EVALUATING THE EFFECTS AND INTERACTION

OF ITEM SET SIZE AND INSTRUCTIONAL TIME ON

STUDENT FLUENCY GROWTH RATES WITH

MULTIPLICATION FACTS

By

MARGARITA PATRICIA HERNANDEZ-NUHFER

Bachelor of Arts in Psychology
University of Oklahoma
Norman, Oklahoma
2007

Master of Arts in School Psychology
University of Central Oklahoma
Edmond, Oklahoma
2012

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2018

EVALUATING THE EFFECTS AND INTERACTION

OF ITEM SET SIZE AND INSTRUCTIONAL TIME ON

STUDENT FLUENCY GROWTH RATES WITH

MULTIPLICATION FACTS

Dissertation Approved:

Dr. Brian Poncy
_____
Dissertation Adviser

Dr. Gary Duhon
_____

Dr. Terry Stinnett
_____

Dr. Robert Evan Davis
_____

ACKNOWLEDGEMENTS

The research contained in this dissertation was by far the hardest thing I have ever done at a professional level and the most rewarding accomplishment. This is a task that was beyond one person's ability. It took all of the people in this acknowledgement in order to complete this project. From conception to completion, I was never alone and had the privilege of working with this long list of volunteers who gave their time and effort to support my study.

I would like to start by thanking my advisor and dissertation chair, Dr. Brian Poncy, whose brilliant mind for research design and mathematics interventions gave birth to the current study. To Dr. Gary Duhon, who greased the wheels at the research sites making data collection of this magnitude possible. To Dr. Evan Davis, without whom the statistical analysis presented would not have been possible. To Dr. Terry Stinnett, for being the mentor I did not know I needed but I am grateful I had.

Among OSU School Psychology graduate students, special thanks to Chase Kitterman and Meredith Webber. Thank you for all the trees you killed making sure that my 5,000 pages of probes were printed every week. Words cannot convey the gratitude I have for all the work you put in to make sure these probes were produced. In addition, to all the graduate students who helped with fidelity assessments and scoring of hundreds of protocols: Audrey, Hannah, Meghan, Eryn, Ayla, Daniel, Janna, Cristina and Shelby… you guys rock!

I would also like to thank my long-time mentor, Dr. Scott Singleton, for giving me the behaviorism Kool-Aid and for setting me up with some of his students (Lauren, Kalen, Eleigha,

Stephanie and Cade) at the University of Central Oklahoma to help with scoring and fidelity assessments. To Dr. Erika Olinger, thank you for allowing me to use your facility at the UCO Learning and Behavior Clinic to hold weekly scoring parties.

On a personal level, I would like to thank my dad for planting the seed that someday I could have a PhD and the belief that I could do it. To my mom, thank you for the countless meals and endless babysitting hours you provided for my children while my time was spent on my academic endeavors. To all of my children, thank you for putting up with my many hours focused on school. Alex, thank you for being the star of the intervention videos; Ashley, thanks for the late nights and many paper cuts stuffing intervention folders; Nathan, thank you for being so patient through all the times I was an absentee parent. To Nicole, you were the inspiration that set me off on this career path, thank you for being the compass that keeps my course. And most of all, to my husband Michael, my most loyal supporter and the glue that has kept our family together and stronger than ever throughout my graduate pursuits.

Name: MARGARITA PATRICIA HERNANDEZ-NUHFER

Date of Degree: MAY, 2018

Title of Study: EVALUATING THE EFFECTS AND INTERACTION OF ITEM SET
SIZE AND INSTRUCTIONAL TIME ON STUDENT FLUENCY
GROWTH RATES WITH MULTIPLICATION FACTS

Major Field: EDUCATIONAL PSYCHOLOGY (OPTION: SCHOOL)

Abstract: The present study evaluated the effects and interaction of item set size and instructional time on students' fluency growth rates with multiplication facts over time when using an Explicit Timing intervention. The first goal was to determine an interaction between set size and instructional time across time that would influence the fluency growth rate on multiplication facts. A second goal was to determine an optimal combination of set size and instructional time to promote highest fluency growth rate. A third goal was to determine an optimal combination of set size and instructional time to enhance generalization of multiplication facts. A fourth goal was to determine an optimal combination of set size and instructional time to enhance maintenance of multiplication facts over time. A total of 11 fluency measures were taken among 204 fourth grade students from 10 general education classrooms among two public schools in central Oklahoma, who were randomly assigned to one of nine condition groups. Condition groups represented a combination among three levels of set size, defined as the number of multiplication problems, and three levels of instructional time, defined as minutes of instruction per session. Intervention and assessments were given in a class-wide group format. Teachers administered the intervention daily by playing a video, which contained instructions and four 2-minute built-in intervention timed intervals. The total number of digits answered correctly per minute determined fluency performance on each dependent measure (i.e., pre-test, progress monitoring, post-test). Data were analyzed using a 3 x 3 x 8 mixed ANOVA. The between-subjects factors were set size and instructional time, each containing three levels: 9-problems, 18-problems and 36-problems for set size and 2-minutes, 4-minutes and 8-minutes for instructional time. The within- subjects factor was time with eight levels, in the form of progress monitoring assessments (PM1-PM8). Results of the final analysis indicated the absence of a significant three-way interaction between set size, instructional time and time. However, within-subjects effects indicated a significant interaction between time and set size as well as between time and instructional time, indicating that all levels of set size and instructional time performed differently across time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The National Center for Educational Statistics (NCES) reported that in 2015 the average

scores in mathematics in grades fourth and eight were one and two points lower, respectively,

than the average scores in 2013 (Provasnik et al., 2015). These results indicate that only 40% of

fourth-grade students and 33% of eighth-grade students performed at or above proficient level.

Additionally, the Programme for International Student Assessment (PISA) ranked American 15-

year old students 25th in math literacy and problem solving, among 30 developed nations, in

2007 (Baldi & National, 2007). The Trends in International Mathematics and Science Study

(TIMSS) reported similar results, with only 7% of fourth-graders in the United States performing

at the advance level, compared to 38% of fourth-graders in Singapore (Aksoy & Link, 2000).

These statistics highlight the need for effective mathematics instruction at all levels of K-12

education in the U.S.

In 2006, the President of the U.S. created the National Mathematics Advisory Panel

(NMAP) in order to evaluate scientifically based methods that would improve the instruction and

performance in mathematics (National Mathematics, 2008). Regarding elementary school aged

children, the panel found that students are much less fluent in solving single-digit basic math

computation problems than children in many other countries. Therefore, much of the panel's

recommendations involved addressing early remediation through interventions focused on

developing the accuracy and fluency of basic math computation facts, since automatic recall of basic math facts "frees up working memory for more complex aspects of problem solving" (p. 30). On the topic of curriculum sequence, the panel proposed three clusters of mathematical knowledge students are to master before entering an algebra course: 1) fluency with whole numbers, 2) fluency with fractions, and 3) particular aspects of geometry and measurement. Regarding the first cluster, the panel recommended that by the end of third grade, students should be proficient in the automatic recall of addition and subtraction facts, and by the end of sixth grade students should be proficient in the automatic recall of multiplication and related division facts. In the end, the panel highlighted the need for research that would identify effective instructional methods that would produce greater gains in outcome measures of student learning.

To that end, studies such as the panel analysis conducted by Aksoy and Link (2000), which utilized data from the National Education Longitudinal Study of 1988 (NELS:88), stressed the demand for identifying key factors in effective mathematics instruction. The NELS:88 followed an initial sample of over 24,000 eight grade students, providing direct academic measures as well as survey data on school, work and home experiences. Aksoy and Link's results highlighted time spent on math instruction as one of those key factors. More specifically, their results indicated that ten extra minutes of instruction "was associated with an increase in mathematics achievement scores of approximately 5.4-6.2%" (p. 14).

This idea of the time spent on mathematics instruction and its relation to students' outcomes was also examined by Lewis and Seidman (1994), through a cross-country data analysis of the 1982 International Association for the Evaluation of Educational Achievement (IEA) math exam data collected among 13-year olds in 20 countries. For their analysis, Lewis and Seidman concentrated only in a comparison between the U.S., which ranked 13th in the IEA exam, and Japan, which ranked first. After accounting for differences in the length of the school year between the two countries, they concluded that the amount of time a typical eighth grader spends on math in and out of school is 30%

more in Japan than in the U.S. Furthermore, Lewis and Seidman (1994) calculated that if the U.S. were to increase the time students spent on math by 19%, their IEA scores would increase by 9%, placing them 8th in the international ranking.

Increasing time of instruction is typically discussed in terms of increases to the school day or the school year. Considering the high cost of such approaches, recent research has focused on instructional efficiency as an alternative to increase students' learning rates without increasing the already allocated instructional time (Skinner, Fletcher & Henington, 1996). Learning rate is defined as the ratio between the amount of behavior change and the time spent in the activity that led to such change (Skinner, 2010). Skinner, Fletcher and Henington (1996) summarized various methods to increase students' learning rate by increasing the number of learning trials in a fixed period of time. For example, a study comparing a Cover, Copy, and Compare (CCC) math intervention across two different response types, a verbal response only versus a written response, indicated that the verbal response condition yielded greater increases in accuracy and fluency. A verbal response took less time and therefore students in that condition had more trials in the same amount of time. Another method discussed in the Skinner, Fletcher and Henington (1996) summary involved the use of timing procedures. Van Houten and Thomas (1976) first demonstrated that explicit timing procedures could increase the number of problems students completed correctly. This study originated the Explicit Timing (ET) intervention, which increases students' rates of responding when addressing fluency (Codding et al., 2007).

Instructional efficiency research is still in its infancy, as researchers are still trying to establish procedures for the standard reporting of instructional time and efficiency (Skinner, 2010). The present study sought to add to this line of research by examining not only instructional time, but also set size, henceforth hypothesized to be a second factor affecting the efficiency of an ET intervention. Specifically, fluency growth rate was compared between nine condition groups that varied on three levels of instructional time and three levels of set size. The problem sets were based

3

on response automaticity (Duhon, Poncy, & Fontenelle, 2011). The primary goal of the current investigation was to evaluate the effects and interaction of item set size and instructional time on students' fluency growth rates with multiplication facts over time when using an ET intervention in order to identify the optimal combination to obtain highest growth rate.

CHAPTER II

REVIEW OF LITERATURE

Math Instructional Time

The need for improvement in math proficiency among American students has been highlighted in recent years by data from national and international studies (Aksoy & Link, 2000; Baldi & National, 2007). Government mandates and expert panels call for the use of empirically validated interventions in order to remediate the skill deficits displayed by K-12 students (Petrill et al., 2012; National Mathematics, 2008). Effective interventions in the school setting available to the students who are struggling academically are necessary for the issues to be addressed successfully.

