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A PILOT INVESTIGATION OF A MULTI-TIER SYSTEM OF MATHEMATICS INSTRUCTION FOR PREKINDERGARTEN STUDENTS

By

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B.A. University of Maine – Farmington, 2009

M.S. University of Southern Maine, 2013

A DISSERTATION

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor in Psychology

(in School Psychology)

The University of Southern Maine

August, 2016

Advisory Committee:

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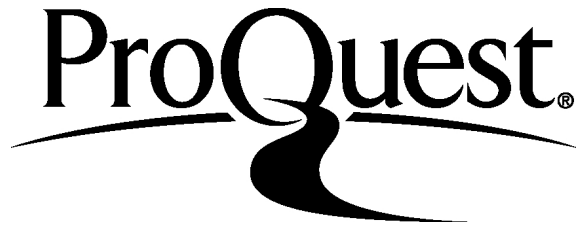Robin L. Hojnoski, Associate Professor of School Psychology, Lehigh University

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By

William B. Roy, M.S.

Dissertation Advisor: Dr. Rachel Brown

An Abstract of the Dissertation Presented

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A Multi-Tier System of Support (MTSS) for academic skills is widely recognized as the best practice framework for supporting all students. Additionally, the recent shift from constructivist pedagogy toward more intentional teaching of mathematics at the preschool level has encouraged more explicit mathematics instruction with younger children. In spite of these advances, there are no published best practice guidelines for implementing MTSS for mathematics at the prekindergarten level. The current study sought to investigate one possible way to implement effective instructional practices for preschool mathematics within a multi-tier system, including the use of validated screening and progress monitoring instruments. A centers-based mathematics curriculum was implemented at the universal level within an inclusive preschool classroom. Universal screening was conducted using curriculum-based measurement (CBM) in order to

identify at-risk students in need of additional instruction. A supplemental prekindergarten program was implemented with small instructional groups at the secondary tier of support. Students receiving supplemental instruction were progress-monitored using growth-sensitive CBMs in a multiple baseline across dyads research design. Results and limitations of the study are discussed. Finally, topics for future exploration in preschool mathematics are suggested.

ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Recent international assessment data suggest that students in the United States rank behind 29 other nations in terms of mathematics achievement for 15 year olds (OECD, 2014). This ranking comes despite the U.S. scoring in the average range on the reading and science components of the assessment. It is puzzling that the United States ranks below other major industrialized nations in mathematics despite maintaining the largest economy in the world (World Bank, 2014). In addressing these findings, U.S. Secretary of Education, Arne Duncan, pointed to investment in "high-quality, early learning systems" as one of the keys to closing the international achievement gap in mathematics (Duncan, 2013). These statements beg the question of what constitutes a high quality early learning system for mathematics. The present study begins with a review of efficacy and effectiveness research in terms of pedagogy, curriculum, assessment, and remedial intervention for mathematics at the preschool level (e.g., ages 3-5).

Preschool Mathematics during the 20th Century

Several authors have offered accounts of the evolution of early mathematics instruction in the United States. Newton and Alexander (2013) described the progression of preschool mathematics instruction in the United States during the 20th century. Their account begins with the era of experiential learning in the early 20th century, largely influenced by the pedagogy of Friedrich Froebel. Froebel posited that mathematic principles were best learned by young children when they were given the opportunity to explore math within socially valued, self-chosen activities (Newton & Alexander, 2013). Preschool programming based on the theories of Maria Montessori and John Dewey was

also prevalent during this era. Following the experiential learning era (1900-1920), preschool education was dominated by the idea of childhood readiness (1920-1940), informed by the theories of Arnold Gesell. Readiness theory posited that explicit instruction in areas such as mathematics must be withheld until the child demonstrates various readiness criteria (Newton & Alexander, 2013). These constructivist theories of pedagogy, much like Froebel's, resulted in a dearth of explicit mathematics instruction in early childhood during the first half of the 20th century (Newton & Alexander, 2013).

The trend of a relative lack of explicit instruction in early childhood mathematics during the childhood readiness era gave way to another conservative era of preschool mathematics, the cognitivist era of Jean Piaget; this era included a theoretical approach that dominated the latter half of the twentieth century (Newton & Alexander, 2013). Piaget's theories on child development created widespread attention to the concept of "developmental appropriateness" of instructional practices (Newton & Alexander, 2013). According to Piaget, formal instruction in mathematics at the preschool level would cause more harm than good due to the cognitive immaturity of preschool-aged children. Piagetian theory extended the notion that children must first pass from the "pre-operational stage" to the "concrete operational stage" of cognitive development before they can utilize the logical thinking necessary to benefit from numbers-based mathematics instruction (Elkind, 1981; Piaget, 1952). While there were some advocates for formal mathematics instruction operating in preschools during this era (e.g., Bereiter & Engelmann, 1966), Piagetian theory drove mathematics programming for many decades in the second half of the 20th century. The theoretical dominance of Piagetian

theory effectively preempted a majority of early educators from teaching basic

mathematic skills (i.e., number sense) to preschoolers (Newton & Alexander, 2013).

While Piaget's model suggested a more explicitly cognitive understanding of

child development, it still posited that children should not be pressured to learn before

they were "ready" for verbal mathematics instruction. In this regard, Piaget's work was

an extension of the constructivist models of earlier decades because he suggested that

instruction should wait for the student to indicate readiness to build on prior learning.

The unifying feature of both constructivist and readiness models was one that required

teachers to wait for students to be ready for instruction.

While explicit, verbal mathematics instruction was largely absent from preschool

classrooms through the end of the 20th century, two influential documents were published

in the early 21st century that helped to shift preschool mathematics philosophy. The first

was a report by the National Council of Teachers of Mathematics (NCTM), which

emphasized greater active teacher involvement in fostering mathematical thinking in

preschoolers (NCTM, 2000). The report by the NCTM entitled *Principles and Standards*

for School Mathematics emphasized the importance of scaffolding the everyday

experiences of preschoolers in order to promote the development of early skills in

numeracy and geometry (NCTM, 2000). In addition to the NCTM report, the National

Mathematics Panel called for early childhood educators to be made aware of the

importance of early math skills, as well as for continued research on effective

mathematics instruction at the preschool level (National Mathematics Advisory Panel,

2008). The report of the National Mathematics Advisory Panel, as well as the NCTM

report, along with accumulating data that the United States was behind internationally in

mathematics achievement, suggested that the United States was poised for a major revision in early mathematics education.

Although a paradigm shift in U.S. early childhood mathematics instruction was not initiated until the end of the twentieth century, the seeds for a significant theoretical realignment were sown as early as the 1960s. In order to outline what can currently be considered best practices in preschool mathematics instruction, it is important to consider empirical investigations that began midway through the twentieth century. In particular, the direct instruction approach to teaching mathematics can be traced to its genesis in preschool classrooms pioneered in the 1960s.

Early Research on Preschool Mathematics Instruction

In 1964, President Lyndon B. Johnson declared his "War on Poverty," a set of initiatives that included the creation of a program for low-income preschool children called Head Start (The Council of Economic Advisors, 2014). Part of the purpose of the Head Start initiative was to close the achievement gap between children raised in poverty and those from middle to upper income households (The Council of Economic Advisors, 2014). The implementation of Head Start opened the door for the investigation of several comprehensive early childhood curricula, many of which were field-tested in a series of longitudinal studies in the 1960s. Some of these curricula reflected the pedagogical zeitgeist of the time, namely constructivism, although others took a more explicit approach in teaching mathematics.

One highly explicit system for explicitly teaching at-risk students is direct instruction as developed in an Illinois preschool program in the early 1960s (Bereiter & Engelmann, 1966). Direct instruction involves deliberately planned lessons,

demonstrations, drills, and immediate learner feedback (Bereiter & Engelmann, 1966). In its earliest form, direct instruction included strands for teaching language, reading, and arithmetic. Several effectiveness studies were conducted using direct instruction at the preschool level in the late 1960s. One such study examined the overall effectiveness of prekindergarten programs on learners in the New York State school department (Di Lorenzo & Salter, 1967). This study was carried out over two years, across two cohorts of preschoolers in eight New York school districts. In total, 1,235 preschoolers participated in the study. Of these participants, half received prekindergarten services for a year, while half did not. The researchers used a pretest/posttest design to calculate the effectiveness of the preschool programs. All children were administered the Stanford-Binet Intelligence Scales at the beginning and end of the prekindergarten year. At the end of the first wave of the experiment, there were no significant differences in IQ improvement between students who did and did not attend preschool programs. However, the second cohort in the study did demonstrate a significant difference in growth, with the experimental group gaining, on average, nearly 4 IQ points at posttest than the control group (Di Lorenzo & Salter, 1967).

A closer examination of the Di Lorenzo and Salter study reveals that not all experimental condition students received the same prekindergarten programming. Each district employed a different preschool program in the study, with various programs yielding a range of results. For example, the Mount Vernon district used a "modified Montessori" approach, which yielded no significant improvement in IQ score for either cohort (Di Lorenzo & Salter, 1967). In contrast to the Mount Vernon approach, the Cortland district used the Bereiter-Engelmann direct instruction model during the second

wave of the experiment. Students in the Cortland district who participated in the direct instruction curriculum demonstrated significantly greater IQ growth than students in the control group, with an average of nearly 11 points greater growth on the Stanford-Binet at posttest (Di Lorenzo & Salter, 1967). This result is significant because IQ scores are expected to remain constant over the lifespan. These findings support the effectiveness of direct instruction on preschool aptitude in general, but fail to provide metrics that directly measure the effectiveness of the arithmetic portion of the curriculum.

In a similar investigation, three structured, task-oriented preschool curricula were compared to each other and to a control group within the Ypsilanti Public Schools in Michigan (Weikart, 1969). Those researchers compared the IQ gains from pretest to posttest on the Stanford-Binet for prekindergarten-aged students receiving (a) a social-emotional development curriculum based on the Bing Nursery School, (b) the High/Scope cognitively-based curriculum, (c) the Bereiter-Engelmann direct instruction model, or (d) no preschool programming. Students receiving *some* form of preschool programming significantly outperformed children in the control group at posttest, improving 20 points more on the Stanford-Binet. No significant difference was found among the different preschool curricula used in the study, leading the researchers to suggest that the common features of the programs (i.e., high expectations for all students, explicit instruction of skills) were more important than the differences among them (Weikart, 1969). Although this study further validated the use of structured teaching programs at the preschool level, it did not directly address achievement in mathematics.

A long-term study carried out in Louisville (KY) Head Start programs in the late 1960s further substantiated the evidence for using explicit and systematic approaches in

preschool programs (Miller & Dyer, 1975). Researchers in that study compared the effects of four different programs including (a) the Bereiter-Engelmann direct instruction model, (b) the Demonstration and Research Center for Early Education (DARCEE) program, (c) the Montessori Method, (d) a traditional Head Start program, against (e) a control group that did not attend a preschool program. Students in the Bereiter-Engelmann programs made the greatest gains from pretest to posttest on the Stanford Binet, followed by the traditional Head Start program, the Montessori program, and finally the DARCEE program. This study also used additional measures to test the subjects during the posttest portion of the project. On the researcher-developed arithmetic test, children in the direct instruction classrooms vastly outperformed students in the DARCEE, Montessori, and traditional preschool classrooms (Miller & Dyer, 1975).

