use student math journals as part of their instruction to better evaluate individual and classroom understanding of the taught math content.

After the research lesson was developed, the identified teacher utilized the SWIVL video system to record and upload her lesson. Teachers within each lesson study then spent time after school or at-home observing the lesson and making annotated comments available to the entire team. When schedules or substitute teachers were available, a live observation supplemented the video record. After the lesson, teachers met to discuss the research lesson and provide feedback. Although an important part of the lesson study cycle includes lesson revision, school pacing guides made this challenging.

Math Strong Treatment teachers met with a math coach each month following an in-class observation. Math coaches helped teachers reflect on the selected math lesson mathematical content as well as student learning. In addition, math coaches used a rubric to identify instances of one or more of the 8 mathematical practices identified in the NCTM Principles to Action (National Council of Teachers of Mathematics, 2014). Less often, coaches also used the *TRU Math* rubric (Schoenfeld et al., 2014) to help teachers reflect on their lesson. Math Coaches also attended and led grade level meetings monthly as an additional embedded strategy to further develop, reflect and provide feedback on teacher and student math content understanding.

4. FINDINGS

Evaluation of the *Math Strong* Professional Development model is organized around three essential questions. Each question is repeated here with findings and analyses reported by an independent external evaluator of the *Math Strong* research.

To answer the research question on incresing teacher mathematical knowledge through professional development, two subscales from the TKAS online assessment for *Learning Mathematics for Teaching* (LMT) were administered to Control and Treatment teachers before and after a complete professional development cycle. The TKAS generates IRT scores, which are scaled in terms of variation in the original norm group in standard deviation units, with items that range (in this case between approximately -3.0 and 3.0, with a 0 score representing roughly a mean value in the original norm group). Change scores for the scales are therefore also in standard deviation units. Individual graphs are reproduced for both the Number, Concepts and Operations (NCOS) subscale and Patterns Function and Algebra (PFA) subscale. Significant increases were recorded for Treatment teachers on both subscales as reported below.

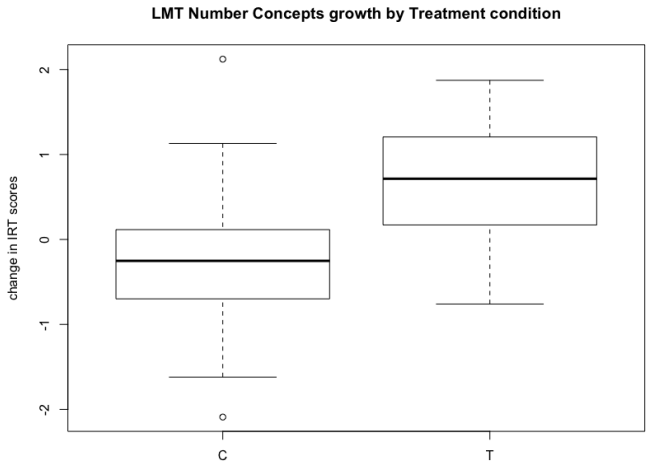
The large increase in Treatment teacher's knowledge of basic number, concepts and operations was significantly greater than changes from pretest to post-test for Control teachers ($p<0.0001$) as seen in Table 1. Control teachers reported a small drop in their TKAS-NCOP scores (see figure 1).

Table 1.
TKAS-NCOP ANOVA scores by group's pre- and post- professional development training.

	Df	*Sum Sq*	*Mean Sq*	*F Value*	*Pr(>F)*
Treatment	*1*	*9.708*	*9.708*	*16.62*	*0.000167****
Residuals	*49*	*28.615*	*0.584*		

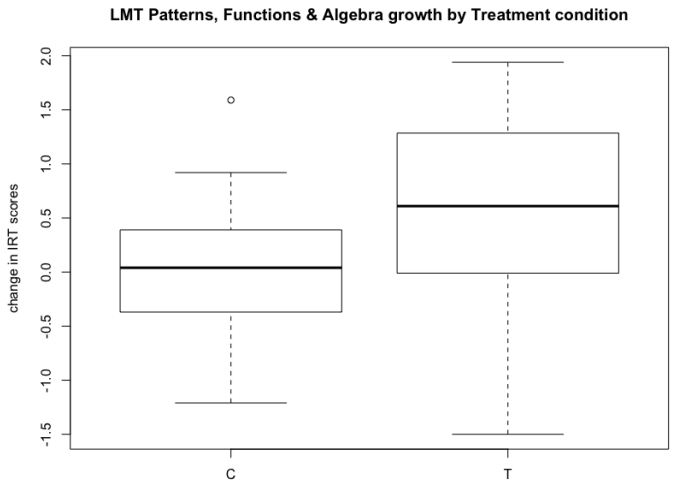
Figure 1 shows graphically the change between teacher groups as a function of IRT scores.

Figure 1.
Change in TKAS-NCOP scores in Treatment and Control groups pre- and post- professional development training.