Effective interventions also imply cost-effective treatment. Governments and policy makers are looking at those international studies for guidance on low cost educational methods which are effective in promoting student proficiency (Aksoy & Link, 2000). Furthermore, effective treatment leads to academic achievement, which is directly correlated to the time spent on active learning (Zeith & Cool, 1992). According to Lewis and Seidman (1994), the amount of time Japanese students spend on math in school and out-of-school by the 8th grade is 30% higher than in the US. A 21 day increase in the length of the school year in the US would be necessary to match the Japanese instructional time. While conducting the Study of Instructional Improvement,

Phelps, Cory, DeMonte, Harrison and Loewenberg (2012) compared the average daily instructional time for English language arts and mathematics among the participating classrooms. They found variations as large as 56 minutes in English and 30 minutes in math within the 112 elementary schools in the study. These variations, if accumulated over the course of the school year, could translate into large inequalities in the total instructional time received by the students.

Considering the already existing variation in instructional time, adding minutes of instruction to the school day, or days to the school year, would not necessarily lead to students receiving more instructional time in math or English, since teachers have the discretion to use that time as they see fit, and they may use it for non-instructional activities (Phelps et al, 2012). Effective interventions therefore should not only target the skill deficit of the students who are struggling academically, but they should also yield the highest growth in the least amount of time possible.

Instructional Hierarchy and Fluency

Haring and Eaton (1978) created a model with which the students' skill deficit can be matched to evidence-based interventions to remediate that particular skill deficit (Daly, Witt, Martens, & Dool, 1997). The instructional hierarchy (IH) model (Haring & Eaton, 1978) presents the learning process as a sequence of four stages. The first stage refers to the acquisition of a skill, or the performance of the skill accurately without assistance. The second stage is fluency, which refers to the quick and accurate performance of the skill. The third stage is generalization, in which an already learned skill is applied to a new set of stimuli that resemble those used in the first two stages. The fourth and final stage is adaptation, which refers to the ability to modify a previously learned skill to respond to new stimuli.

The IH cannot only guide the process of identification of the skill deficit, but it can also guide the process of selecting the most appropriate intervention to address that particular skill deficit (Ardoin & Daly, 2007). As such, a student who has difficulty with the procedure to execute a two-digit addition with regrouping would be identified as having an accuracy deficit.

Modeling and error correction would be the most appropriate course of action for that particular skill deficit. Instead, if a student presents accurate rates of responding in single-digit multiplication facts but at low rates of response, the student can multiply but does so slowly, the skill deficit for that student would be identified as fluency, which is best addressed by a drill intervention (Ardoin & Daly, 2007). The sequential hierarchy of Haring and Eaton's model (1978) implies that for students to perform well in higher level math skills, such as fractions for example, they must first master the more basic skills, such as addition, subtraction, multiplication and division.

Mastery of those basic skills requires that the skills be mastered at the accuracy stage and at the fluency stage. High levels of fluency allow for the skill to become automatized, which means the student can respond correctly to the stimuli with minimal awareness and without sacrificing cognitive resources (Axtell, McCallum, Mee Bell & Poncy, 2009; Hartnedy, Mozzoni & Fahoum, 2005). This concept of automatization is supported by the information-processing theory, which, according to Woodward (2006), explicates how utilizing inefficient methodology to solve a problem, as in finger counting, would often lead to errors, either at the declarative or procedural level, or both. For example, a student who has difficulty solving 4×5 as the first step in an algebraic formula, is going to be less likely to follow the correct order of operations in solving that formula because all of the cognitive resources are being utilized on the computation fact (Axtell, McCallum, Mee Bell, & Poncy, 2009).

On the other hand, students who can respond automatically to basic math facts are more likely to successfully respond to higher level math questions (Skinner, Fletcher, & Hennington, 1996). In addition, Singer-Dudek & Greer (2005) found that students who master a skill to fluency are able to maintain proficiency of the skill over time, compared to those who only mastered the skill to accuracy.

Explicit Timing (ET)

ET is an intervention aimed to improve the fluency of basic math facts (Van Houten & Thompson, 1976). During ET, students are given a specific amount of time to complete as many problems as they can. During their 1976 study, Van Houten and Thompson administered the ET intervention to 20 second-graders who displayed basic math fact deficits. During baseline, the teacher told the students to work on their math problems without any instruction as to how long they should work for. The teacher timed their work for 30 minutes without the students' knowledge. During the intervention phase, the teacher told the students they needed to complete as many problems as they could in one-minute intervals, over a 30-minute period. The teacher then repeated the baseline and intervention procedures to implement a reversal design. Their results reflected that the students averaged a two problem per minute increase between the intervention and the baseline condition during the first intervention period, while they averaged a one problem increase during the second intervention phase.

ET was found to be less effective when used with students who are not accurate responders. In a 2007 study, Codding et al, compared the effectiveness of ET and Cover, Copy & Compare (CCC) on basic math fact fluency among second and third grade students. At first glance the results showed no significance difference between the two interventions. However, once the initial fluency level of the students was taken into account, the results indicated that ET was more effective for those students who had a higher initial fluency measure, which means they were at the instructional level for fluency. Additionally, ET was less effective for those students for whom their initial fluency was at a frustrational level.

The effects of ET on increasing rates of responding have been replicated by multiple studies (Duhon, House, & Stinnett, 2012; Poncy, Duhon, Lee, & Key, 2010; Rhymer et al, 2002). However, no studies have looked to isolate the effects of different instructional time intervals (i.e., 2-min, 4-min or 8-min) and different set sizes (i.e., 3 problems, 6 problems, 9 problems) on

the ET intervention. The manipulation of these two factors, instructional time and set size, could facilitate implementation and allow educators to maximize individual learning and growth rates in students, while utilizing a classroom wide intervention that minimizes teacher effort and time.

Learning Rate and Instructional Efficiency

Among the many functions of school psychologists, working with students who display learning deficits is at the top. In fact, the majority of referrals that school psychologists receive are academic in nature (Bramlett et al, 2002). Learning can be defined as "a relatively permanent change in behavior or behavioral potential brought about by experience…" (Skinner, 2008, p. 309). Instead of considering learning problems as the inability to learn, learning difficulties may in fact relate to the pace at which learning occurs (Skinner, Fletcher, & Henington, 1996). Therefore, students referred for learning problems typically display a learning rate problem (Skinner, 2008). Learning rate, also referred to as instructional efficiency, comprises the time required for learning (Cates et al, 2003; Nist & Joseph, 2008; Skinner, 2008). While some academic interventions may be considered equivalent in their effectiveness (learning took place), they may present differences in their instructional efficiency (amount of time required for learning to take place) (Cates et al, 2003). When considering classroom interventions, teachers may prefer those requiring less instructional time (Cates et al, 2003).

A study that explored the differences between instructional effectiveness and efficiency was that of Nist and Joseph (2008), in which they compared three word-reading interventions, total drill and practice (TDP), interspersal training (IST) and incremental rehearsal (IR), on the acquisition of six unknown words after five weeks of intervention. The results from that study pointed at IR as being more effective, while TDP was more efficient. Skinner (2008) elaborated on the Nist and Joseph (2008) results by introducing a hypothetical scenario in which the acquisition of 330 words would require five weeks of intervention when utilizing TDP, while the same amount of words would require 11 weeks of intervention when utilizing IR, highlighting the importance of learning rate as the measure of learning efficiency. This measurement of

instructional time is important because time in schools is limited (e.g., a teacher may have only 10 min extra to provide an intervention for a student) and failure to measure learning rates may result in the endorsement of an intervention that is much less efficient (Cates et al, 2003; Skinner, 2008).

Set Size

If learning is defined as the change in behavior that results from an experience (Skinner, 2008), then characteristics of that experience are important variables that moderate learning. Specific to basic mathematics facts instruction, one of those main variables involves the number of problems, or set size, being presented in a learning trial (Poncy et al., 2015). Educational research related to explicit timing as an intervention to improve math computation fluency displays a wide variety of set sizes, and yet little attention has been paid to how the set size affects the overall growth, and therefore the efficiency of the intervention (Poncy et al., 2015).

Early studies related to memory supported the idea that isolated target items would facilitate learning, as with the Von Restorff experiments in which isolation was achieved by presenting a list of nine numbers and one syllable, or nine syllables and one number (Wallace, 1965). These experiments led to the Von Restorff effect, or isolation effect, which states that an item is learned faster when it is the only item in its set than when it is in the same set as all other items (Wallace, 1965). Similarly, a later study sought to investigate the isolation effect by comparing the isolated condition, in which a single list of 8 nonsense syllables was presented, and a crowded condition, in which the list was presented in three quick successions (Buxton & Newman, 1940). Recall measures taken at one hour, 24 and 48 hours indicated that crowded items were forgotten relatively more rapidly than isolated ones. (Buxton & Newman, 1940). Curiously, another Von Restorff effect study found that learning of target nouns among a list of adjectives was facilitated when the number of target items was the same as the non-target items (Newman & Jennette, 1975). In a more recent study investigating ratios of target to non-target

items utilizing sight word flash cards, researcher found that learning rates decrease when too much time is spent on known targets (Forbes et al., 2013).

In a study specific to math instruction, 20 single-digit addition problems were presented to second grade students across three condition groups (Duhon, Poncy, Hubbard, Purdum, & Kubina, 2012). The control group received all 20 problems; group one received the problems in sets of five, with a mastery criterion to be met before receiving the next set of five; group two followed the same procedure as group one but with a set of ten problems. Results indicated that group one displayed significant increases in learning rate, while there were no significant differences between group two and the control group. However, the data revealed that the gains achieved by group one were not maintained across the early phases, indicating that although the smaller set size yielded higher learning rates, larger set sizes led to maintaining the skill over time.

In a literature analysis, Poncy et al. (2015) examined the relationship between set size, or curricular scope, and effect size among 24 single-case studies focusing on math-fact fluency interventions. Data from their analysis indicated that fluency gains were inversely related to set size. Furthermore, results revealed the methodical effect of set size on comparisons of intervention effectiveness.

Rationale

The need for improvement in math proficiency among American students has been highlighted in recent years by data from national and international studies (Aksoy & Link, 2000; Baldi & National, 2007). Effective interventions therefore should not only target the skill deficit of the students who are struggling academically, but they should also yield the highest growth in the least amount of time possible. The instructional hierarchy model (Haring & Eaton, 1978) can guide the process of identification of skill deficit, but it can also expedite the process of selecting the most appropriate intervention to address that particular skill deficit (Ardoin & Daly, 2007).