Although the direct instruction approach had dramatic effects on cognitive aptitude as measured by the Stanford-Binet, and mathematics achievement as measured by the researcher-developed test of arithmetic, these effects appeared to have faded by the time the researchers conducted a second grade follow-up (Miller & Dyer 1975). This fadeout phenomenon led Carl Bereiter to posit that no program should be expected to completely inoculate children from the risk factors inherent in an impoverished childhood. However, Bereiter suggested that preschool programs can be part of a continuum of learning designed to increase the likelihood that achievement and aptitude gains during preschool are maintained in the long-term (Bereiter, 1972). Bereiter's conclusion confirms that effective instruction matters and that ongoing effective instruction is the best way to improve learning outcomes for all students. The Miller and Dyer findings support the use of direct instruction at the preschool level, particularly with

learners who are at-risk for academic problems. However, it is possible that the core components of high quality education (e.g., explicitness, repetition) are responsible for the positive gains, rather than the curricular model as a whole.

Late 20th Century Research on Preschool Mathematics

Although a number of studies published in the twentieth century demonstrated the efficacy of direct instruction in mathematics at the preschool level, these findings went largely ignored. While direct instruction methods in arithmetic were applied with some select remedial and at-risk preschool populations, by the late 1970s a majority of preschool programs had adopted Piagetian theory in their approach to mathematics. This resulted in a lack of teacher-directed, explicit instruction in number skills. Instead, most preschools in the latter half of the twentieth century employed discovery learning approaches to mathematics, adhering to Piaget's contention that children must *develop* skills like seriation and classification before they can grasp number concepts (Piaget, 1952). But, in the late 1970s and early 1980s, the evidence began to mount that Piaget may have underestimated the mathematical capability of young children (i.e., Carpenter, 1980; Starkey, Spelke, & Gelman, 1983; Thornton, 1978; Young & McPherson, 1976). This line of empirical investigation culminated in an influential study by Doug Clements in the early 1980s. Such research evidence contributed to a phenomenon termed the "math wars" among certain academics.

Clements (1984) sought to compare the effects of a number-skills program and a logical foundations program on preschoolers' number abilities and logical operations. In Clements' investigation, 45 preschoolers were randomly assigned to one of three conditions: (a) a group receiving instruction in logical foundations including

classification and seriation, (b) a group receiving direct instruction in number skills including counting, or (c) a control group receiving direct instruction in literacy skills (e.g., letter matching, vocabulary development, and auditory discrimination). All conditions included 24 lessons between pretest and posttest. The pretest and posttest instruments were constructed of 59 items relating to number skills, as well as 50 items relating to logical operations, all of which had been validated in previous studies. At pretest, all three groups exhibited significantly low scores on both measures. Children in the number skills treatment group earned a significantly higher mean score on the number posttest than children in the logical foundations group and children in the control group. Additionally, there was no significant difference in mean scores between the number skills group and logical foundations group on the logical operations posttest. These results suggest that not only can number skills be taught explicitly to preschoolers, but also this instruction might, in fact, have a transfer effect to the logical tasks of seriation and classification (Clements, 1984).

These findings also provide evidence that children do not need to have explicit experiences with seriation and classification before they can learn number skills such as counting. Given the improvement of both treatment groups on the logical operations posttest, it is possible that explicit instruction in number skills also may provide implicit experience with logical operations such as classification and seriation. Moreover, the children in the logical operations group showed some improvement on the numbers posttest, but these transfer effects were significantly lower than for the other treatment group. This suggests that explicit readiness instruction in logical operations may be

unnecessary and inefficient, and an explicit approach to teaching number skills might improve both numbers skills and logical operations (Clements, 1984).

Preschool Mathematics in the New Century

In the past few decades, the evidence suggesting that quality preschool experiences can improve long-term school success by reducing early academic achievement gaps has started to accumulate (Magnuson, Meyers, Ruhm, & Waldfogel, 2004; Tucker-Drob, 2012; Wong, Cook, Barnett, & Kwanghee, 2008). Notably, these improvements have been observed in both math and reading. This mounting evidence has led to increased interest in the nature of mathematics instruction at the preschool level. The theoretical battles that comprised the "math wars" of the twentieth century created a false dichotomy between constructivist learning and direct instruction at the preschool level (Newton & Alexander, 2013). Importantly, the final report of the National Mathematics Panel called for the end of extreme positions on "teacher-directed" and "student-centered" learning, suggesting that a balanced approach incorporating both strategies is needed for effective math instruction (National Math Panel, 2008). This federally endorsed position opened the door to a new era of comprehensive preschool math curricula.

One systematic investigation followed 2,501 preschoolers and their families, as well as their 335 teachers, over a year of instruction in Head Start classrooms (Hindman, 2013). All teachers were surveyed about the frequency of math instruction in their classrooms. In addition, observers spent a total of four hours over several visits in each of the 335 classrooms using the Classroom Assessment Scoring System (CLASS) pre-Kindergarten version. The CLASS tool values high levels of formative teacher feedback,

effective modeling of academic skills and maximum opportunities for student responding and learning, among other factors (Hamre, Goffin, & Kraft-Sayre, 2009). All students in the study were assessed on their mathematics ability at the beginning and end of their preschool year using an instrument derived from the Woodcock-Johnson Tests of Academic Achievement, Third Edition (WJ-III) Applied Problems subtest and the Early Childhood Longitudinal Study – Birth (ECLS-B) mathematics battery (Hindman, 2013).

Several significant findings emerged from this study, including a mean improvement of 5 points from pretest to posttest on the mathematics measure. A majority of teachers reported daily mathematics instruction when surveyed, but only about half were directly observed delivering mathematics instruction during classroom visits. However, frequency of mathematics instruction during CLASS observations did not significantly impact student mathematics scores. Instead, a more valid predictor of student mathematics achievement was quality of instruction as rated using the CLASS tool. Ratings on the CLASS observation tool were positively correlated with student scores on the mathematics posttest, suggesting that quality of mathematics instruction might be more important than quantity at the preschool level (Hindman, 2013). Given the characteristics of instruction valued by the CLASS pre-K tool, these findings also support the relative effectiveness of a direct instruction approach to preschool mathematics (Hamre, Goffin, & Kraft-Sayre, 2009).

Effective Preschool Math Curricula

In conjunction with the call of the National Math Panel to test the effectiveness of preschool math curricula using randomized controlled trials, several groups of researchers have recently demonstrated the effectiveness of comprehensive, core

mathematics curricula at the preschool level (e.g., Starkey, Klein, & Wakeley, 2004), as well as shorter duration, intensive intervention programs (e.g., Arnold, Fisher, Doctoroff, & Dobbs, 2002). However, a thorough review of evidence-based preschool curricula revealed a number of effective programs focused on early literacy development, but only one effective preschool mathematics program (Chambers, Cheung, Slavin, Smith, & Laurenzano, 2010). The lone program with demonstrated effectiveness in the review by Chambers and colleagues was the *Pre-K Mathematics* curriculum (Klein, Starkey, & Ramirez, 2003).

In a large-scale study across 40 public preschool and Head Start classrooms in California and New York, including nearly 300 preschool students, *Pre-K Mathematics* (Klein et al., 2003) was paired with computer-based activities from the *DLM Express Math Software* (Clements & Sarama, 2003) over a period of one school year and compared to a control group (Klein, Starkey, Clements, Sarama, & Iyer, 2008). Children in the experimental group received 58 small group (e.g., 4-6 students) lessons that were approximately 20 minutes in length each, as well as 27 computer-based activities. Lessons spanned seven units including (a) counting and numbers, (b) understanding arithmetic operations part 1, (c) spatial sense and geometry, (d) patterns, (e) understanding arithmetic operations part 2, (f) measurement and data, and (g) logical reasoning. Children in the control group received 21 minutes a day of math instruction from several curricula, including Montessori, High/Scope, and the Creative Curriculum. In order to measure the effectiveness of the instruction, a pretest/posttest design was employed, using the WJ-III Applied Problems subtest, Child Math Assessment-Abbreviated (CMA-A), and a researcher-designed Shape Composition Task (Klein et al.,

2008). While the control and experimental groups both showed significant improvement on the CMA-A from pretest to posttest, the experimental group improved by an additional 8 points on average than the control group. Moreover, the effect size of the intervention on the WJ-III Applied Problems measure was calculated to be a robust +0.22 at posttest for the students in the experimental group (Chambers et al., 2010). A major limitation of this study lies in the variability of the curricula employed in the control group.

Another well-researched, comprehensive mathematics curriculum for preschoolers is the *Building Blocks* program (Clements & Sarama, 2007). *Building Blocks* is based on years of research on preschool mathematics learning trajectories (Clements & Sarama, 2004). These learning trajectories outline the component skills of broader mathematical concepts and the instructional hierarchy inherent to each concept (Clements & Sarama, 2004). The curriculum combines direct instruction methods, guided practice, interactive learning strategies, and software to foster mathematics achievement in young children, while emphasizing frequent formative assessment to ensure that all learners are making progress along the learning trajectories (Clements & Sarama, 2007).

In one investigation, a randomized controlled design was used in which 68 New York state preschoolers were assigned to one of two conditions: (a) the *Building Blocks* curriculum or (b) a control condition consisting of less structured mathematics instruction (Clements & Sarama, 2007). In order to measure the effectiveness of each condition on mathematics achievement, a pretest/posttest design was employed, using a researcher-designed assessment of early mathematics skills, the Building Blocks Assessment of Early Mathematics (Sarama & Clements, 2007). Preschoolers receiving the *Building*

Blocks curriculum made significantly greater gains at posttest than students in the control group (Clements & Sarama, 2007). Notably, this study was limited by its primary measure, which was designed by the researchers to measure the effectiveness of their curriculum, and thus was susceptible to treatment inherent bias (Slavin & Madden, 2011). Due to the lack of a treatment independent measure in this study, these results must be interpreted with caution.

In a second, expanded investigation in New York State, 927 preschoolers from 42 different schools received instruction using *Building Blocks*, while a control group of 378 preschoolers received instruction using one of two constructivist-based curricula (e.g., *Where Bright Futures Begin* or *Opening Worlds of Learning*) over a school year (Clements, Sarama, Spitler, Lange, & Wolfe, 2011). Once again a pretest/posttest design was employed, this time using an updated version of the Building Blocks Assessment of Early Mathematics known as The Research-based Elementary Math Assessment (REMA; Clements, Sarama, & Liu, 2008). Children receiving instruction using the *Building Blocks* curriculum showed significantly greater growth at posttest than the control group, with an overall effect size of +0.72 (Clements et al, 2011). However, this study was limited by its lack of treatment independent measures and must be interpreted with caution. In spite of the limitations of these studies, there is adequate evidence to suggest that *Building Blocks* might be effective as a core mathematics curriculum at the preschool level.