TKAS-NCOP scores in Treatment and Control groups pre- and post- professional development training when compared with Control teachers. Reported as changes in standard deviation, the Treatment condition increased (.48 s.d.) while the Control showed virtually no growth for the Control condition (-.20 s.d.), resulting in a significant difference favoring the Treatment group ($F(1,50)= 4.45$, $p < .05$, MSE=0.684).

Figure 2.
Year 2 LMT – FA Res.



Teachers provided responses to the question, "*How did your participation in the professional development change your content knowledge about mathematics?"* The responses aligned into three categories, which were, increased understanding of mathematics, a better understanding of student learning of mathematics, and learning new ideas about classroom instruction.

In summary, on both subscales of the TKAS-LMT, Treatment teachers demonstrated significant growth in comparison to matched Control teachers. Qualitative assessment of anonymous responses about the impact of Math Strong professional development indicate a strong and positive teacher belief that the Treatment positively influenced their math content knowledge as well as instructional practice. From observational data, Treatment teachers from both participating schools and one Control school recorded one math lesson toward the beginning and end of the professional development process using the Swivl system. Due to the extensive period of time required to code and evaluate teacher lessons, quantitative assessment is not available at this time. Anecdotal reports by math coaches suggest that Treatment teachers made substantially greater use of the eight standards for mathematical practice. In addition, as teacher reflected on their lessons during lesson study, teachers showed an improved capacity to evaluate student errors and consider instructional strategies to improve student learning.

Qualitative data was collected from Treatment teachers who were asked how professional development changed their mathematics teaching. Teachers who participated in the professional development were asked to describe how their understanding of mathematical content had changed and how their mathematics teaching changed as a function of the professional development. First, they reported changes in how they thought about mathematics, including how to approach "tough problems", and reviewing mathematical content that they hadn't reflected on before. Several teachers mention an increased understanding of fractions, a key elementary school topic. Second, they reported that they increased the amount of student discussion and concomitant decreases in teacher talking. Third, they reported the use of Math Journals and rich problems as ways of promoting student discussion and cooperative work. And fifth, they reported an increased focus on math concepts and explanations. Many of the comments reported in response to how professional development changed their understanding of mathematics also apply to changes in instruction.

Without quantitative assessment of teacher videos, it is more difficult to state that math instruction has changed significantly because of professional development. However, teacher self-reports and math coach feedback provide a strong indication that professional development changed instructional practice. If math instruction changes are significant, expecting changes in student math achievement provides a more powerful coincident indicator of changed instruction.

Evaluation of the effect of professional development on student achievement with multiple measures required a separate analysis by grade level that matched achievement measures with students at specific grades. Grade level student achievement analysis reduced sample size, making it more difficult to find significant changes in Treatment vs. populations. Despite this challenge, significant and robust changes were found, particularly for younger students. Individual analyses by measures follow.

The Research-Based Early Mathematics Assessment (REMA) short form as developed and validated by Weiland et al. (2012) and Clements et al. (2008) was created to provide a validated measure of preschool and kindergarten mathematics achievement. Nineteen items from the number competency domain were administered individually to preschool teachers

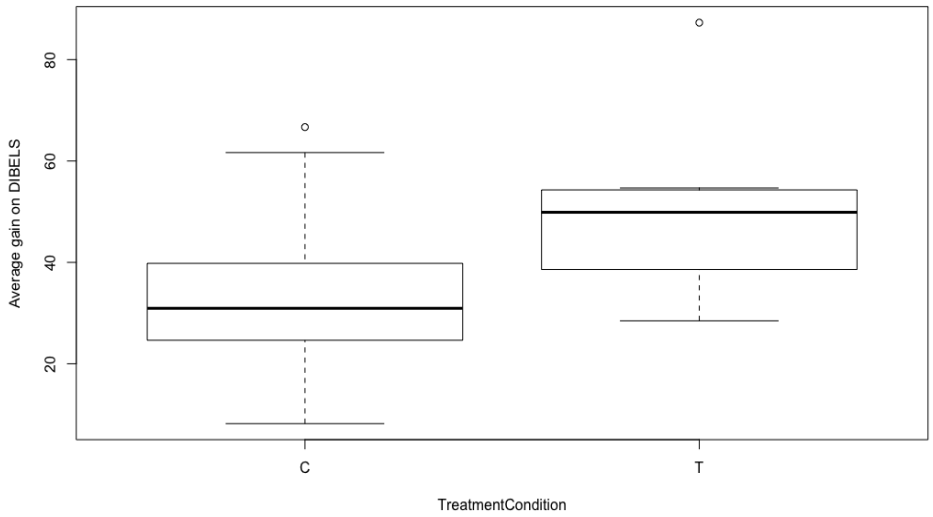
in the Control and Treatment classrooms. Data from 65 students in the Control group and 72 students in the Treatment group from which pre and post-data was available.

For Year 2, data were available for 65 students (43 with both pre- and post-data) in the Control group, and for 82 students in the Treatment group (72 with both pre- and post- data). A boxplot below shows the effect of Treatment on changes in the REMA from pre to post periods. Despite the small sample size, there was a significant difference in student improvement on the REMA test favoring teachers in the Treatment group. An ANOVA on gain scores with Treatment and Teacher as effects found a significant effect only for Treatment ($F(1,107)=8.85$, $p<.01$ (MSE=5.46) strongly suggesting that professional development had a substantial impact on preschool student number competencies.