The sequential hierarchy of Haring and Eaton's model (1978) implies that for students to perform well in higher level math skills, they must first master the more basic skills, such as addition, subtraction, multiplication and division. Mastery of those basic skills requires that the skills be mastered at the accuracy stage and at the fluency stage. High levels of fluency allow for the skill to become automatized, which means the student can respond correctly to the stimuli with minimal awareness and without sacrificing cognitive resources (Axtell, McCallum, Mee Bell & Poncy, 2009; Hartnedy, Mozzoni & Fahoum, 2005). Explicit timing is an intervention aimed to improve the fluency of basic math facts (Van Houten & Thompson, 1976).

Considering that learning problems may relate to the pace at which learning occurs (Skinner et al, 1996), students referred for learning problems typically display a learning rate problem (Skinner, 2008). Learning rate, or instructional efficiency, comprises the time required for learning (Cates et al, 2003; Nist & Joseph, 2008; Skinner, 2008), helping to differentiate academic interventions based on their effectiveness (whether learning took place), and their instructional efficiency (amount of time required for learning to take place) (Cates et al, 2003). This measurement of instructional time is important because time in schools is limited and failure to measure learning rates may result in the endorsement of an intervention that is much less efficient (Cates et al, 2003; Skinner, 2008).

Educational research related to explicit timing as an intervention to improve math computation fluency displays a wide variety of set sizes, and yet little attention has been paid to how the set size affects the overall growth, and therefore the efficiency of the intervention (Poncy et al., 2015). Previous studies indicate that smaller set sizes yield higher learning rates; however, larger set sizes led to maintaining the skill over time. Moreover, set size was found to have a methodical effect on comparisons of intervention effectiveness across math fluency studies (Poncy et al., 2015). However, no studies have looked to isolate the effects of different instructional time intervals (i.e., 2-min, 4-min or 8-min) and different set sizes (i.e., 9 problems, 18 problems, 36 problems) on the explicit timing intervention. The manipulation of these two

factors, instructional time and set size, could facilitate implementation and allow educators to maximize individual learning and growth rates in students, while utilizing a classroom wide intervention that minimizes teacher effort and time.

The primary goal of the current study was to evaluate the effects and interaction of item set size and instructional time on students' fluency growth rates with multiplication facts over time when using an explicit time intervention. Growth rate was defined as the measure of learning rate that accounts for the set size employed under each condition. The current study also examined how different levels of set size and instructional time influence the maintenance and generalization of fluency performance. As a result, this study aimed to answer the following questions:

1. Is there an interaction between set size and instructional time across time that would influence the fluency growth rate (i.e., increase in fluency performance, measured as DCPM, per minute of instructional time) on multiplication facts?

2. Is there an optimal combination of set size and instructional time to promote highest multiplication fluency growth rate?

3. Is there an optimal combination of set size and instructional time to enhance generalization of multiplication facts?

4. Is there an optimal combination of set size and instructional time to enhance maintenance of multiplication facts?

CHAPTER III

METHODOLOGY

Participants and Setting

The participants in the study included 204 students from ten 4th grade classrooms in two elementary schools in an urban Midwest school district in the United States. Prior to the experiment, approval from both Oklahoma State University's and the school district's institutional review board were granted. In addition, informed consent for participation from parents of students and assent from the students were obtained.

Participants were recruited through the school district. Initially, the researcher contacted the district's RtI coordinator to request support for the study. Principals from two schools responded to the request. Meetings with the principals and school psychologists at both school sites took place, where the nature and purpose of the project was discussed. A second meeting at each site took place, this time with the teachers, in order to provide them with information on the demands and the benefits of participation, as well as to answer any questions. Once teachers agreed to participate, permission forms to be signed by the students' parents and students' assent forms were provided by the researcher and disseminated by the teachers. The documents provided a brief explanation of the study, as well as appropriate contact information. Both parent consent and child assent forms stated that the student could withdraw permission for the study at any time.

Materials

This study utilized single-digit multiplication problems. Each probe presented multiplication problems for numbers 2 to 9 in a vertical format, on a single page, with eight rows of nine problems each (72 problems total). Randomized probes were created for each session of the study using a Microsoft Excel spreadsheet. Students were issued a folder containing the probes for the week. All students received the math fluency intervention daily. However, since different students received the math fluency intervention at varying instructional times, reading comprehension probes were administered instead of the multiplication probes, according to group membership. The reading comprehension probe consisted of a one-page passage in which every seventh word was replaced with the correct word and two distracters; students chose the word from among the three choices that fit best with the rest of the passage.

Intervention probes. Three different multiplication problem sets were utilized, one for each set size condition. Target problem sets were selected using specific math fact sets, consistent with previous research evaluating student growth (Poncy, Fontanelle, & Skinner, 2013; McCallum et al., 2006; Poncy & Skinner, 2011). These problem sets did not contain reciprocal problems (i.e., if 3 x 5 is presented, 5 x 3 will not be presented). Set A consisted of nine target problems randomized throughout the probe (see Appendix A). Set B and Set C consisted of 18 and 36 target problems, respectively, also randomized throughout the probe (see Appendices B and C). Furthermore, intervention probe daily packets included reading comprehension probes, in addition to the multiplication probes, according to the instructional time condition participants were assigned to, as described in the nine conditions below.

Condition A1: One Set A multiplication probe, followed by three reading comprehension probes (see Appendix D).

Condition A2: Two Set A multiplication probes, followed by two reading comprehension probes.

Condition A3: Four Set A multiplication probes only.

Condition B1: One Set B multiplication probe, followed by three reading comprehension probes.

Condition B2: Two Set B multiplication probes, followed by two reading comprehension probes.

Condition B3: Four Set B multiplication probes only.

Condition C1: One Set C multiplication probe, followed by three reading comprehension probes.

Condition C2: Two Set C multiplication probes, followed by two reading comprehension probes.

Condition C3: Four Set C multiplication probes only.

28 daily packets were created for each condition. Each day students received a folder containing all of the daily packets for the week. Each of the daily packets displayed the weekday (i.e., Monday, Tuesday, etc…) in the top right corner of the page, in order for participants to use the correct packet.

Assessment probes. Participants' performance was assessed on eleven separate occasions. The first assessment was administered as a pre-test, prior to the start of the intervention. A progress monitoring (PM) assessment was administered every third day of the intervention implementation, with a total of eight PM assessments. The tenth and final assessment included a post-test, a maintenance assessment and a digit writing speed assessment, which took place one week after the end of the intervention.

During each PM assessment session, participants' folders contained one additional multiplication fluency probe, which was administered before the regular daily packet. The pre-test and post-test assessments contained all 36 target problems and their reciprocals, regardless of group membership.

Training and Intervention Videos. Videos were created by the researcher using a PowerPoint presentation format. A file was made to match each of the 24 intervention sessions, in addition to a training, a pre-test and a post-test sessions files. All 27 files were constructed in the same manner, with the researcher first reading a set of directions, using standardized curriculum based measurement procedures (Shinn, 1989), to include begin and stop points for each probe and with

the timed-intervals per probe built-in to the video. Size of video files varied between 2.55 MB and 2.63 MB. Videos were presented to participants using the SMART Boards located in each classroom.

Procedures

      Pre-test session procedures. A pre-test was administered in which all fourth grade students were allotted one minute to complete a single digit multiplication probe. The researcher presented the training video to the students in each class. Each student completed three consecutive multiplication probes in order to establish a stable current performance rate. Each multiplication probe was scored according to the total Digits Correct Per Minute (DCPM). The median score of the three probes was calculated and utilized as the single pre-test score for each student. Since the intervention targeted fluency of multiplication facts, only students whose performance was at least 80% accurate was included in the analysis.

      Assignment to groups. For purposes of the intervention, the students were assigned to groups via random assignment across classrooms. The groups represented three different levels of instructional time and three different levels of set size. Instructional time levels were set to 2-minutes, 4-minutes and 8-minutes, in order to evaluate three different levels of mass practice conditions (Schutte, Duhon, Solomon, Poncy, Moore, & Story, 2015). Set size levels were set to 9 problems, 18 problems and 36 problems. Students received the multiplication fluency intervention according to a combination of the three levels of instructional time and set size, as listed below.

Condition A1: nine-problem set size and two-min instructional time.

Condition A2: nine-problem set size and four-min instructional time.

Condition A3: nine-problem set size and eight-min instructional time.

Condition B1: 18-problem set size and two-min instructional time.

Condition B2: 18-problem set size and four-min instructional time.

Condition B3: 18-problem set size and eight-min instructional time.

Condition C1: 36-problem set size and two-min instructional time.

Condition C2: 36-problem set size and four-min instructional time.

Condition C3: 36-problem set size and eight-min instructional time.

Intervention procedures. The classroom teacher carried out the intervention daily with the aid of the intervention video. The teacher first distributed the folders containing five daily probe packets to each student. The teacher then played the video that provided instructions to the entire class, using standardized curriculum based measurement procedures (Shinn, 1989). Intervention was administered daily on consistent schedule determined by each teacher. The students were given two min to work on the first math probe. After the time limit, the video instructed students to turn the page to the second probe, which was either a math or a reading probe, depending on group membership. Students had two minutes to work on the second probe. The same procedure was repeated for probes three and four. Upon completion of the four daily probes, the video instructed the students to place their probe packet in the folder. The teacher then collected all of the folders. Every third day of intervention, all of the students received one additional one-minute math probe designed as the PM assessment. The intervention video instructed students to complete the PM assessment before working on the regular daily packet. All PM assessments were scored and results were entered in a data base. The reading probes were not scored. After 24 school days, all students were administered a post-test according to the same procedures as the pre-test. During the post-test session, participants were also administered a maintenance assessment according to group membership, and a digit writing speed assessment. The fluency scores from the pre-test and post-test, as well as the eight PM assessments, maintenance and digit writing speed assessments were employed for the statistical analysis.

Dependent Measure. The dependent measure was the DCPM obtained from participants' performance on the PM assessment probes. Fluency was defined as the number of total digits completed accurately in one minute (Shinn, 1989). A digit was scored as correct if it

18

was located in the correct column of the answer (Skinner, Turco, Beatty, and Rasavage, 1989).

For example, an answer of "15" to the question "3 x 5" received 2 points since both digits were in

the appropriate column, while an answer of "12" received 1 point since 1 digit was in the correct

column. An answer of "21" received 0 points since both digits were incorrect. These data was

collected every third day throughout the implementation of the intervention.

Math Fluency Intervention. The intent of the intervention was to improve students'

multiplication fluency on single digit multiplication facts. Explicit Timing (ET) is an intervention

in which timed practice at fixed ratio contingencies is administered in order to improve fluency of

an academic task (Cates & Rhymer, 2006; Van Houten & Thompson, 1976). For the purpose of

this study, ET was employed using three different time intervals, with one group being timed for

2 min, one group for two 2 min intervals, and one group for four 2 min intervals. In addition,

three levels of set size were employed, 9 problems, 18 problems and 36 problems.