Response to Intervention in Early Childhood

Response to Intervention (RTI), otherwise known as a Multi-Tiered System of Student Supports (MTSS), is an approach to increasing the effectiveness and efficiency

of education by combining high quality instruction, frequent formative assessment, and data based decision-making (Brown-Chidsey & Bickford, 2015; Brown-Chidsey & Steege, 2010). While the success of RTI at the elementary, middle, and high school levels has been well documented (i.e., Burns, Riley-Tillman, & VanDerHeyden, 2012; Riley-Tillman, Burns, & Gibbons, 2013), the application of RTI/MTSS to the preschool level remains in its infancy. Recognition & Response (R&R) is one approach to preschool RTI/MTSS that has been piloted (Buysse & Peisner-Feinberg, 2010). R&R suggests using an effective, research-based core curriculum at Tier 1 with intentional teaching while providing universal screening to determine which students need additional support. Tier 2 in R&R consists of explicit small group interventions and progress monitoring, while Tier 3 includes the addition of individualized scaffolding and more frequent progress monitoring (Buysse & Peisner-Feinberg, 2010).

One obstacle inhibiting the implementation of RTI/MTSS at the preschool level is the historical lack of normative and predictive validity data of preschool screening measures and progress monitoring instruments (Ball & Trammell, 2011). While data have been published validating the use of various general outcome measures in the realm of early literacy (i.e., Greenwood, Carta, & McConnell, 2011; Greenwood et al., 2011), curriculum-based measurement of early numeracy is still largely in the process of being validated (Clarke, Baker, Smolkowski, & Chard, 2008; Norwalk, DiPerna, & Lei, 2014). Furthermore, preschool-age universal screening measures have largely focused exclusively on number skills (Gersten et al., 2012). While number skills are vital to early mathematics development, other mathematical skills are appropriate to begin targeting at

the preschool level, such as geometry (Clements & Sarama, 2011) and patterns (NCTM, 2000).

Currently, there is one set of preschool mathematics screening and progress monitoring measures which offers national norms, local norms, and cut-scores for making data-based decisions within an RTI/MTSS framework (MyIGDIs, 2014). *My Indicators of Individual Growth and Development* (MyIGDIs) include a set of five early literacy measures and four early numeracy measures. The numeracy measures, formerly known as the *Preschool Numeracy Indicators* (IGDIs-ENs), were developed by researchers at the University of Memphis (Floyd, Hojnoski, & Key, 2006) and were recently renamed the Individual Growth and Development Indicators–Early Numeracy (IGDIs-EN). The IGDIs-EN are curriculum-based measures of one-to-one correspondence counting fluency, oral counting fluency, number naming fluency, and quantity comparison fluency. These measures were shown to have excellent technical features when tested with a sample of 163 preschool-aged children, including adequate reliability, as well as concurrent validity with the Bracken Basic Concepts Scales – Revised (BBCS-R), Woodcock-Johnson Third Edition (WJ-III) Applied Problems subtest, and the Test of Early Mathematics Ability – Third Edition (TEMA-3; Floyd, Hojnoski, & Key, 2006).

The four original IGDIs-ENs were additionally field-tested as progress monitoring measures with 139 Head Start students on a monthly basis from October to May of a single school year (Hojnoski, Floyd, & Silberglitt, 2009). Results from the field test yielded adequate data in terms of sensitivity to growth, thus supporting the use of these IGDIs-ENs as general outcome measures (GOM). Although other measures have

shown promise in their development as progress monitoring tools for early learners (i.e., Norwalk, DiPerna, & Lei, 2012), the IGDIs-ENs were the first commercially available progress monitoring and screening tools for preschool-aged math students that offered normative data. Recently, a new assessment system known at the *Formative Assessment System for Teachers* (FAST) offers a set of prekindergarten and kindergarten CBMs focused on early numeracy skills (Christ, 2014). However, the FAST early numeracy measures are still in the process of validation and norms for these measures were not yet available at the time of this investigation. The shortage of mathematics curriculum-based measures for preschool-aged students is indicative of the relative immaturity of the application of RTI/MTSS to early learners.

Research Question and Hypothesis

The recent validation of the effectiveness of core mathematics instruction at the preschool level (e.g., Clements & Sarama, 2007), paired with the large evidence base for remedial approaches such as *DISTAR Arithmetic* and *Number Worlds*, provides a foundation for an implementation of RTI/MTSS for mathematics at the preschool level. This line of thinking is further substantiated by the recent validation of the IGDIs-ENs. However, an exhaustive search of the literature revealed no published accounts of RTI/MTSS implementation for mathematics at the preschool level. Given the national agenda to improve early learning in mathematics, investigations into best practices in RTI/MTSS at the preschool level are critically needed.

The use of a multi-tier system of support for academics has been well validated for students in grades K-12. Research on the use of fully developed MTSS systems for early learners is important to help refine approaches to early mathematics instruction in

order to help prevent math failure. The purpose of the current study was to validate a multi-tier approach to prekindergarten math instruction using screening and progress monitoring of all students using the Early Numeracy Individual Growth and Development Indicators (IGDIs-ENs), the *Building Blocks* curriculum at the primary tier, and *Pre-K Mathematics* at the secondary tier. For students in need of secondary tier instruction, a multiple baseline across dyads design was employed to evaluate the effectiveness of the *Pre-K Mathematics* curriculum as a Tier 2 intervention. The research hypothesis was that students in need of secondary tier mathematics instruction would make substantial and meaningful gains with early mathematics skills given supplemental instruction using the *Pre-K Mathematics* intervention.

CHAPTER 2: METHOD

Design

The study employed a multiple baseline across dyads design (MBD) combined with a multiple probe component. In an MBD, replication is achieved across participants, settings, or various stimuli. This is accomplished by staggering the implementation of the treatment across conditions (i.e., subjects, settings, or stimuli). The lag between each experimental phase allows for the potential of experimental control, as extended baseline phases within the other conditions allow the experimenter to rule out external variables being responsible for any observed changes (Cooper et al., 2007). The MBD is indicated when the withdrawal of a potentially effective intervention would be unethical, or would not lead to a return in baseline levels of responding, as is often the case with academic skill-building interventions. The MBD is useful for demonstrating the generalized effects of interventions across a variety of students, and is thus well suited to applied research in school settings (Riley-Tillman & Burns, 2009). As with any baseline condition in a single-case research design, at least three data points indicating a stable level of responding must be observed before an experimental phase change is introduced (Cooper et al., 2007). It should be noted that *The What Works Clearinghouse* requires a minimum of five data points in a phase to meet evidence standards without reservations (Kratochwill et al., 2010).

Participants

The sample of students included a purposeful selection of students from differing backgrounds, and with differing individual characteristics. The participants were recruited from the preschool classroom of a private preschool located in the Northeast

U.S. All participants were between the ages of 50 and 60 months at the beginning of the study. In accordance with the program's policies, all children attending the preschool were previously screened using the IGDIs-EN. The participants eligible for the Tier 2 intervention were identified using local normative data gathered during the January 2016 administration of the IGDIs-EN, including Oral Counting, One-to-One Correspondence Counting, Number Naming, and Quantity Comparison tests. Students scoring at or below the 40th percentile on more than one of the IGDIS-EN measures were considered in need of supplemental instruction. Students were excluded from the study if they were unable to demonstrate the prerequisite skills to participate in the *Pre-K Mathematics* lessons including attending to dyad-based instruction for 20 minutes at a time. The parents of all possible participants were contacted regarding informed consent (permission) for participation. Parent permission was documented through written procedures. In addition, all participants provided witnessed assent for participation. All data collection was conducted following the approval of the University's Institutional Review Board (IRB), as well as parental permission, and student assent.

The participants included six children ranging from 51 to 59 months of age at the beginning of the study. The sample included four male students and two female students. One of the participants, Eunice (51 months old at the start of the study), was receiving special education services under the category of Autism through an Individualized Education Program (IEP). Her diagnosis of Autism Spectrum Disorder (ASD) indicated level 2 severity (requiring substantial support) for social communication and level 2 severity (requiring substantial support) for restricted repetitive behaviors; without accompanying intellectual impairment; with accompanying language impairment. The

other participants included Rose (57 months), Ted (57 months), John (51 months), Robert (59 months), and Joe[*] (56 months). All six participants demonstrated a need for additional math intervention as evidenced by IGDIs-EN scores that fell at or below the 40th percentile for the class. Instructional dyads were established based on stability of baseline data. Rose and John were paired together as the first dyad to receive instruction, while Robert and Eunice comprised the second instructional dyad, and Ted and Joe formed the final instructional dyad.

Setting

The study was carried out in a private preschool program that is housed within a special-purpose private school for children with disabilities in the northeast. The preschool program includes students with and without disabilities and functions as an inclusive setting for students receiving special education services. The private preschool program included a 3 year old classroom as well as a 4 year old classroom; the study recruited students from the 4 year old classroom only. The 4 year old preschool classroom included two classroom teachers, as well as 3-5 paraprofessionals present at any given time. The preschool program operated from 8:30 am to 3:00 pm. 15 children were enrolled in the 4 year old program at the time of the study.

Materials

Tier 1 instruction was delivered in the classroom using elements of the *Building Blocks* prekindergarten mathematics curriculum (Clements & Sarama, 2007). *Building Blocks* provides a blend of explicit group instruction and demonstration, guided practice, game-based practice, cooperative exploration activities, and computer-based activities to

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[*] All student names are pseudonyms.

promote the development of early mathematics skills. The *Building Blocks* curriculum utilizes a number of manipulatives, storybooks, and integrated activities to encourage ample practice and exposure with a number of mathematical topics. Full class instruction using selected parts of the *Building Blocks* curriculum was part of the preschool curriculum and was delivered on a daily basis. The parts in use during the study were hands-on lessons, didactic instructional elements, and games contained within the curriculum kit, but other elements, such as the computer-based games were not in effect. This implementation strategy is not consistent with the procedures used in the *Building Blocks* validation studies. It should be noted that the *Building Blocks* curriculum constitutes universal mathematics instruction for the classroom, was in effect prior to the start of the study, and should not be considered an independent variable for the current investigation. Rather, *Building Blocks* can be considered an element of baseline instruction for the selected sample. In addition to the *Building Blocks* elements, other mathematics lessons were presented using a variety of materials pulled from the internet and other early childhood education resources.

Tier 2 instruction was delivered using the *Pre-K Mathematics* curriculum. *Pre-K Mathematics* is a scripted, supplemental curriculum designed to develop the informal mathematical knowledge and skills of preschool children. The program includes content organized into seven units including Number Sense and Enumeration, Arithmetic Reasoning [Part 1], Spatial Sense and Geometric Reasoning, Pattern Sense and Pattern Construction, Arithmetic Reasoning [Part 2], Measurement and Data Representation, and Logical Relations. Lessons were designed to be delivered one per week; for the current study, two lessons were delivered each week, one on Mondays and one on Fridays.

Concepts and skills from each unit were taught through teacher-guided, small group activities using concrete manipulative materials. Sample lessons from *Pre-K Mathematics* are provided in Appendix A.