Administration of *DIBELS Math* assessed grade level competencies for early numeracy, computation, and problem solving that function as indicators of the essential skills that every child must master in order to become proficient in mathematics. For this project, the Treatment and Control classrooms were from kindergarten through grade 5. Project staff provided one-on-one assessment in the early grades, kindergarten and first grade. Teachers administered *DIBELS Math* to their entire classroom in grades 2 through 5.

The *DIBELS Math* post-test administered in one school by the school in took place in nonstandard conditions. To ensure comparability of comparisons, the analyses used the other schools. This left 13 classrooms in the Control condition and 9 in the Treatment group for which we had reliable pre- and post-data. On the *DIBELS Math* test, the Treatment classes gained an average of 49.2 points on the *DIBELS Math*, compared with 32.3 for the Control classes. An ANOVA comparing the groups showed a significant difference (F (1, 20) =4.904, $p<.05$, MSE=312).

Figure 3.
Change in DIBELS Math scores in Treatment and Control groups pre- and post.



STAR Math data was used in Treatment and Control schools as part of routine progress monitoring of grade level student math understanding. As a global measure of grade level math competency, it is not well aligned with the professional development focus. It does provide a general indication of the generalization of professional development to a wide

range of grade level math competencies. Data from teachers in the Control and Treatment classrooms from grade 1 through 5 were analyzed. This had the effect of reducing preschool and kindergarten teachers in both groups, 11 teachers from the Treatment group and 2 teachers from the Control group. This resulted in a final sample size of 12 Treatment teachers and 27 Control teachers limiting the ability to find a statistically significant finding comparing the two groups.

The average median student growth percentile for the Treatment teachers was 61.92 compared with 54.06 for the Control teachers. As the boxplot shows, there was quite a bit of variability in each group of teachers. An ANOVA of median student growth percentile by condition showed a nonsignificant effect favoring the Treatment group, $F(1,37)=2.239$, $.10 < p < .15$, MSE=229.3. While the results are not statistically significant, the direction of change is encouraging. In average median growth, Treatment teacher's students showed greater gains than Control teacher's students.

Student achievement is considered a lagging indicator since changes in instruction as a result of teacher professional development increase over time. Nonetheless, significant statistical differences between Treatment and Control teacher classrooms on the *REMA* and *DIBELS Math* do demonstrate a robust effect on student math competency. Changes in *STAR Math*, while not statistically significant do show a qualitative change in the desired direction. Given the statistical challenges of small sample size, the differences observed on all three measures validate the power of professional development on student achievement. These finding also provides support for the belief that professional development as organized in *Math Strong* changed instructional practice. Ideally, a follow-up student examining changes in student achievement over time would provide additional evidence about the influence of professional development on student achievement.

5. FUTURE RESEARCH DIRECTIONS

The qualified success of the *Math Strong* professional development design is in contrast to the findings of most math professional development programs. In a rigorous recent review of 643 math professional development programs, only two programs demonstrated statistical evidence for positive gains in student math achievement (Gersten, Taylor, Keys, Rolfhus, & Newman-Gonchar, 2014). The findings from the *Math Strong* professional development appear to be positive and worthy of further study.

Math Strong was a hybrid of multiple strategies including video-assisted lesson study, math coaching and whole group professional development. Within the research design, it is not possible to identify which individual factors or combination thereof provided the power to influence the statistical gains reported here. As a result, further study particularly of the promising strategy of video-assisted lesson study may be valuable in future research endeavors.

6. DISCUSSION

A review of the data and analyses from the *Math Strong* professional development program provide strong and statistically robust evidence of a Treatment effect in two specific areas: (1) gains in teacher math content knowledge for teaching and (2) improvement in student achievement/proficiency. Additional corroborating qualitative evidence further supports the gains recorded from analysis of valid and reliable measures analyzed within a quasi-experimental design with matched Controls. Quantitative evidence for changes in teacher instructional practice is incomplete at the time of publication. However, teacher and math coach reports suggest that professional development did result in changes in instruction.

Another possible factor contributing to positive results was the alignment with best professional development practices suggested earlier. These include providing focused content, incorporating active learning, supporting collaboration, using of effective practice models, coaching and expert support, feedback and reflection and sustaining duration. (Darling-Hammond, Hyler, & Gardner, 2017). Reflecting on the project it also seems important that teacher ownership for implementing instructional changes through lesson study and coaching contributed to our findings. In addition, encouragement of teachers to use math journals to make student thinking more "visible" and the frequent use of engaging activities and games that were transportable to classroom instruction contributed to the positive findings.

One final observation is the importance of alignment between valid student achievement measures and the content focus of the professional development. Measures, which are global or unaligned with the focus of professional development, may not capture changes in student math thinking and proficiency (Gersten, et al. ,2014). The findings from the *Math Strong* professional development appear to be positive and worthy of further study.

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