Post-test procedures. A total of five assessments were administered one week after the

conclusion of the treatment phase (following 24 consecutive school days). The first three probes

constituted a post-test measure in which, following pre-test procedures, the median DCPM score

was used. The fourth probe was a one-minute PM assessment, distributed according to group

membership, aimed to be used as a fluency maintenance measure.

Reliability. Reliability data was collected for the fluency scores on the multiplication

probes. A second experimenter rescored 25% of the multiplication probes collected to obtain an

overall reliability score of the dependent variable (CDPM). Additionally, interobserver agreement

data was collected to ensure adherence to procedures and accurate data collection. A second

experimenter checked off steps on the script that were correctly implemented during every PM

assessment session in order to calculate the overall agreement percentage. Interobserver

agreement data was collected for 100% of the progress monitoring sessions, during which

dependent variable measure was administered, and 30% of regular intervention sessions.

Experimental Design

A 3 x 3 x 8 mixed factorial analysis of variance (ANOVA) design was utilized for this study. A mixed factorial ANOVA allows the researcher to examine simultaneously the effects of multiple independent variables and their degree of interaction when at least one of them has been subject to repeated-measures. This special type of experimental factorial design contains both between-subjects and within-subjects factors. The independent variables for the current study were the set size and instructional time as the between-subjects factors. Set size contained three levels: 9-problems, 18-problems and 26-problems. Instructional time also contained three levels: 2-minutes, 4-minutes and 8-minutes. The within- subjects factor was time (repeated-measures) with eight levels (PM assessments). The dependent variable was the math fluency score, which was measured by digits correct per minute at every PM assessment.

Data Analysis

Data was analyzed using a mixed factorial ANOVA. The within-subjects factor was time with eight levels (PM assessments) and the between-subjects factors were set size with three levels (9-problems, 18-problems, and 36-problems), and instructional time with three levels (2-minutes, 4-minutes, and 8-minutes). The analyses were computed using the general linear model repeated measure function (GLM) through SPSS software. The data was interpreted for significant main effects, two- way interactions, and three-way interactions.

CHAPTER IV

RESULTS

This study examined the effects and interaction of varying levels of set size and instructional time on students' fluency growth rates with multiplication facts. Two hundred and fifty 4th grade students participated in the class-wide intervention. However, data for 14 students who failed to obtain consent was omitted. In addition, the data for 32 students with accuracy scores below 80% were also omitted from the study. The final data set consisted of 204 subjects (N=204).

Data were analyzed using a 3 x 3 x 8 mixed ANOVA. The between-subjects factors were set size and instructional time, each containing three levels: 9-problems, 18-problems and 36-problems for set size and 2-minutes, 4-minutes and 8-minutes for instructional time. The within-subjects factor was time with eight levels, in the form of progress monitoring assessments (PM1-PM8). The analyses were computed using the general linear model repeated measure function (GLM) through SPSS software. The data were interpreted for three-way interactions, two-way interactions and significant main effects. The results of the mixed factorial ANOVA are presented in Table 1.

Table 1

Repeated Measures Analysis of Variance for Mean Fluency Scores

Source	SS	df	MS	F	p	η_p^2
Between subjects						
Instructional Time	25,832.17	2	13,173.81	3.44	0.03*	0.03
Set Size	80,898.82	2	40,449.41	10.56	0.00**	0.10
Instructional Time x Set Size	11,079.96	4	2,769.99	0.72	0.58	0.02
Error	746,998.57	195	3,830.76			
Within subject						
Time	61,812.22	7	10,684.35	62.91	0.00**	0.24
Time x Instructional Time	5,463.33	14	472.29	2.78	0.00**	0.03
Time x Set Size	5,345.45	14	462.00	2.72	0.00**	0.03
Time x Instructional Time x Set Size	3,821.09	28	165.12	0.97	0.50	0.02
Error	191,595.73	805	169.85			
Total	1,132,847.34	1,071				

Note. *p<.05. **p<.01.

After the initial analysis, a group of outliers was identified. Upon review of the treatment integrity forms, those data points were found to correspond to participants in two classrooms in which the teachers failed to use the PowerPoint video with the standardized time intervals during the third PM measure. Due to the documented lack of treatment fidelity, those 36 data points were imputed. The SPSS Missing Value Analysis feature was utilized to run five possible outcomes, and the average of those was taken. Mauchley's test indicated that the assumption of sphericity had been violated, $\chi^2(27) = 177.95$, p < .001, therefore a Huynh-Feldt correction was used as a safeguard against type I error.

The first research question this study aimed to answer was whether there is an interaction between set size and instructional time across time that would influence the fluency growth rate on multiplication facts. Results of the final analysis indicated the absence of a significant three-way interaction between set size, instructional time and time. However, within-subjects effects indicated a significant interaction between time and set size, $F(14,805) = 2.72$, $p < .001$, $\eta_p^2 = .03$, as well as between time and instructional time, $F(14,805) = 2.78$, $p < .001$, $\eta_p^2 = .03$. This indicates that all levels of set size and instructional time performed differently across time. See Figures 1 and 2 for visual analysis of the group means on the set size and instructional time repeated measures, respectively. Moreover, there was a significant main effect for set size, $F(2,195) = 10.56$, $p < .001$, $\eta_p^2 = .1$, and for instructional time, $F(2,195) = 3.44$, $p < .05$, $\eta_p^2 = .03$.

Figure 1
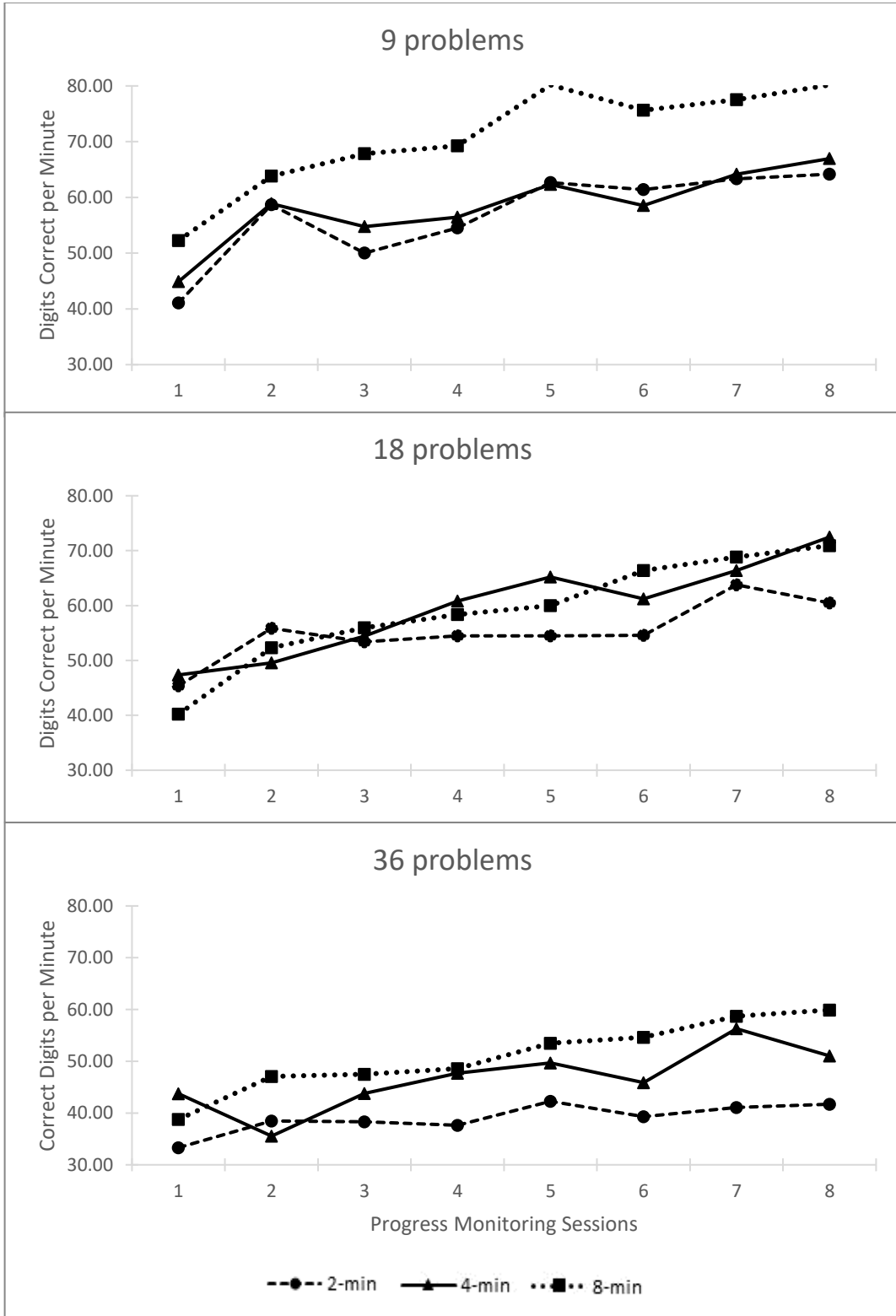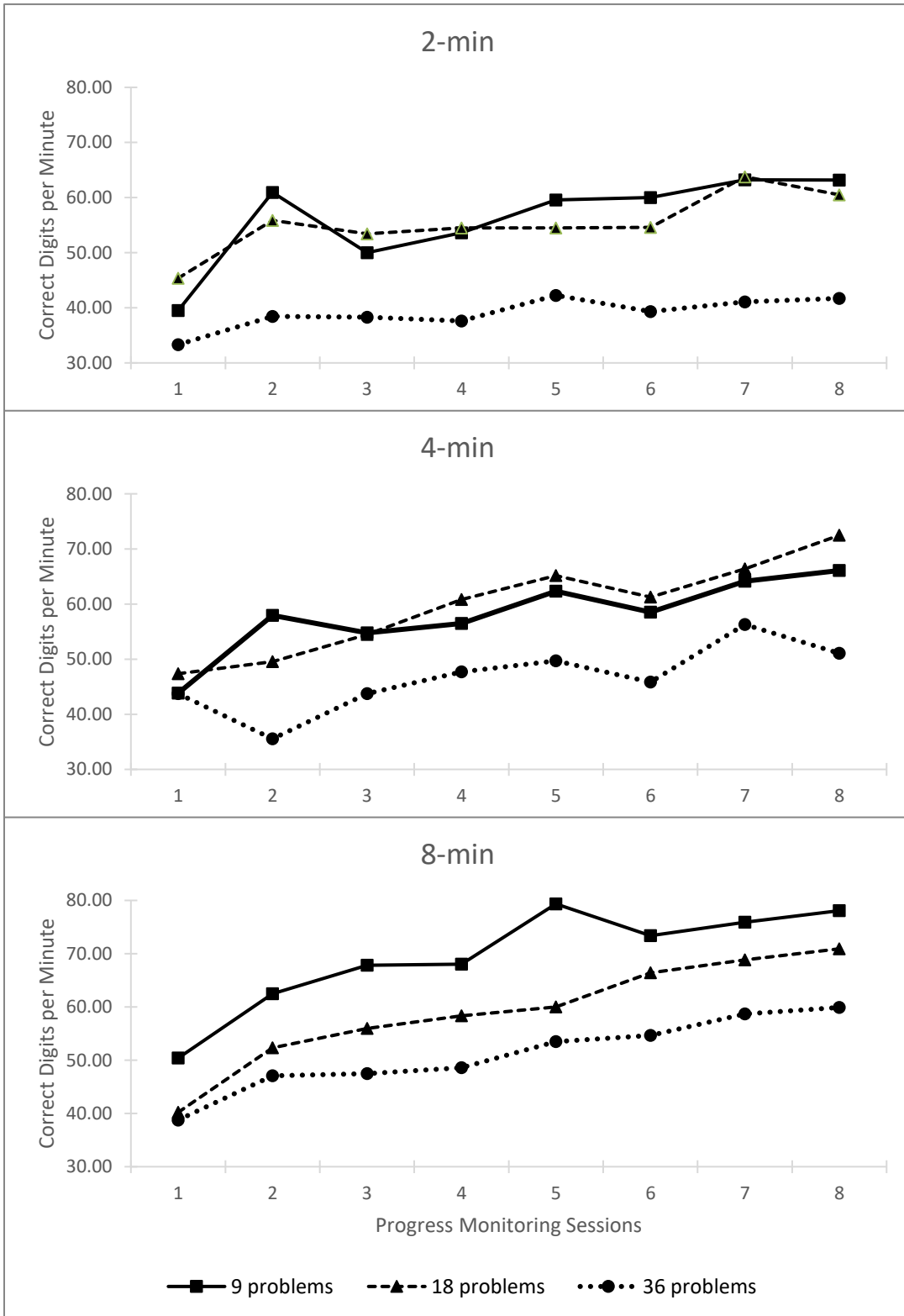
Observed Repeated Measures Performance by Set Size