Measures

Student performance in mathematics was screened and progress-monitored using the IGDIs-ENs, which are part of the My Individual Growth and Development Indicators (MyIGDIs) assessment suite. The IGDIs-ENs consist of curriculum-based measurement (CBM) of four separate general outcome measures related to early mathematics instruction: Oral Counting (OC), One-to-One Correspondence Counting (OCC), Number Naming (NN), and Quantity Comparison (QC). The IGDIs-EN are delivered using a series of spiral-bound administration books. Previous research on the IGDIs-EN suggested each task was sensitive to growth over time, with growth rates for three of the tasks (i.e., QC, OC, and OCC) calculated at 1 item per month, and NN at a rate of 0.5 items per month. These rates were deemed sensitive enough to be detected upon a visual analysis of graphed progress data (Hojnoski, Floyd, & Silberglitt, 2009). These growth rates were used to assess participant response to intervention in the current study.

In addition to the IGDIs-EN, students receiving intervention were administered the *Test of Early Mathematics Ability – Third Edition* (TEMA-3) just prior to intervention, and were administered an alternate form of the TEMA-3 directly following the intervention period. The TEMA-3 is a psychometrically sound measure of mathematics ability for individuals aged 3-0 to 8-11. The TEMA-3 can be used to measure progress, evaluate programs, screen for readiness, and guide instruction and remediation. The test measures a variety of mathematics concepts and skills including:

numbering skills, number-comparison facility, numeral literacy, mastery of number facts, calculation skills, and understanding of concepts. The test has two parallel forms, each containing 72 items. The standardization sample was composed of 1,219 children. The characteristics of the sample approximated those in the 2001 U.S. Census. The TEMA-3 provides standard scores, percentile ranks, and age and grade equivalents. Internal consistency reliabilities were reported to be above .92; immediate and delayed alternative form reliabilities were reported to be in the .80s and .90s. The TEMA-3 is individually administered using a spiral-bound presentation book and a number of manipulatives; it takes approximately 40 minutes to administer (Ginsburg & Baroody, 2003).

In addition to the primary dependent measures, a treatment integrity checklist was developed by the primary investigator based on the *Pre-K Mathematics* manual (See Appendix B). An open-ended social validity questionnaire was also developed by the primary investigator to gauge participant acceptability of the lessons and assessment measures (See Appendix C).

Procedure

The study began with reviewing winter screening data from all students in the preschool classroom. Such screening data are collected three times a year as part of the preschool's curriculum by a state certified early childhood education teacher. The screening data were gathered during the winter benchmark screening period for the IGDIS-ENs, between January 15 and January 30 of 2016. All interventionists completed the CITI human subjects research training prior to the onset of the research project. Upon receiving IRB approval for the study, screening data were analyzed to determine which students might benefit from supplemental instruction.

Those students whose parents provided consent -- and who themselves agreed to participate in supplemental instruction using *Pre-K Mathematics* -- were progress-monitored on a twice weekly basis as they participated in class-wide instruction in order to collect baseline data on their mathematics skills. All four IGDIs-EN measures were used for progress monitoring and were administered in the order used by Hojnoski et al. (2009): OC, OCC, NN, and QC. Additionally, subjects were administered the TEMA-3 prior to their participation in small group *Pre-K Mathematics* instruction. Once stable responding was observed for two students being progress-monitored with the IGDIs-EN, those two students began receiving small group instruction using *Pre-K Mathematics* twice a week, while all other participants continued to be progress-monitored on a weekly basis.

The *Pre-K Mathematics* lessons were incorporated into the existing mathematics enrichment block of the prekindergarten classroom schedule, which allowed all participants to continue receiving universal instruction along with their peers. Following favorable response to intervention by the first dyad, and once a second dyad of students achieved stable baseline data, the second dyad began to receive small group instruction using *Pre-K Mathematics* as well. For each new dyad, additional instructional groups were formed. All dyads were progress-monitored until they demonstrated stable responding on a majority of the IGDIs-EN, at which point they began the *Pre-K Mathematics* intervention. All participants in the intervention phase were progress-monitored using the full set of IGDIs-EN twice a week. The study took place over a seven week period. Following completion of the *Pre-K Mathematics* intervention, all participants but one were administered the alternate form of the TEMA-3. Eunice was not

available to complete the alternate form of the TEMA-3 following intervention due to illness.

As discussed below, initial baseline data collection suggested that a practice effect was suspected after multiple administrations of the IGDIs-EN, so an additional multiple probe element was added. A multiple probe design utilizes intermittent probes of skills in place of continuous baseline measurement. A multiple probe design is indicated when baseline data collection might prove reactive due to practice effects, is impractical or cumbersome for participants, and a strong a priori assumption of data stability can be made (Horner & Baer, 1978). Upon initiation of the multiple probe component, at risk students were administered the four IGDIs-EN once a week during extended baseline phases after the first instructional dyad had begun.

The primary investigator conducted all instructional sessions using the *Pre-K Mathematics* curriculum. A second interventionist, a post-doctoral intern, was trained using the *Pre-K Mathematics* manual during professional development sessions provided by the primary researcher to prevent missed instructional sessions in the case of the primary interventionist's illness. A doctoral intern systematically monitored 30% of intervention sessions for treatment integrity using the treatment integrity checklist (See Appendix B). Students not participating in the *Pre-K Mathematics* lessons participated in enrichment activities in mathematics concurrent to the delivery of the Tier 2 lessons.

A trained post-doctoral intern was responsible for the primary data collection using the IGDIs-EN. The intern scoring the IGDIs-EN was blind to the phases of the study and to which instructional dyad the subject belonged. All training for the IGDIs-EN utilized the published training materials available on the *My IGDIs* website including the

procedural checklists for each of the discrete assessments. The primary investigator

administered the *TEMA-3* to all study participants. In addition, the primary investigator

collected inter-observer agreement (IOA) data during 45% of administration sessions of

the IGDIs-EN across all phases of the study. These data were collected in vivo during the

selected IGDIs-EN administrations. IOA was calculated using the total count approach

such that the number of agreements between observers was divided by agreements plus

disagreements to yield a percentage.

In order to measure the level of perceived social importance of the current study,

a number of social validity measures were employed following completion of data

collection. Social validity is often separated into three distinct categories: social

significance of the goals, social significance of the procedures, and social significance of

the actual effects of the research (Wolf, 1978). A researcher-designed oral questionnaire

was administered to study participants to gauge their perceptions of the intervention

process (see Appendix C). Each participant debriefed in a quiet office with the primary

investigator and orally answered a questionnaire concerning his or her experience with

the study. This debriefing session also provided each participant the opportunity to ask

any questions about the purpose of the study.

Data Analysis Methods

During the baseline and intervention phases, all participant data were graphed on

time series line graphs in order to facilitate visual analysis. Data were recorded directly

following each administration of the IGDIs-EN onto four separate graphs, with one for

each IGDI-EN used. Each student's graphs were visually inspected directly following

each occurrence of progress monitoring to analyze changes in level, variability, and trend

of responding (Riley-Tillman & Burns, 2009). In addition to visual analysis, the percentage of non-overlapping data points (PND) was calculated in order to determine robustness of intervention effects. This process involves drawing a horizontal line through the highest score in the baseline phase and dividing the total number of data points above this line by the total number of intervention data to yield a percentage (Riley-Tillman & Burns, 2009). Scruggs and Mastropieri (1998) recommended that a large effect is observed when the PND is at or above 80%. Rate of Improvement (ROI) was calculated for each subject, relative to each of the IGDIs-EN, for baseline and intervention. ROI was calculated using the guidelines set by Kovaleski et al. (2013), by subtracting the first data point within a phase from the last and dividing by the total number of weeks within the phase.

TEMA-3 data were analyzed on an individual basis only (i.e., no group statistical calculations were completed) due to small sample sizes and lack of random assignment. All subjects who completed the TEMA-3 prior to intervention and following intervention had their scores assessed for improvement based on the number of standard deviations their scores improved. There are currently no formal guidelines for analyzing progress when using the TEMA-3, however, it was deemed an important supplemental source of subject performance data due to its contents having a wide-reaching survey of mathematics skills and concepts.

CHAPTER 3: RESULTS

Mean treatment integrity data showed that the accuracy of the intervention was 97.7%, and ranged from 86% to 100% across all sessions, indicating that the *Pre-K Mathematics* lessons were delivered with satisfactory levels of fidelity. The average IOA of the study, as calculated using the total count approach (i.e., the number of agreements between observers was divided by agreements plus disagreements to yield a percentage across all sessions) was 96.5%, ranging from 87% agreement to 100% agreement, thus documenting strong observer agreement. Both the treatment integrity and IOA data indicate that the study results could be interpreted with confidence.

All of the study participants entered intervention with at least two IGDIs-EN scores that fell at or below the 40th percentile based on classroom normative data. Given that the local normative data suggested that all six subjects were performing at the 40th percentile or below for at least two of the measures, all subjects were deemed appropriate to receive tier 2 intervention. Although the 40th percentile is within the average range of scores, it is a commonly used threshold for students whose current school performance might indicate risk for later school difficulties. Given the focus of the curretn study on preschool intervention, the 40th percentile was maintained as the cut point for identifying students who might have future difficulties with mathematics in school. Winter screening results for all six participants are presented in Table 1 below. As hypothesized, the results suggest that the *Pre-K Mathematics* curriculum, when presented in supplement to the classroom's universal math instruction, accelerated the learning of all the study participants as measured by the IGDIs-EN. The participants' IGDIS-EN scores are displayed in Figures 1 through 4 below.

Table 1

Winter Screening Scores for Oral Counting (OC), One to One Correspondence Counting (OCC), Number Naming (NM), and Quantity Comparison (QC)

Subject	OC	OCC	NN	QC
Rose	12*	12*	2*	14*
John	12*	0*	12	14*
Eunice	11*	6*	5*	19*
Robert	10*	4*	18	19*
Ted	15*	3*	8*	14*
Joe	3*	7*	2*	9*

*Score fell below the upper cut score

Rose began the study with stable OC scores, stable OCC scores, relatively stable NN scores, and QC scores that appeared to be on a slight downward trend. After three instructional sessions, Rose had not made progress on any of the four measures; in fact, her OC scores (12) and OCC scores (12) remained the same from baseline through the first three progress monitoring sessions. However, she showed tremendous growth on OC and OCC beginning with the fourth session of progress monitoring, elevating her OC score to 29 and her OCC score to 20. Rose's OC score remained stable at 29 until the final progress monitoring session when she scored a 39. Her growth with respect to OCC and QC was more gradual. Rose did not make large gains with NN, although the calculated percentage of non-overlapping data points (PND) was 100% with respect to Rose's performance on the NN task. This high PND, but small effect, suggests that Rose improved her number naming capabilities but only slightly. In contrast, the PND for

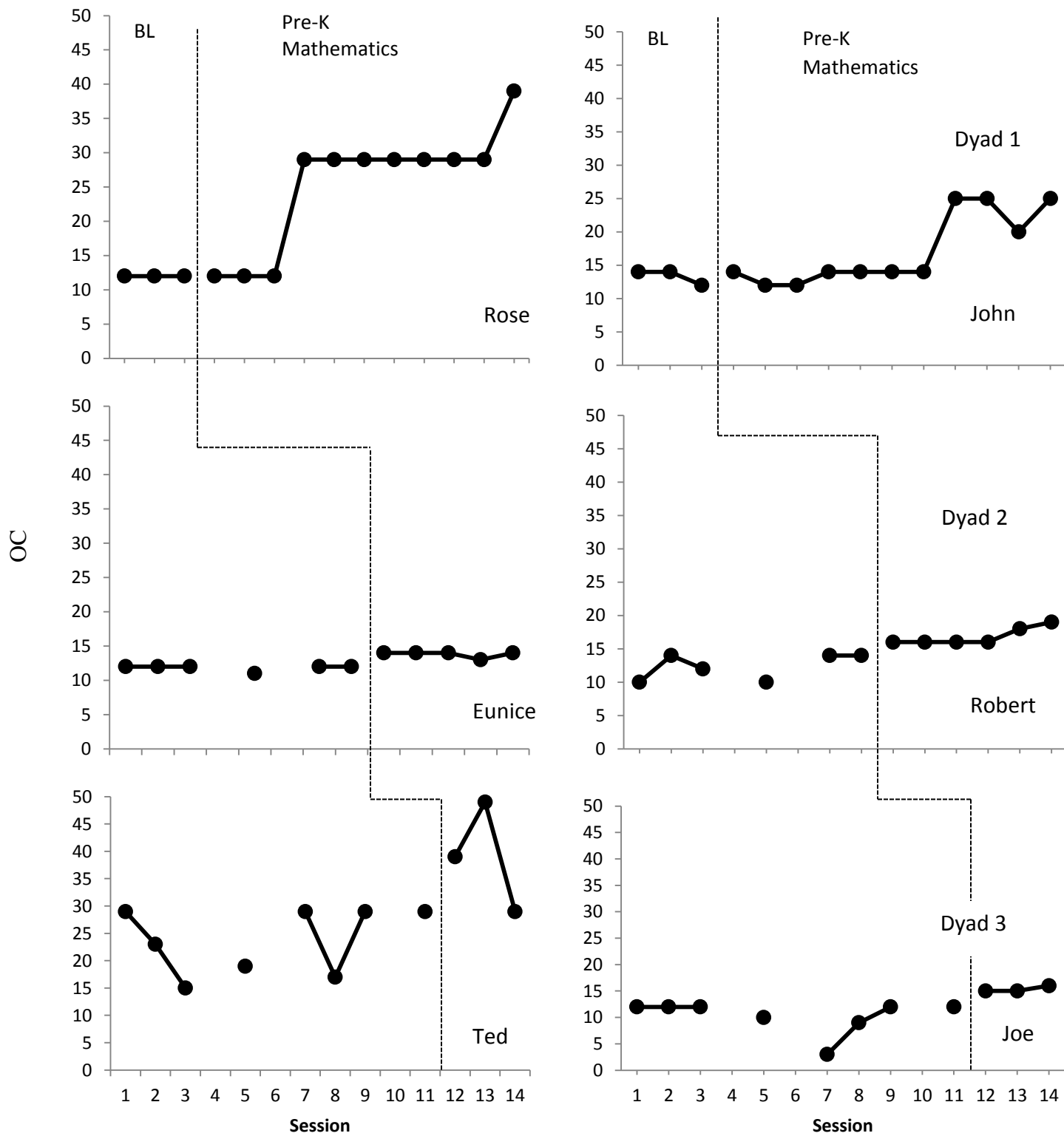Figure 1: Oral Counting (OC) Scores for All Participants

Figure 2: One to One Correspondence Counting (OOC) Scores for All Participants
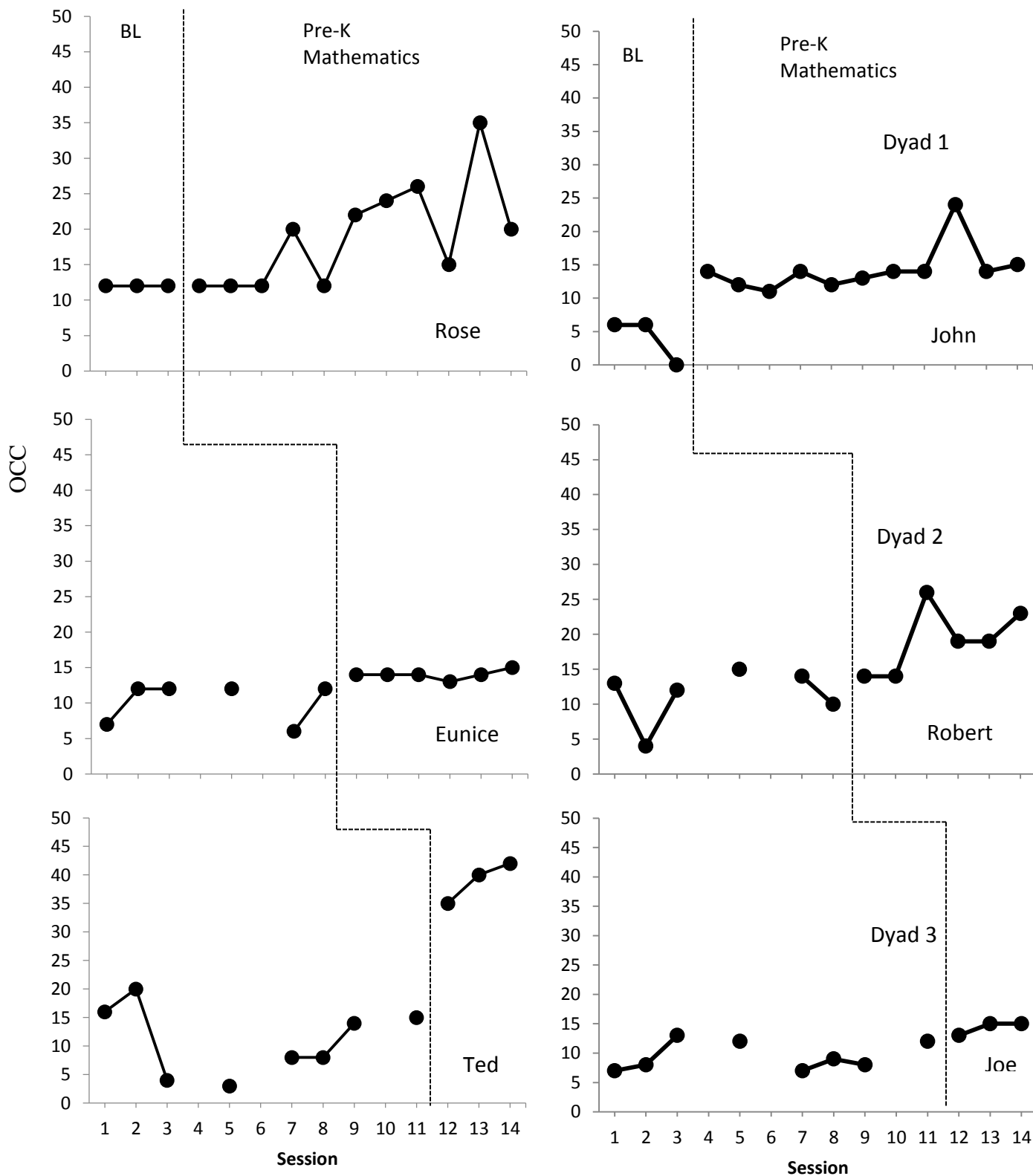
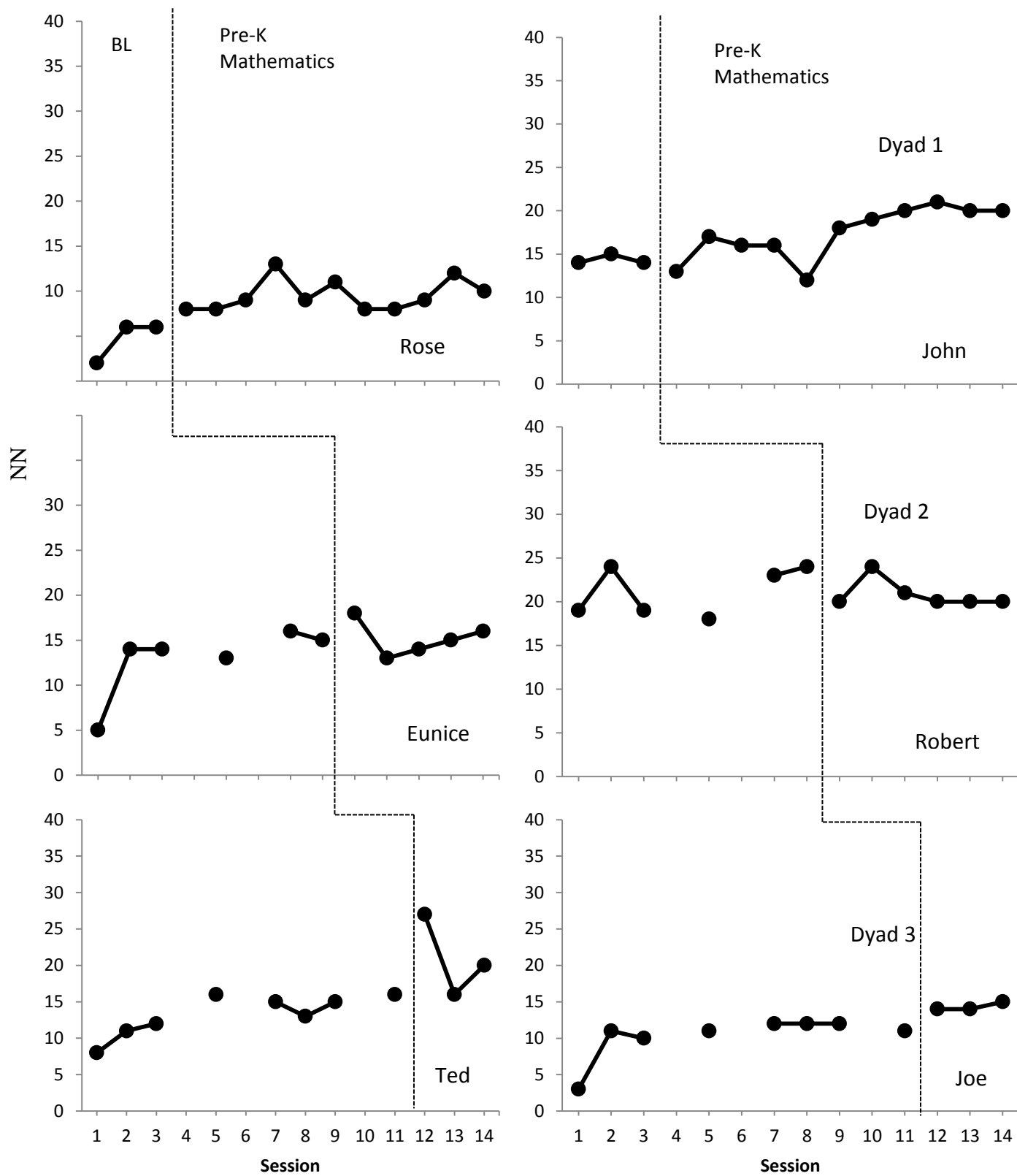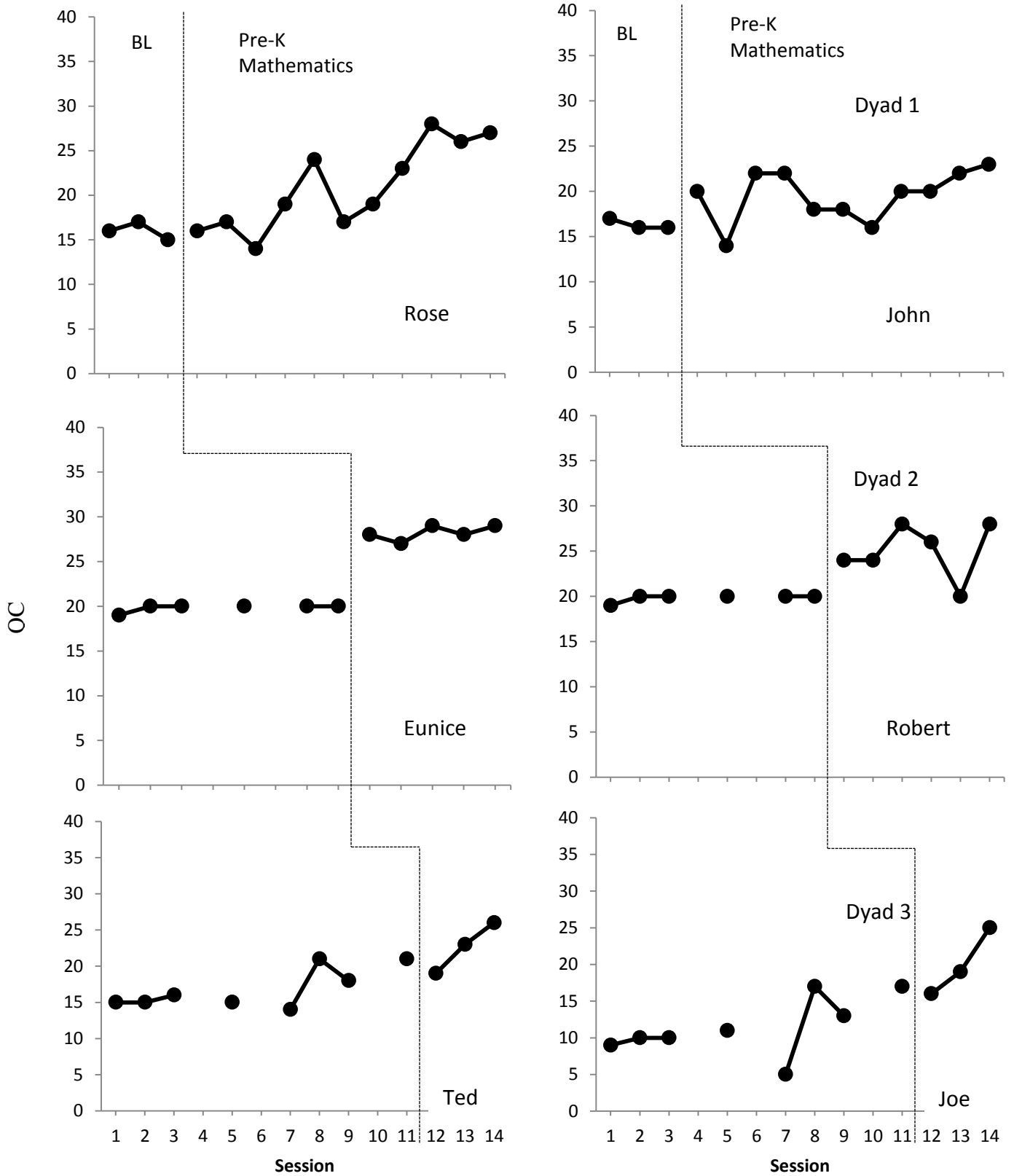Figure 3: Number Naming (NN) Scores for All Participants