Figure 2

Observed Repeated Measures Performance by Instructional Time

The second research question addressed the optimal combination of set size and instructional time to promote highest multiplications fluency growth rate. To answer that question, the estimated marginal means were utilized to calculate the growth rate, as shown in Table 2. This following formulas were used:

Growth Rate = Learning Rate X Number of Problems (Set Size)

Learning Rate = Overall Growth/Cumulative Instructional Time (Skinner, 2010)

Overall Growth = PM8 – PM1 (DCPM)

CIT = Instructional Time (per session) X 21 Sessions

Table 2

Growth Rate Based on Estimated Marginal Means

Instructional Time (minutes/ session)	Set Size (problems)	Overall Growth (DCPM)	CIT (minutes)	Learning Rate	Growth Rate
	9	23.125	42	0.551	4.955
2	18	14.443	42	0.344	6.190
	36	9.111	42	0.217	7.810
	9	21.731	84	0.259	2.328
4	18	25.784	84	0.307	5.525
	36	10.213	84	0.122	4.377
	9	27.920	168	0.166	1.496
8	18	27.927	168	0.166	2.992
	36	21.143	168	0.126	4.531

Growth rates were calculated using a MS Excel spreadsheet. A visual comparison of the overall growth, learning rate and growth rate (Figure 3) clarifies the need for set size to be included when measuring efficiency of the intervention. The growth rate graph indicates the 2-minute/36-problem condition obtained the highest growth rate.

Figure 3

Overall Growth, Learning Rate and Growth Rate by Condition Group
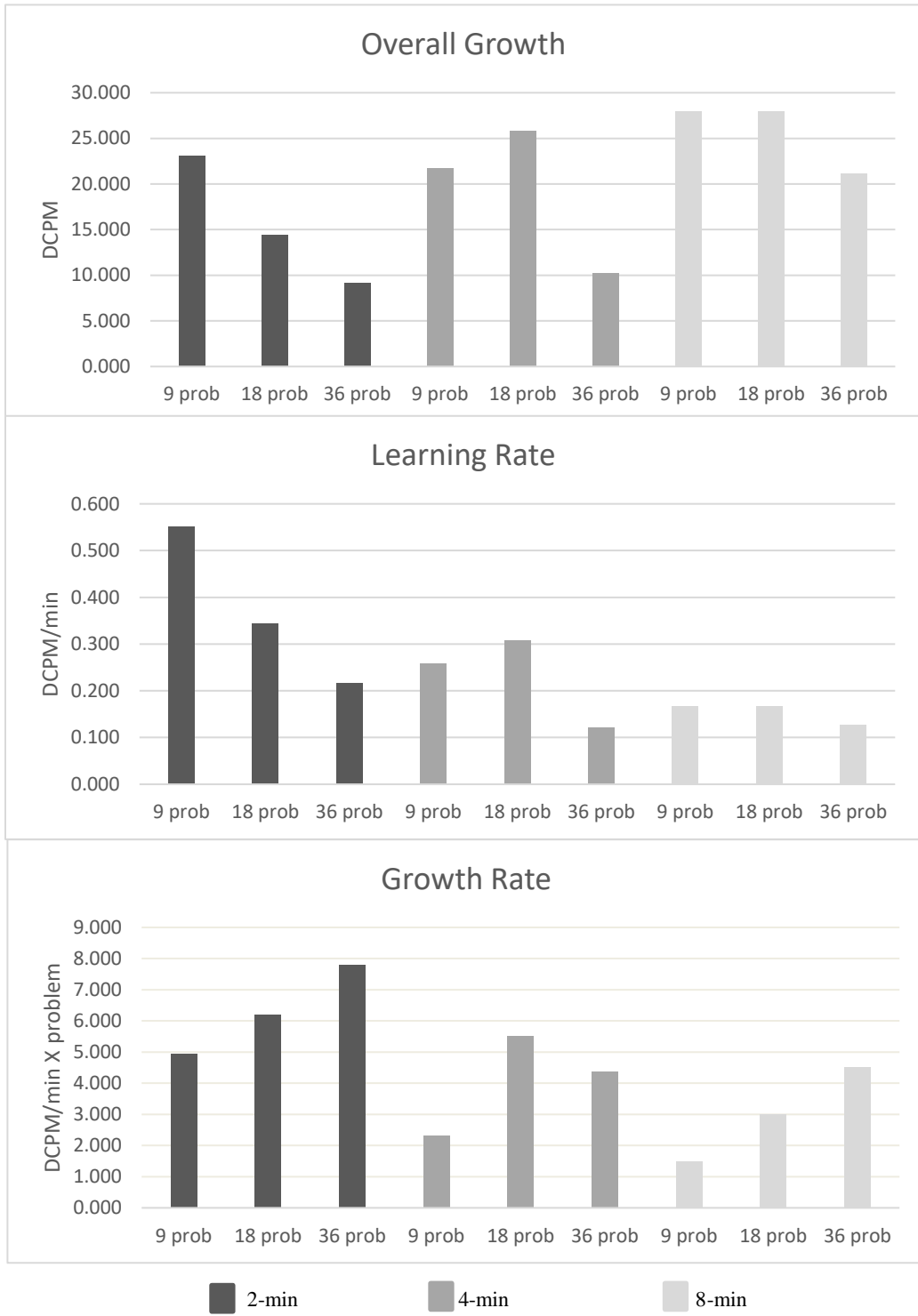
The third research question this study aimed to address was whether a particular combination of set size and instructional time would enhance generalization of multiplication facts. Generalization was defined as the student's proficiency to correctly answer reciprocal multiplication facts, to which they had not been exposed during the intervention phase. To this end, an analysis of covariance was used to assess which instructional time condition group obtained the greatest gain when the pre-test was used as a covariate. Results indicated that instructional time did have a significant effect on the post-test measure of generalization, $F(2,192) = 4.67$, $p < .05$. Further examination of the pairwise comparisons indicated that the 2-minute and 8-minute conditions significantly differed from each other, p = 0.008 (See Table 3).

Table 3

Post-test Pairwise Comparisons of Instructional Time Conditions

Instructional Time		Mean Difference	Standard Error	Significance
2-minutes	4-minutes	-3.911	2.390	0.310
	8-minutes	-7.148	2.339	0.008**
4-minutes	2-minutes	3.911	2.390	0.310
	8-minutes	-3.237	2.319	0.493
8-minutes	2-minutes	7.148	2.339	0.008**
	4-minutes	3.237	2.319	0.493

*$p < 0.05$, ** $p < 0.01$

Please see Table 4 and Figure 4 for descriptive statistics and visual analysis of the group means for the 36-problem reciprocal assessment.

Table 4

Means and Standard Deviations for Groups on 36-Reciprocal Problems Assessment

Group	n	Pretest		Posttest	
		M	SD	M	SD
2-min/9-prob	24	29.789	14.353	34.417	16.639
2-min/18-prob	20	40.632	21.303	47.950	24.235
2-min/36-prob	20	28.200	19.303	40.250	22.643
4-min/9-prob	24	32.125	15.809	35.958	16.137
4-min/18-prob	23	35.857	20.994	48.522	23.357
4-min/36-prob	22	31.526	20.479	52.955	28.506
8-min/9-prob	25	33.565	15.267	42.200	16.086
8-min/18-prob	25	32.720	14.837	44.240	17.018
8-min/36-prob	21	30.000	14.510	60.476	23.784

Figure 4

Observed Group Mean Performance on 36-Reciprocal Problem Assessment
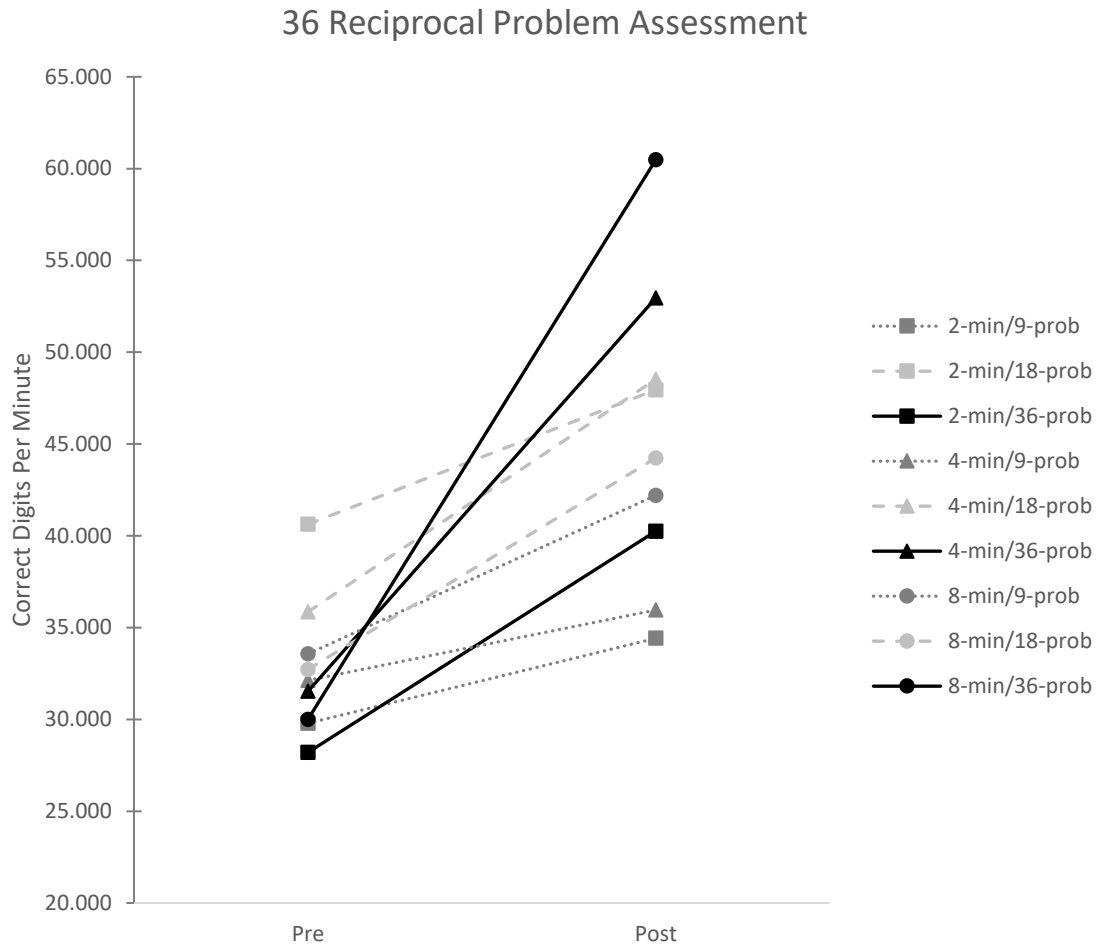
The fourth and final research question this study proposed was whether a particular combination of set size and instructional time would enhance maintenance of multiplication facts. To this end, a paired t-test conducted to compare the fluency measure (PM8) and the maintenance measure taken one week after the intervention had ended revealed a significant difference in the scores for PM8 ($M = 64.01$, $SD = 26.32$) and Maintenance ($M = 73.93$, $SD = 26.97$), $t(199) = -10.631$, $p < 0.001$.

CHAPTER V

DISCUSSION

Current literature focuses on learning rate as the measure for instructional efficiency. Learning rate only accounts for the amount of behavior change, or overall growth, by unit of time spent in the learning experience, or instructional time (Skinner, 2010). However, the literature shows a wide variety of set sizes used in studies utilizing ET as a math computation fluency intervention, and yet little attention has been paid to how the set size affects the overall growth, and therefore the efficiency of the intervention (Poncy et al., 2015).

The primary goal of the current study was to evaluate the effects and interaction of item set size and instructional time on students' fluency growth rates with multiplication facts over time when using an ET intervention. To accomplish this, a total of 11 fluency measures were taken among participants randomly assigned to one of nine condition groups. The condition groups represented a combination among three levels of set size, defined as the number of multiplication problems (9, 18, and 36), and three levels of instructional time, defined as minutes of instruction per session (2-min, 4-min, and 8-min). Intervention and assessments were given in a class-wide group format. The teachers administered the intervention daily by playing a video, which contained instructions for the entire class and four 2-minute built-in intervention timed intervals. The results of this study indicated that ET was effective in producing overall growth, that is in increasing the fluency of multiplication facts across all condition groups, which support

previous findings (Van Houten & Thompson, 1976; Rhymer et al., 2002). In addition, a one-week

follow-up assessment indicated that fluency gains were maintained across all condition groups.

The lack of a three-way interaction between instructional time, set size and time suggested that

the performance of the different condition groups over time followed similar patterns.

A significant two-way interaction between time and set size indicated that students in all

three levels of set size performed differently across time. In particular, data from the 9-problem

condition revealed that the 8-min group yielded higher fluency measures than the 2-min and 4-

min groups consistently over time, while there were no differences among the performance of the

2-min and 4-min groups. Data from the 18-problem condition revealed that while the 2-min and

4-min groups had the same initial fluency, the upward trend of the 4-min group yielded

significantly higher fluency scores in the end. The 8-min group also presented an upward

trajectory that led the group to match the fluency scores of the 4-min group in the end, despite

displaying lower initial fluency. Data from the 36-problem condition revealed that the 2-min

group consistently yielded lower fluency rates over time, while the 8-min group presented a slight

upward trajectory that led to higher fluency scores consistently over time. Across all set size

levels, the 2-min group consistently yielded lower fluency rates.

Similarly, the significant two-way interaction between time and instructional time

indicated that those condition groups performed differently across time. The 2-min and 4-min

conditions yielded very similar trajectories among the 9-probem and 18-problem groups, with

both of those groups displaying higher fluency scores than the 36-problem group consistently

over time. The 8-min condition revealed that the 9-problem group maintained higher fluency

scores consistently over time, while the 36-problem group ended the study with lower fluency

scores than the 18-problem group, despite presenting no significant differences in their initial

fluency measure. Across all instructional time levels, the 36-problem group consistently yielded

lower fluency rates.

The second goal of the current study was to determine an optimal combination of set size

and instructional time to promote highest fluency growth rate. For this purpose, estimated marginal means were utilized to calculate the growth rate. Growth rate comparisons indicated that the 2-min/36-problem condition group obtained a gain of 7.810 digits per minute of instruction, a gain about 21% above the second highest group (2-min/18-problem), and 81% above the least efficient condition (8-min/9-problem).

The third goal of the present study was to determine an optimal combination of set size and instructional time to enhance generalization of multiplication facts. Although fluency gains on the reciprocal problems were observed across all condition groups, an analysis of covariance indicated that only instructional time, and not set size, had a significant effect on the post-test measure of generalization. Pairwise comparisons revealed that the fluency gains on reciprocal problems increased by over 100% in the 8-min/36-problem condition, and by about 68% in the 2-min/36-problem condition. On the opposing end, the 4-min/9-problem condition led to the lowest fluency gains on the generalization measure, with an increase of about 12% in digits correct per minute.

The fourth goal was to determine an optimal combination of set size and instructional time to enhance maintenance of multiplication facts over time. Results indicated that fluency gains were maintained across all condition groups and no significant differences among any of the groups were determined.

General Implication of Findings

Results from the present study support previous findings regarding the efficacy of ET as an intervention to build multiplication facts fluency. In fact, students across all condition groups showed overall growth, ranging from nine to 27 digits, during the five-week intervention. Similarly, learning rate comparison data supported previous findings indicating the need to account for the overall time required to learn in order to determine intervention efficiency (Skinner, 2010). Specifically, results indicated that the combination of 2-min instructional time level and 9-problem set size level produced the highest learning rate, yielding a gain of about half

a digit per minute of instruction. However, when accounting for set size, the 2-min/9-problem condition did not yield the highest efficiency.

Growth rate comparisons in the present study made evident that set size affects performance differently across instructional time levels. Based on growth rate, the 2-min/36-problem condition yielded the highest efficiency, contrary to the expectation that smaller size sets would lead to higher efficiency (Poncy et al., 2015). The biggest set size group also yielded highest efficiency in the 8-min condition. However, it was the 18-problem group that produced highest efficiency within the 4-min condition. Growth rate comparisons indicated no significant differences between the 2-min/9-problem and 4-min/18-problem conditions. Data from learning rate analyses supported the use of the smallest levels of instructional time to produce the highest efficiency, while data from growth rate analyses indicated that the largest set size combined with the smallest instructional time produces the highest gains in fluency in the shortest amount of time.

General Limitations and Future Directions

The first limitation identified in the current study involved the inclusion criteria, which was restricted to those students whose performance was at least 80% accurate in multiplication facts. Measures of initial fluency were obtained, but they were not taking into consideration in the inclusion criteria, leading to much variability in the scores. Future math facts fluency studies that investigate homogeneous fluency groups may obtain a better estimate and understanding of the effects of set size and instructional time on performance over time. Specifically, a replication of the present study using randomized block design based on initial fluency may allow for better identification of significant variance among the different combinations of set size and instructional time. Understanding how students respond to those combinations, or doses, of the ET intervention based on their initial fluency performance may facilitate the identification of prescriptive thresholds for such intervention. For example, data from the current study

indicated that the 2-min/9-problem condition produced a learning rate of half a digit per minute of instruction. If such learning rate is validated and found to be consistent among students whose initial fluency is between 30-40 CDPM, then that particular dose of the ET intervention may be prescribed for students presenting an initial fluency level within that range, while a different dose may be more appropriate for students presenting lower fluency rates.

A second limitation involved the order in which the math intervention was administered among the different condition groups. Instructional time condition groups received the ET intervention in consecutive intervals, instead of following randomized assignment. Future studies should investigate the effectiveness of the ET intervention applied under different order of instructional time intervals. Considering that the present data suggests the 2-min instructional time interval to be the most effective, examining the same interval under different conditions may provide useful data to aid in the design of effective interventions. For example, instead of presenting the 4-min instructional time condition as two consecutive 2-min intervals, the ET intervention could be presented at the first and third intervals under one condition, and the first and fourth intervals under another condition, in order to determine if and how the effectiveness of the intervention varies when presented in scattered intervals with breaks in between.

A third limitation implicated the administration of the intervention via video. Although class-wide gains in fluency of multiplication facts across condition groups were obtained by utilizing video as the method of delivery of the ET intervention, the videos required teachers to manually operate the equipment. In fact, data from two classrooms were compromised due to teachers altering the instructional time of the third progress monitoring measure by failing to use the video altogether. This limitation highlights the need for additional training for teachers to address the importance of treatment integrity when conducting applied research in the classrooms.

A fourth limitation included the limited population used in the study. Although this study counted with 204 participants, they were all in the fourth grade at two elementary schools in a

suburban school district in central Oklahoma, making it difficult to generalize the current findings to other ages and math skills. Future studies should investigate the effects and interaction of set size and instructional time across different age/grade levels and types of mathematical skills (i.e., addition, subtraction).

Summary

In summary, current literature focuses on learning rate as the measure for instructional efficiency. However, the literature shows a wide variety of set sizes used in studies utilizing explicit timing as a math computation fluency intervention, and yet little attention has been paid to how the set size affects overall growth and learning rate. The current study evaluated the effects and interaction of item set size and instructional time on students' fluency growth rates with multiplication facts over time when using an explicit timing intervention. Specifically, nine groups of students were exposed to different combinations of set size, defined as the number of multiplication problems (9, 18, 36), and instructional time, defined as the minutes of instruction per session (2-min, 4-min, and 8-min).