Figure 4: Quantity Comparison (QC) Scores for All Participants

Rose's OC was only 73%, but her actual gains were quite significant in that she raised her score 27 points from baseline. The PND for both OCC and QC was 64%, but a visual analysis suggests that her gains were substantial with both of these skills. Overall, Rose appeared to benefit from *Pre-K Mathematics* instruction, but with a relatively long latency before a significant growth step was observed. Rose finished the study with all four of her IGDIs-EN scores falling above baseline levels.

Rose's dyad partner, John, entered intervention with slightly decreasing OC, OCC, and QC scores, and stable NN scores. John demonstrated growth with OC only upon the eighth progress monitoring session, when his score climbed from 14 to 25, and remained at 20 or above during all subsequent progress monitoring sessions. Even though John did not continue a downward trend with OC once intervention started, the long latency between the start of intervention and John's improvement with OC makes it difficult to attribute his growth with this skill primarily to the *Pre-K Mathematics* lessons. The PND for John's OC data in intervention was 36%. In contrast, John made immediate and significant gains with respect to OCC, improving from his final baseline score (0) by 14 points after just one session of intervention. He showed gradual progress with OCC throughout the rest of the intervention phase of the study, with his highest score (24) coming in the final two weeks of the study. The PND for John's OCC data was 100%, which suggests the instructional lessons were responsible for his gains. John exhibited steady progress on NN beginning with the second session of progress monitoring. The PND for John's NN data was 82% and his highest score came during the last two weeks of intervention. These results suggest that John made considerable progress with NN during the intervention phase of the study. John demonstrated immediate gains with QC

upon starting intervention, but demonstrated his lowest score (14) during the second session of intervention data collection. John's performance with QC rebounded for two sessions following the second data point of intervention, dropped slightly for three consecutive sessions, and finally trended up to his highest QC score (23) which he attained during the last session of data collection. The PND for John with respect to QC was 82%, which suggests that he improved from baseline to intervention. John finished the study with OC, NN, OCC, and QC scores significantly above his levels of performance at baseline.

Eunice, who was part of the second dyad to receive intervention, entered intervention with highly stable OC, NN, and QC scores. Her OCC scores during baseline were relatively stable with four of the six data points being 12 and two others falling below 12. Eunice made immediate, but small, gains with respect to OC and OCC; the PND for each of these measures was 100%, but with only minimal score increases for both. Eunice demonstrated an immediate score increase for NN upon entering intervention, but this increase was not sustained, resulting in a PND of 17% for NN. In spite of minimal growth on the first three measures, Eunice made significant and immediate gains with QC, raising her score by eight points from the final baseline data point to the first intervention phase data point. Eunice continued to make steady progress with QC through the final part of the study, resulting in a PND of 100%. Eunice finished the study with all but her NN scores falling above baseline levels.

Eunice's dyad partner, Robert, entered intervention with highly stable baseline data for OC and QC, relatively stable data for OCC, and a slight increasing trend for NN. He demonstrated immediate improvement with OC and QC, made slightly delayed gains

with OCC, but did not make any progress with respect to NN. Robert's improvement with OC was small, but showed a steady upward trend in the final few weeks of intervention. Nonetheless, the PND for Robert's OC data was 100%, supporting the role of the intervention in improving his oral counting skills. Robert did not demonstrate significant improvement with OCC until the third data point of the intervention phase, when his score increased by 12 points; subsequent data points for OCC remained well above baseline levels, resulting in a PND of 67%. Robert performed at baseline levels on the NN measure throughout the entire intervention phase, resulting in a PND of 0%. However, it should be noted, that Robert demonstrated the highest NN scores of any of the subjects during baseline, and all of his NN scores during the study across baseline and intervention exceeded the upper cut score for his age. He demonstrated immediate and sustained growth with QC with his three highest scores occurring during the final two weeks of intervention. The PND for Robert's QC data was 83%, suggesting that his gains can be attributed to the intervention. Robert finished intervention with all but one (NN) of his IGDIs-EN scores falling above baseline levels.

Ted, one half of the final instructional dyad, entered intervention with relatively stable OC performance (three of the four final baseline data points were sores of 29), relatively unstable OCC performance, relatively stable responding for NN, and a slight increasing trend for QC. Ted showed immediate responsiveness to the *Pre-K Mathematics* intervention, with his OC score increasing by 10 points from the final baseline data point to the first intervention data point. He improved 10 additional points from the first OC data point during intervention to the second. Unfortunately he skipped a number while counting orally during the final administration of the IGDIs-EN during

intervention which resulted in a baseline level data point of 29. Overall, his improvements with respect to OC were impressive and resulted in a PND of 67%. Ted demonstrated the most significant growth of any subject with respect to OCC with his score increasing by 20 points from the final baseline data point to the first intervention data point. His OCC scores remained on an upward trend for the rest of the intervention period, resulting in a PND of 100%. Thus, in spite of slightly unstable baseline data for OCC, Ted's improvements with one to one correspondence counting were significant enough to support the efficacy of the intervention. Ted demonstrated instant improvement with NN as well, improving his NN score by 11 points from the final baseline data point to the first intervention data point. The second intervention data point overlapped with Ted's baseline data, but the third NN data point during the intervention phase was above baseline levels, resulting in a PND of 67%. Ted showed a delayed improvement in QC during intervention, with his second and final QC scores during intervention falling well above baseline levels and on an upward trend. It should be pointed out that Ted appeared to be gradually improving with QC during baseline. However, the slope of improvement for QC during the intervention phase was much steeper than that of baseline, which suggests that although he was improving with QC prior to intervention, the intervention likely accelerated his rate of improvement. The PND for Ted's QC data was 67%. Ted finished with all four of his IGDIS-EN scores falling above baseline levels.

Ted's dyad partner, Joe, demonstrated relatively stable responding during baseline data collection with respect to OC, OCC, and NN, with an increasing trend on QC measures. Joe made immediate, small, gains with respect to OC and NN, as evidenced by a PND of 100% for both measures. He demonstrated improvements with OCC beginning

with the second data point collected during intervention, resulting in a PND of 67%. With respect to QC, Joe began intervention with a slightly increasing trend; his performance during the intervention phase resulted in two data points that were well above baseline, but the presence of an increasing trend during baseline jeopardizes the internal validity of the these results. Joe's PND for QC was 67%. Joe finished intervention with all four of his IGDIs-EN scores falling above baseline levels

In order to assess what portion of subject improvement on the various IGDIs-EN was due to repeated practice effects, Rate of Improvement (ROI) was calculated for each subject, relative to each of the IGDIs-EN, for baseline and intervention. ROI was calculated using the guidelines set by Kovaleski et al. (2013), by subtracting the first data point within a phase from the last and dividing by the total number of weeks within the phase. ROI data are presented in Table 3 below.

An analysis of ROI per week data reveals a few noticeable trends among the study participants. With respect to OC, four subjects exhibited greater ROIs during the intervention phase of the study than during baseline; Eunice and Robert demonstrated equal ROIs across baseline and intervention, in spite of initial growth steps upon entering intervention. Regarding OCC, all subjects except Eunice demonstrated higher ROIs during intervention in comparison to baseline; as with OC, Eunice demonstrated an initial improvement upon entering the phase, but her progress plateaued soon after. ROI data were less impressive for NN, as only John and Ted demonstrated higher ROIs during intervention than baseline. Finally, regarding QC, all six subjects demonstrated greater ROIs during the intervention phase of the study. Ted and Joe each demonstrated

Table 2

Baseline (BL) and Intervention (INT) Rates of Improvement (ROI) for Oral Counting

(OC), One to One Correspondence Counting (OCC), Number Naming (NM), and

Quantity Comparison (QC)

Subject	OC		OCC		NN		QC	
Rose	0	4.5	0	1.3	2.0	0.7	0	1.8
John	0	2.2	0	0.2	0	1.2	0.2	0.3
Eunice	0	0	1.2	1.0	2.5	1.0	1.0	3.5
Robert	1.0	1.0	0.5	3.0	1.2	0	0	0.5
Ted	0	5.0	0	3.5	1.3	3.5	0.3	1.3
Joe	0	0.5	0.8	1.0	1.3	0.5	1.3	4.5

increasing trends in QC during the baseline phase of the study, which suggested potential

repeated practice effects. However, their ROIs for QC during the baseline phase of the

study were 1 and 1.3 respectively, while their ROIs during intervention were 3.5 and 4.5.