Overall, results indicate that fluency performance improved across all condition groups, suggesting that explicit timing is an effective intervention to increase fluency. In addition, while learning rate comparison data support the need to account for the cumulative instructional time to determine intervention efficiency, growth rate comparison data make evident that set size affects performance differently across instructional time levels, and also impacts intervention efficiency. When accounting solely for cumulative instructional time, the 2-minute/9-problem condition was the most efficient. However, when accounting for set size in addition to the cumulative instructional time, the 2-minute/36-problems condition was the most efficient. These results are important for researchers and practitioners who seek to identify more efficient interventions in order to increase academic success among students. Nevertheless, additional research is needed to further disentangle and understand the relationship between set size and instructional time and its impact on intervention efficiency.

REFERENCES

Aksoy, T., & Link, C. R. (2000). A Panel Analysis of Student Mathematics Achievement in the
US in the 1990s: Does Increasing the Amount of Time in Learning Activities Affect
Math Achievement?. *Economics Of Education Review*, *19*(3), 261-77.

Ardoin, S., & Daly, P. (2007). Introduction to the Special Series: Close Encounters of the
Instructional Kind—How the Instructional Hierarchy is Shaping Instructional Research
30 Years Later. *Journal of Behavioral Education, 16*(1), 1-6.Begin typing or pasting the
rest of your chapter 1 text here.

Axtell, P. K., McCallum, R. S., Mee Bell, S., & Poncy, B. (2009). Developing math automaticity
using a classwide fluency building procedure for middle school students: A preliminary
study. *Psychology In The Schools*, *46*(6), 526-538.

Baldi, S., & National Center for Education Statistics. (2007). *Highlights from PISA 2006*
performance of U.S. 15-year-old students in science and mathematics literacy in an
international context. Washington, D.C.]: National Center for Education Statistics,
Institute of Education Sciences, U.S. Dept. of Education.

Bramlett, R. K., Murphy, J. J., Johnson, J., Wallingsford, L., & Hall, J. D. (2002). Contemporary
Practices in School Psychology: A National Survey of Roles and Referral
Problems. *Psychology in the Schools, 39*(3), 327-35.

Buxton, C.E., & Newman, E. B. (1940). The forgetting of 'crowded' and 'isolated' materials. *Journal of Experimental Psychology, 26*(2), 180-198.

Cates, G. L., & Rhymer, K. N. (2006). Effects of Explicit Timing on Elementary Students' Oral Reading Rates of Word Phrases. *Reading Improvement, 43*(3), 148-156.

Cates, G. L., Skinner, C. H., Watson, T. S., Meadows, T. J., Weaver, A., & Jackson, B. (2003). Instructional Effectiveness and Instructional Efficiency as Considerations for Data-Based Decision Making: An Evaluation of Interspersing Procedures. *School Psychology Review*, *32*(4), 601-616.

Codding, R. S., Shiyko, M., Russo, M., Birch, S., Fanning, E., & Jaspen, D. (2007). Comparing Mathematics Interventions: Does Initial Level of Fluency Predict Intervention Effectiveness?. *Journal Of School Psychology*, *45*(6), 603-617.

Daly, Edward J., III, Witt, Joseph C., Martens, Brian K., & Dool, Eric J. (1997). A Model for Conducting a Functional Analysis of Academic Performance Problems. *School Psychology Review, 26*(4), 554-74.

Duhon, G. J., House, S. H., & Stinnett, T. A. (2012). Evaluating the Generalization of Math Fact Fluency Gains across Paper and Computer Performance Modalities. *Journal of School Psychology, 50*(3), 335-345.

Duhon, G., Poncy, B., & Fontenelle, S. (2011). Examining student response latency performance on multiplication facts. Manuscript in preparation, Department of Education, Oklahoma State University, Stillwater, Oklahoma.

Duhon, G., Poncy, B. C., Hubbard, M., Purdum, M., & Kubina, R. (2012). *An examination of various intervention components with explicit timing procedures to increase math fact fluency.* Symposium at the meeting of the Association of Behavior Analysis, Seattle, WA

Fontenelle, S., Poncy, B. C., Davis, R., Duhon, G. & Stinnett, T. (2014). *The Effects of Curricular Modifications on Math Fact Fluency Rates,* ProQuest Dissertations and Theses.

Forbes, B. E., Skinner, C. H., Black, M. P., Yaw, J., Booher, J., & Delisle, J. (2013). Learning rates and known-to-unknown flash-card ratios: Comparing effectiveness while holding instructional time constant. *Journal of Applied Behavior Analysis, 46*(4), 832-837.

Haring, N. G., & Eaton, M. D. (1978). Systematic instructional procedures: An instructional hierarchy. In N. G. Haring, T. C. Lovitt, M.D. Eaton, & C. L. Hansen (Eds.), The fourth R: Research in the classroom (p. 23-40). Columbus, OH: Charles E. Merrill Publishing Company.

Hartnedy, S. L., Mozzoni, M. P., & Fahoum, Y. (2005). The effect of fluency training on math and reading skills in neuropsychiatric diagnosis children: A multiple baseline design. *Behavioral Interventions, 20*(1), 27-36.

Lewis, K. A., & Seidman, L. S. (1994). Math—time capital matters: A cross-country analysis. *Economics of Education Review, 13*(3), 215-226.

McCallum, E., Skinner, C. H., Turner, H., & Saecker, L. (2006). The taped-problems intervention: Increasing multiplication fact fluency using a low-tech, classwide, time delay intervention. *School Psychology Review*, *35*(3), 419-434.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: U.S. Department of Education. Retrieved from https://ed.gov/about/bdscomm/list/mathpanel/reports.html

Nist, L., & Joseph, L. M. (2008). Effectiveness and efficiency of flashcard drill instructional methods on urban first-graders' word recognition, acquisition, maintenance, and generalization. *School Psychology Review*, *37*(3), 294-308.

Petrill, S., Logan, J., Hart, S., Vincent, P., Thompson, L., Kovas, Y., & Plomin, R. (2012). Math Fluency Is Etiologically Distinct from Untimed Math Performance, Decoding Fluency,

and Untimed Reading Performance: Evidence from a Twin Study. *Journal Of Learning Disabilities*, *45*(4), 371-381.

Phelps, G., Corey, D., DeMonte, J., Harrison, D., & Loewenberg Ball, D. (2012). How Much English Language Arts and Mathematics Instruction Do Students Receive? Investigating Variation in Instructional Time. *Educational Policy*, *26*(5), 631-662.

Poncy, B. C., Duhon, G. J., Lee, S. B., & Key, A. (2010). Evaluation of techniques to promote generalization with basic math fact skills. *Journal of Behavioral Education, 19*(1), 76-92.

Poncy, B., Fontenelle, S., & Skinner, C. (2013). Using Detect, Practice, and Repair (DPR) to Differentiate and Individualize Math Fact Instruction in a Class-Wide Setting. *Journal Of Behavioral Education*, *22*(3), 211-228.

Poncy, B. C., & Skinner, C. H. (2011). Enhancing First-Grade Students' Addition-Fact Fluency Using Classwide Cover, Copy, and Compare, a Sprint, and Group Rewards. *Journal Of Applied School Psychology*, *27*(1), 1-20.

Poncy, B., Solomon, B., Duhon, G., Moore, K., Simons, S., & Skinner, C. (2015). An Analysis of Learning Rate and Curricular Scope: Use Caution when Choosing Academic Interventions Based on Aggregated Outcomes. *School Psychology Review, 44*(3), 289-305.

Provasnik, S., Malley, L., Stephens, M., Landeros, K., Perkins, R., Hang, J., (2016). Highlights from TIMSS and TIMSS Advanced 2015: Mathematics and Science Achievement of U.S. Students in Grades 4 and 8 and in Advanced Courses at the End of High School in an International Context. *National Center for Education Statistics*. Retrieved from https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2017002

Rhymer, K. N., Skinner, C. H., Jackson, S., McNeill, S., Smith, T., & Jackson, B. (2002). The 1-Minute Explicit Timing Intervention: The Influence of Mathematics Problem Difficulty. *Journal Of Instructional Psychology*, *29*(4), 305.

Schutte, G. M., Duhon, G. J., Solomon, B. G., Poncy, B. C., Moore, K., Story, B. (2015). A
    comparative analysis of massed vs. distributed practice on basic math fact fluency growth
    rates. *Journal of School Psychology, 53*, 149-159.

Shinn, M. (1989). *Curriculum-based measurement : Assessing special children* (Guilford school
    practitioner series). New York, NY: Guilford Press.

Singer-Dudek, J., & Greer, R. (2005). A Long-Term Analysis of the Relationship Between
    Fluency and the Training and Maintenance of Complex Math Skills. *The Psychological
    Record, 55*(3), 361-376.

Skinner, C. H. (2008). Theoretical and Applied Implications of Precisely Measuring Learning
    Rates. *School Psychology Review, 37*(3), 309-314.

Skinner, C. H. (2010). Applied comparative effectiveness researchers must measure learning
    rates: A commentary on efficiency articles. *Psychology In The Schools*, *47*(2), 166-172.

Skinner, C. H., Fletcher, P. A., & Henington, C. (1996). Increasing learning rates by increasing
    student response rates: A summary of research. *School Psychology Quarterly, 11*(4), 313-
    325.

Skinner, C. H., Turco, T. L., Beatty, K. L., & Rasavage, C. (1989). Cover, copy, and compare: A
    method for increasing multiplication performance. *School Psychology Review*, *18*(3),
    412- 420.

Van Houten, R., & Thompson, C. (1976). The effects of explicit timing on math performance.
    Journal of Applied Behavior Analysis, *9*(2), 227–230. http://doi.org/10.1901/jaba.1976.9-
    227

Wallace, W. P. (1965). Review of the historical, empirical, and theoretical status of the von
    Restorff phenomenon. *Psychological Bulletin*, *63*(6), 410-424.

Woodward, J. (2006). Developing Automaticity in Multiplication Facts: Integrating Strategy
    Instruction with Timed Practice Drills. *Learning Disability Quarterly*, *29*(4), 269-289.

Zeith, Timothy Z., & Cool, Valerie A. (1992). Testing Models of School Learning: Effects of

    Quality of Instruction, Motivation, Academic Coursework, and Homework on Academic

    Achievement. *School Psychology Quarterly, 7*(3), 207-26.