These numbers suggest that repeated administration of the QC may have led to repeated

practice effects, but only accounted for a ROI per week of approximately 1.

A visual analysis of subject data in the Figures shows that all six participants

demonstrated marked improvement from baseline on at least three of the four progress

monitoring measures when provided small group instruction using *Pre-K Mathematics.*

In addition to improvements indicated in the IGDIs-EN data, five of the six participants

showed improvement on the TEMA-3 from pretest to posttest (Table 3). Rose's

performance on the TEMA-3 prior to intervention resulted in a Math Ability Score of 87,

while after intervention she scored a 114, which is greater than 1.5 standard deviations

higher. These results help corroborate her gains on the IGDIs-EN. John's

Table 3

TEMA-3 Math Ability Scores Before and After Intervention

Subject	Pretest*	Posttest*
Rose	87	114
John	95	120
Eunice	95	NA
Robert	97	109
Ted	72	109
Joe	82	97

*TEMA-3 standard scores have a mean of 100 and a standard deviation of 15

performance on the TEMA-3 before intervention resulted a Math Ability Score of 95,

while following intervention he received a Math Ability score of 120, also an

improvement of more than 1.5 standard deviations, lending support to the notion that he

made meaningful gains from the intervention process. Eunice was unfortunately struck

with a significant illness during the final week of the study and was not available to

participate in a post intervention administration of the TEMA-3; her score on the TEMA-

3 prior to intervention was 95. Robert's performance on the TEMA-3 prior to

intervention resulted in Math Ability Score of 97, which improved slightly to 109

following intervention. Overall, Robert exhibited small gains from baseline to

intervention. Ted's performance on the TEMA-3 prior to intervention resulted in a Math

Ability Score of 72, while his performance after intervention resulted in a score of 109,

an improvement of greater than 2 standard deviations. These scores suggest that Ted

acquired a significant amount of math skills during the intervention period. Joe received

a TEMA-3 Math Ability Score of 82 prior to intervention; his performance following

intervention resulted in a Math Ability Score of 97, an improvement of one standard deviation.

Social Validity

Following the completion of intervention and IGDIs-EN data collection, five of the six subjects debriefed with the interventionist and were asked 3 open-ended questions about their experiences during the project and whether or not they learned anything (see Appendix D for full questionnaire). As was previously mentioned, Eunice was not available for the social validity data collection due to significant illness. When the subjects were asked what they liked about the math activities, their responses included "counting animals," "putting the eggs in the cups," "naming the numbers," "the games," and "the puppet." When the subjects were asked what they didn't like about the math activities, their responses included "loved it all," "nothing," "no," and "counting the dots." When the subjects were asked if they thought the math activities helped them to learn math and why or why not, their responses included "yes, but I can't remember why," "yes, I learned how to do my homework," "yes, mom says now I'm ready for kindergarten," "yes, I learned how to count really high," and "yes, I don't know why." Overall, the students appeared to find the *Pre-K Mathematics* lessons enjoyable and were consistently willing to enthusiastically complete the IGDIs-EN.

CHAPTER 4: DISCUSSION

Given that widespread application of intentional teaching of mathematics at the preschool level is a relatively new phenomenon, it is important that researchers continue to carefully examine the effectiveness of curricula and instructional practices on student outcomes. The connection of early learning trajectories to more advanced instructional hierarchies (i.e., algebraic thinking, geometry) must be carefully considered and planned. Moreover, old theoretical alliances that have been made obsolete by empirical investigations must be retired in favor of evidence-based practices in early mathematics. The present study sought to extend the research on intentional teaching of mathematics at the prekindergarten level through application of a multi-tier system of supports for prekindergarten mathematics.

Overall, each of the subjects demonstrated significant growth from baseline to intervention with at least one of the skills measured by IGDIs-EN. All six subjects demonstrated some level of improvement from baseline to intervention with respect to OC and OCC. Four out of the six participants exhibited some level of improvement from baseline to intervention on the NN measures. All six participants demonstrated significant improvement from baseline to intervention with respect to QC, although it must be noted that Ted and Joe were both demonstrating slightly increasing trends in QC performance prior to intervention. These trends suggest that *Pre-K Mathematics* might be most powerful when intervening with skill deficits that directly involve counting skills. This is supported by the scope and sequence of the *Pre-K Mathematics* curriculum, which focuses its first chapter on counting and quantity. Although there are lessons that directly teach number identification, these lessons focus largely on numbers 1-10, while the

IGDIs-EN measure number identification from 0-20. This inconsistency may be responsible for less robust findings with respect to the NN measures.

Improvements with some of the skills measured, particularly OCC for Rose, and OC for both Rose and John, were delayed. It should be noted that both of these subjects were making verbal counting errors prior to intervention. In Rose's case, she entered the study with a habit of skipping the numbers 13, 14, and 15 when counting to 20. John began the study with a habit of counting successfully to 14, then jumping to 20 and accurately reciting the numbers 20 to 29. These error patterns were quite firmly established and required significant corrective re-teaching to remediate. The *Pre-K Mathematics* curriculum provided an adequate amount of repetition and practice to overcome these error patterns, but the latency to improvement was relatively long.

The results of the current study suggest that a highly systematic approach to early mathematics instruction can be implemented without sacrificing the developmental appropriateness and enjoyable nature of early learning strategies. All of the subjects were compliant for a majority of the instructional sessions and appeared to enjoy the explicit mathematics lessons. The preschool teachers were welcoming of the additional instruction within their classroom and expressed interest in continuing implementation of *Pre-K Mathematics* beyond the current study. Overall, the results of the study suggest that *Pre-K Mathematics* and the IGDIs-EN can be incorporated into a powerful system of instruction for early mathematics.

The results of this study are in line with prior research on intentional teaching of mathematics at the preschool level (Clements, 1984; Klein et al., 2003; Clements & Sarama, 2007). The explicit, highly structured nature of the numeracy and quantity skills

targeted through the *Pre-K Mathematics* curriculum led to meaningful gains for all subjects in the study and did not lead to detrimental consequences. These results, taken in consideration with previous research on intentional mathematics instruction for preschool students, support the notion that "high-quality, early learning systems" do in fact require explicit and systematic curricula (Duncan, 2013). The students who participated in the current study expressed satisfaction with the curriculum as well as the feeling that they had acquired new knowledge and skills.

The results of the current study are also consistent with previous research on the implementation of RTI/MTSS at the preschool level. Like the Recognition & Response approach to RTI/MTSS in early childhood education, the current MTSS framework was successful in utilizing well-validated measures to identify and progress monitor students in need of more intensive instruction and providing explicit small group interventions at the secondary tier of intervention (Buysse & Peisner-Feinberg, 2010). *Pre-K Mathematics* was shown to be largely efficacious with the current sample of preschool students. The IGDIs-EN proved sensitive enough to track student response to intervention. Overall, the system proved to be manageable and effective in boosting student performance and would support the use of MTSS for mathematics at the preschool level.

Limitations and Future Research

In spite of the documented gains observed in the current study, there are a number of limitations that must be highlighted. First, the rate of improvement on some of the IGDIs-EN measures was robust for some students but minimal for others. For some of the subjects, this resulted in high levels of PND, but rather low levels of actual skill

improvement. Given that *Pre-K Mathematics* covers a large number of mathematics skills without facilitating targeted practice with one particular skill (e.g., number naming), future studies should explore the potency of *Pre-K Mathematics* when it is supplemented with evidence-based, targeted interventions such as flash card instruction. For example, error pattern analyses could be conducted to highlight which students need more targeted intervention with specific skills in order to inform a selection of additional practice activities to help boost the overall impact of the *Pre-K Mathematics* curriculum.

Second, the *Pre-K Mathematics* curriculum was only implemented for a total of 11 lessons with the first dyad, six lessons with the second dyad, and three lessons with the final dyad. This represents a major limitation within the current study. It is impossible to predict the impact of the full curriculum on the skills measured by the IGDIs-EN with the current sample. Although randomized controlled trials have demonstrated the efficacy of *Pre-K Mathematics* when implemented in its entirety, there are currently no published studies that document student response to the full curriculum using the IGDIs-EN or comparable measures. Future research should involve implementing the entire curriculum consistent with the teacher's manual and employing progress-monitoring procedures akin to the ones used in the present study in order to monitor long-term growth associated with the lessons. This line of research could also determine the durability of the kind of skill acquisition demonstrated in the current results.

Third, the current study focused only on one of the identified early learning trajectories for mathematics, counting and quantity. No lessons were delivered that addressed other early learning trajectories such as shapes and angles, measurement systems, or patterning. The *Pre-K Mathematics* curriculum addresses these topics in

subsequent chapters, as well as higher-level numeracy skills such as basic arithmetical reasoning, but these lessons were not delivered as part of the current intervention package. These skills also were not directly progress monitored. Future research should investigate the efficacy of *Pre-K Mathematics* on developing additional mathematics skills such as patterning, geometry, and arithmetical reasoning. This line of research should employ CBM-based progress monitoring in order to track growth throughout the intervention process.

Fourth, the current study employed a sample of students whose scores on the IGDIs-EN largely fell in the cut range for their respective ages. These students were chosen for the study based on local norms. Still, it is worth noting student performance in the selected classroom, in comparison to national normative data, was relatively high achieving with respect to early mathematics skills. Thus, it is impossible to generalize the current findings to lower achieving populations. Future research should explore the difference in rate of improvement among and between groups of students with scores falling below and above the lower cut scores of the IGDIs-EN. Students scoring below the IGDIS-EN cut scores should participate in the *Pre-K Mathematics* curriculum along with IGDIS-EN progress monitoring in order to assess its impact as a second tier intervention for young students who are normatively at-risk for math failure.

Finally, the current study utilized the primary investigator in the role of interventionist. This decision was made due to a lack of available teaching staff in the classroom whose schedules could include implementing *Pre-K Mathematics* in addition to their other responsibilities. This creates two significant limitations. The first limitation is that the presence of a novel teacher is a potential confounding variable. Although the

principal investigator was relatively known to the subjects in the study, the role of teacher

was novel for the investigator in that setting. The second limitation presented by the

primary investigator serving as interventionist is a loss of potential ecological validity.

The study would have provided more ecologically valid results had one of the classroom

teachers delivered the *Pre-K Mathematics* lessons. Future research should focus on

training classroom teachers or teacher aides to implement *Pre-K Mathematics* in order to

avoid the limitations associated with the results of this study.

Implications for Practice

In spite of the limitations of the current study, the results support a feasible

implementation of a multi-tier system of support for early mathematics instruction. With

academic standards that are steadily increasing in intensity and scope, early mathematics

instruction has become a critical element of early education settings. Screening and

progress monitoring with the IGDIs-EN represents a relatively easy way to ensure that all

students are making adequate gains with respect to important early mathematics skills.

Moreover, *Pre-K Mathematics* is a powerful curriculum that can help prekindergarten

teachers to equip their students with the foundational skills necessary to succeed with

mathematics in kindergarten.

Given the idiosyncratic results across subjects and across dependent variables

within the current study, educators should be prepared to supplement *Pre-K Mathematics*,

or any curriculum at the universal or secondary level of support, with targeted

interventions that will help students to keep pace with their peers. As is often the case at

every level of education, being able to individualize instruction appears to be a critical

component of delivering high quality early mathematics instruction. The IGDIs-EN can

provide meaningful data to help educators decide which students need additional instruction with specific skill areas. *Pre-K Mathematics* can provide a number of well-designed lessons to help boost skill acquisition across a variety of numeracy skills. Together these two tools show promise as the foundation for a multi-tiered system of support for early mathematics.

Educators using the IGDIs-EN should recognize potential repeated practice effects associated with the QC measure. This was specifically suspected in the case of Joe and Ted, who spent the most time in the baseline data collection phase of the study and ultimately demonstrated increasing baseline trends on the QC measure. An attempt was made to reduce the impact of repeated testing effects by employing a multiple probe design during baseline data collection, but increasing trends on QC were ultimately observed with both students. Based on an analysis of ROI data, it appeared that about 1 improvement per week could be attributed to repeated administration of the QC measures. This allowed for an estimate of ROI that could be actually attributed to the intervention. Educators should be aware that a portion of improvement on the QC measures may be due to repeated exposure and practice.

CHAPTER 5: SUMMARY

A Multi-Tier System of Support (MTSS) for academic skills is widely recognized as the best practice framework for supporting all students. The current study sought to determine if this approach to education would apply to prekindergarten mathematics instruction. Specifically, the *Pre-K Mathematics* curriculum was implemented with three dyads of students (six students total) within their prekindergarten classroom. All students were progress monitored using the IGDIs-EN. All six subjects showed some level of improvement from baseline to intervention, and all of the students exceeded at least one of the IGDIS-EN upper cut scores at the end of the study. Additionally, five of the students showed growth on the TEMA-3 from an administration before intervention to an administration after intervention. The findings in this study support the implementation of a multi-tiered system of academic support to improve the outcomes of prekindergarten mathematics instruction.

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APPENDIX A: Sample *Pre-K Mathematics* lesson

Unit 1

ACTIVITY 4
The Egg Carton Game (One-to-One Correspondence)

Key Mathematical Language

Each cup gets one egg, Each egg goes in a cup, match

Set Up

Small group size: 4-6 children seated at a small group table with the teacher seated opposite and facing them.

Materials

Per child: set of egg cartons containing 3, 4, 5, 6, and 7 cups; a bowl to hold the eggs; a tray on which to place the egg cartons and bowl

Teacher: a bag of plastic eggs or egg cut-outs (Activity Aid 6); sets of 2-cup cartons for the Downward Extension; sets of 10-, 11-, and 12-cup cartons for the Upward Extension; Assessment Record Sheet

Child's Goal

The purpose of this activity is to help children learn to make a numerical match between two sets using one-to-one correspondence. In this activity, one-to-one correspondence between the two sets, eggs and egg carton cups, is suggested, or provoked, by the materials.

Teacher's Role

Instruction and Assessment: Your role is to set up the materials, introduce the egg carton game to the children, and model how to use one-to-one correspondence to find the carton that matches a given number of eggs. For each problem, record whether children correctly match the set of eggs with the egg carton that has the same number of cups. If children experience difficulty making a correct match, provide scaffolding in the use of one-to-one correspondence.

TEACHER TIPS

- Discourage children from using counting to solve these problems. The purpose of this activity is to use one-to-one correspondence to make a numerical match between two sets.

- **Safety Note:** Take steps to insure that the egg cartons you use are either sterilized or have never been used for actual eggs as protection from egg-borne diseases.

Downward Extension If a child encounters difficulty with the 3-egg problem (Problem 1), present a 2-egg problem. Place the 2- and 3-cup cartons on the child's tray and put 2 eggs in the child's bowl. Say, "I took these eggs from one of these cartons. Can you find the carton that matches your eggs?" If the child is successful, proceed with the 3-egg problem.

Upward Extension If a child is successful with the 6-egg problem (Problem 2), present an 11-egg problem. Place the 10-, 11-, and 12-cup cartons on the child's tray and put 11 eggs in the child's bowl. Say, "I took these eggs from one of these cartons. Can you find the carton that matches your eggs? Remember, each cup gets one egg, and each egg goes in a cup."

Introducing the Activity

Use the 2-cup egg carton and the bag of eggs to introduce the game to the children. You can say, "We are going to play the egg carton game. Let's pretend these are eggs." Show the children 2 plastic or paper eggs. Next, present the 2-cup carton and say, "Here is an egg carton. The egg carton has cups for holding the eggs. Let's see if the carton matches my eggs."

Take 2 eggs and model the use of one-to-one correspondence by placing the eggs one at a time in each cup of the carton. Say, "See, each cup gets one egg, and each egg goes in a cup. So, this carton matches my eggs."

PROBLEM 1: Set of 3 eggs

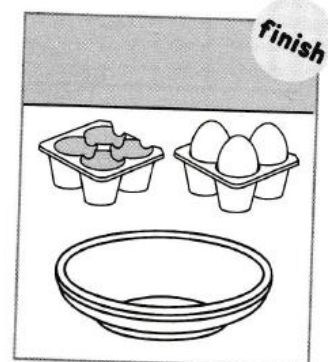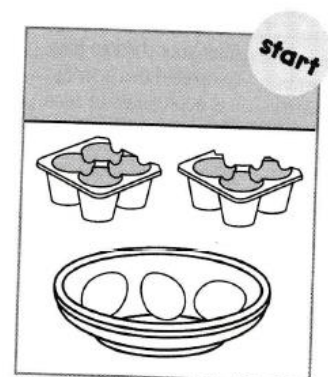Place the 3- and 4-cup egg cartons on each child's tray. Put 3 eggs in each child's bowl.

Point to the eggs and egg cartons on the children's trays. Say, "I took these eggs from one of these cartons. Can you find the carton that matches your eggs?"

Observe how the children put their eggs in the egg carton cups and record whether they use one-to-one correspondence to make a match between the two sets on the Assessment Record Sheet.

After the children have selected the correct carton for their set of eggs, proceed to Problem 2.

Scaffolding

If any children select the incorrect carton, remind them how to use one-to-one correspondence to make a match between the two sets. Say, "Remember how to find the carton that matches your eggs? Each cup gets one egg, and each egg goes in a cup." Provide help as needed in the use of one-to-one correspondence to select the correct carton for the set of eggs.

PROBLEM 2: Set of 6 eggs

Place the 5-, 6-, and 7-cup egg cartons on each child's tray. Put 6 eggs in each child's bowl.

Point to the eggs and egg cartons on the children's trays. Say, "**I took these eggs from one of these cartons. Can you find the carton that matches your eggs?**"

Observe how the children put their eggs in the egg carton cups and record whether they use one-to-one correspondence to make a match between the two sets on the Assessment Record Sheet.

If children succeed in selecting the correct carton for their set of eggs, present an 11-egg problem (Upward Extension).

Scaffolding

If any children select the incorrect carton, remind them how to use one-to-one correspondence to make a match between the two sets. Say, "**Remember how to find the carton that matches your eggs? Each cup gets one egg, and each egg goes in a cup.**" Provide help as needed in the use of one-to-one correspondence to select the correct carton for their set of eggs.

After your children have completed this activity, it is appropriate to send home Unit 1, Home Activity 3 and Activity Aid 25.
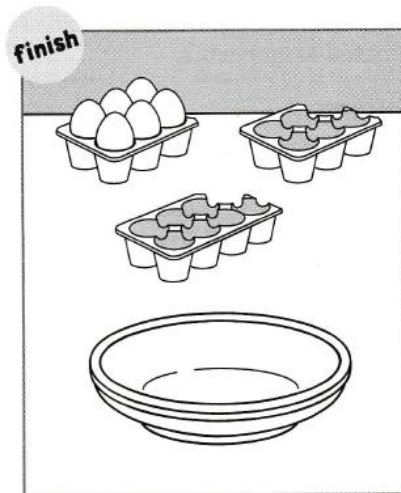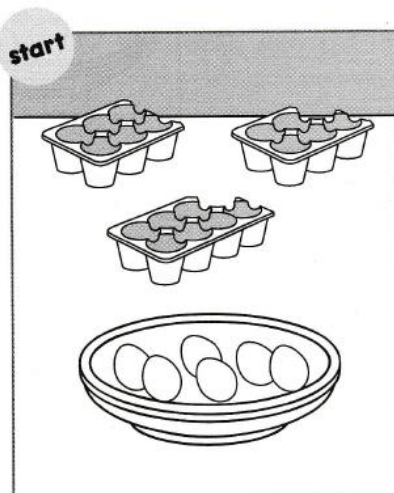
APPENDIX B: Treatment Integrity Checklist for *Pre-K Mathematics*

Treatment Integrity Checklist: *Pre-K Mathematics*

For each step, mark a "+" if completed correctly or a "-" if not completed correctly.

Step	Action	Outcome
1.	Teacher greets the group	
2.	Teacher introduces the activity using the scripted introduction	
3.	All necessary materials for the lesson are present	
4.	The lesson is delivered according to the script outlined in the curriculum book	
5.	All error correction is delivered according to the directions provided in the curriculum book	
6.	Each child is informally assessed on the target skill before the conclusion of the lesson	
7.	Teacher concludes lesson according to the script within the curriculum book	

APPENDIX C: Social Validity Questionnaire for Study Participants

Social Validity Questionnaire for Participants

The items below are intended to measure the social significance of the current intervention and its outcomes. Each item is open-ended and the student response should be recorded verbatim.

1. What did you like about the math activities we did together?

2. What didn't you like about the math activities we did together?

3. Do you think these activities helped you to learn math – why or why not?

BIOGRAPHY OF THE AUTHOR

William Roy is from Turner, Maine and graduated from Leavitt Area High School in 2005. Mr. Roy received a B.A. in Psychology and English from the University of Maine – Farmington in 2009. He received an M.S. in Educational Psychology from the University of Southern Maine in 2013. Mr. Roy has worked for seven years at a special purpose private school for children with a variety of educational challenges, first as an Educational Technician and later as a Board Certified Behavior Analyst (BCBA). Additionally, he has provided consultation to public schools in Maine.

During his time at the University of Southern Maine, Mr. Roy has had the honor of teaching two Master's level courses, one on Multi-Tier Reading Interventions for General and Special Education and another on Educational Research Methods. Mr. Roy has also collaborated with university faculty to develop workshops on topics such as positive psychology and professional supervision.

Currently, Mr. Roy is finishing his pre-doctoral internship requirements. He is a candidate for the Psy.D. degree in School Psychology from the University of Southern Maine in August, 2016.