APPENDICES

Appendix A

Explicit Timing Math Intervention Example Probe

Name:_____

3	7	7	9	8	2	6	5	8
x 2	x 7	x 4	x 2	x 7	x 6	x 9	x 5	x 5

6	7	7	8	3	8	9	2	5
x 9	x 7	x 4	x 5	x 2	x 7	x 2	x 6	x 5

9	7	2	8	3	8	6	5	7
x 2	x 7	x 6	x 7	x 2	x 5	x 9	x 5	x 4

5	8	3	7	6	8	9	2	7
x 5	x 7	x 2	x 4	x 9	x 5	x 2	x 6	x 7

3	2	5	7	9	7	6	8	8
x 2	x 6	x 5	x 7	x 2	x 4	x 9	x 5	x 7

2	8	5	3	9	7	6	8	7
x 6	x 7	x 5	x 2	x 2	x 4	x 9	x 5	x 7

2	3	9	5	6	7	8	7	8
x 6	x 2	x 2	x 5	x 9	x 4	x 7	x 7	x 5

3	7	5	2	7	8	8	9	6
x 2	x 7	x 5	x 6	x 4	x 7	x 5	x 2	x 9

Appendix B

Reading Filler Example Probe

Student Name:_____Classroom :_____Date: _____

The Bakery

Light crept through the bedroom window and woke Josh up. At first he was a bit **(square, disoriented, test)** and did not recognize the room **(unit, relieved, but)** he quickly remembered where he was. **(Thick, Yesterday, Suggest)** had been moving day, and this **(was, fierce, fast)** his new home. "Today, I'll explore **(my, about, noisily)** new neighborhood and, with any luck, **(I'll, place, question)** make some friends," he said to **(himself, range, branch)**. Josh jumped out of bed and **(tall, hair, pushed)** open the window. He stretched and **(substance, outside, took)** a long, deep breath, and that's **(when, unfasten, remove)** he noticed it. The air was **(filled, bland, spoon)** with the most wonderful aroma. "I've **(lip, got, applaud)** to find out where that incredibly **(summer, rough, delicious)** smell is coming from!" exclaimed Josh, **(run, have, as)** he threw on his clothes and **(quality, ran, lively)** down the stairs.

In the kitchen, **(deliver, nerve, his)** stepmother and dad were conversing about **(woken, their, ask)** plans for the day over breakfast. "**(hot, condition, Did)** you notice that wonderful aroma?" his **(rough, stepmother, as)** asked. "Absolutely," replied Josh, "and I'm **(homely, going, cheerful)** to investigate where it's coming from **(amid, wicked, as)** soon as I finish breakfast." "That's **(multiply, brainy, not)** necessary," Dad said, "because I can **(parcel, tell, thrown)** you it's the smell of fresh **(hourly, anxiously, bread)** from a nearby bakery. In fact, **(squeaky, I, drink)** bought these breakfast muffins there just **(awful, a, realize)** little while ago. You should stop **(by, snow, attend)** and introduce yourself. Mr. Lee, the **(baker, ornament, anxiously)**, really wants you to meet his **(son, writing, brick)**." After he had devoured his breakfast, **(embarrassed, road, Josh)** ambled down the sidewalk toward the **(skirt, bakery, open)**. He found it at the corner **(soap, motion, where)** his street intersected the main road. **(Somebody, Inside, Division)** the bakery, Josh saw a counter **(forgave, where, cooley)** loaves of bread were stacked alongside **(so, muffins, fell)**, cookies, and sweet rolls. They all **(puzzled, smelled, obedient)** and looked mouthwateringly delicious. Mr. Lee **(came, bucket, froze)** out and welcomed Josh to the **(irritably, brother, bakery)**. After they chatted for a while, **(hot, try, he)** introduced Josh to Li-Young, his son. **(Amidst, The, Boldly)** two boys began talking and soon **(sand, fragile, found)** they had many things in common. **(Li-Young, Bury, Frantic)** offered to show Josh around the **(poorly, per, neighborhood)**, and they spent the morning roaming **(bounce, around, fish)** together. Josh headed home for lunch **(cord, force, with)** a good feeling. He had, indeed, **(made, snake, poised)** a new friend, and what could **(head, island, be)** better than waking up each day **(to, meat, cheerfully)** the smell of fresh-baked bread? He **(bird, ran, couldn't)** wait to learn more about his **(kindly, attend, new)** neighborhood and meet more friends.

45

Appendix C

Parent Consent Form

PARENT/GUARDIAN PERMISSION FORM
OKLAHOMA STATE UNIVERSITY

PROJECT TITLE: Practice Makes Perfect: Identifying the Optimal Intervention Strength to Obtain the Most Growth in Multiplication Facts Fluency

INVESTIGATOR(S): Gary Duhon, PhD, Patty Nuhfer, Cristina Serrano, Sheridan Smith

PURPOSE:
The purpose of the present study is to examine how different rates of practice of multiplication facts among elementary school students affect the fluency of those facts in order to identify the most optimal intervention rate.

PROCEDURES:
For the present study, a class wide intervention approach will be used. During daily sessions, the students will receive a math probe or a written expression probe based on the group assignments. The class will be directed to wait for instructions as the probes are placed face down on their desks. Students receiving the math intervention will receive an individualized multiplication probe containing their name and the goal for the session. The students will have two minutes to work on the math or writing probe. After the time limit, the papers will be collected and a second math or writing probe will be distributed according to the prior procedures. Each time a student exceeds a goal, he or she will receive one point. The number of cumulative goal points for the week will be written on the math probe. At the end of each school week, rewards will be distributed to all students based on the number of points earned.

RISKS OF PARTICIPATION:
There are no known risks associated with this project which are greater than those ordinarily encountered in daily life.

BENEFITS OF PARTICIPATION:
The benefits of participation include your child potentially increasing fluency scores of multiplication facts. This may help to improve performance in other areas of mathematics.

The results of this study can also be used to give the principal and teachers feedback about the effectiveness of varying the intensity level of the intervention.

CONFIDENTIALITY:
The records of this study will be kept private. Any written results will discuss group findings and will not include information that will identify you or your child. Research records will be stored on a password protected computer in a locked office and only researchers and individuals responsible for research oversight will have access to the records.

CONTACTS:
You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study: Gary Duhon, Ph.D., 423 Willard Hall, Dept. of SAHEP- School Psychology, Oklahoma State University, Stillwater, OK 74078, (405) 744-9436. If you have questions about your rights as a research volunteer, you may contact the IRB Office at 223 Scott Hall, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

PARTICIPANT RIGHTS:
I understand that my child's participation is voluntary, that there is no penalty for refusal to participate, and that I am free to withdraw my permission at any time. Even if I give permission for my child to participate I understand that he/she has the right to decline.

CONSENT DOCUMENTATION:
I have been fully informed about the procedures listed here. I am aware of what my child and I will be asked to do and of the benefits of my participation. I also understand the following statement:

I have read and fully understand this permission form. I sign it freely and voluntarily. A copy of this form will be given to me. I hereby give permission for my child _____, to participate in this study.

_____   _____
Signature of Parent/Legal Guardian   Date

Appendix D

Student Assent Form

ASSENT FORM
OKLAHOMA STATE UNIVERSITY

Dear Student,

We are interested in learning what the best rate of practice is to gain fluency in multiplication facts. We need your permission in order for you to participate in the project. Your parent/guardian is aware of this project.

Please understand that you do not have to do this. You do not have to answer any questions that you do not want to. You may stop at any time and go back to your classroom.

Your name will not be on the forms you fill out, and you will be given a number that will be put on your answer sheet so no one will know whose answers they are. If you have any questions about the form or what we are doing, please ask us. Thank you for your help.

Sincerely,

Gary Duhon, PhD
Associate Professor Oklahoma State University

I have read this form and agree to help with your project.

_____
(your name**)**

_____
(your signature)

_____
(date)

Appendix E

Treatment Fidelity Checklist

Fidelity Assessment Protocol

Teacher: _____   School: _____

Observer: _____   Date: _____

Start Time: _____ am / pm   End Time: _____ am / pm

Initial in the provided space when you observe a step in the intervention.

1. Pass out the folders to students _____

2. Play the video. Ensure the volume is appropriate for the whole class to hear _____

3. Record the start time of the intervention on the *Intervention Log* _____

4. Walk around the room to make sure the students write their first and last name on the first page _____

5. Continue walking around throughout the intervention to make sure the students are: 1) following each step as per the instructions on the video, 2) completing the worksheets correctly, 3) to give encouragement if needed _____

6. Once the intervention is completed, make sure the students place the packets inside their folder _____

7. Collect all of the folders _____

8. Record the end time of the intervention on the *Intervention Log* _____

9. Keep folders in a secure place to prevent tampering _____

Appendix F

Institutional Review Board Approval Letter

Oklahoma State University Institutional Review Board

Date:	Friday, April 10, 2015
IRB Application No	ED1524
Proposal Title:	Practice makes perfect: Identifying the optimal intervention strength to obtain the most growth in multiplication facts fluency
Reviewed and Processed as:	Exempt

Status Recommended by Reviewer(s): Approved   Protocol Expires: 4/9/2018

Principal
Investigator(s):

Gary J Duhon	Patty Nuhfer	Cristina Serrano
423 Willard	415 Willard	423 Willard Hall
Stillwater, OK 74078	Stillwater, OK 74078	Stillwater, OK 74078
Sheridan Smith		
423 Willard Hall		
Stillwater, OK 74078		

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Cordell North (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Hugh Crether, Chair
Institutional Review Board

VITA

Margarita Patricia Hernandez-Nuhfer

Candidate for the Degree of

Doctor of Philosophy

Thesis: EVALUATING THE EFFECTS AND INTERACTION OF ITEM SET SIZE
AND INSTRUCTIONAL TIME ON STUDENT FLUENCY GROWTH
RATES WITH MULTIPLICATION FACTS

Major Field: Educational Psychology (Option: School)

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Educational
Psychology (Option: School) at Oklahoma State University, Stillwater,
Oklahoma in May, 2018.

Completed the requirements for the Master of Arts in School Psychology at the
University of Central Oklahoma, Edmond, OK in 2012.

Completed the requirements for the Bachelor of Arts in Psychology at the
University of Oklahoma, Norman, OK in 2007.

Experience:

Pre-Doctoral Intern at the University of Nebraska Medical Center's Munroe
Meyer Institute (Behavioral Pediatrics), July 2017-June 2018; Systems-Level
Consultant for Oklahoma Department of Education, May 2015-June 2017;
Graduate Teaching Assistant at Oklahoma State University, August 2014 – May
2015; 400-hour clinic-based practicum at the Oklahoma State University School
Psychology Center, May 2015-June 2017; 1200-hour school psychology
internship at Applied Behavior Analysis of Oklahoma, January 2013-December
2013; 1500-Applied Behavior Analysis supervised field hours at UCO Autism
Day School, Good Shepherd Catholic School at Mercy and Applied Behavior
Analysis of Oklahoma, August 2011-December 2012.

Professional Memberships:

National Association of School Psychologists; American Psychological
Association; Oklahoma School Psychologist Association; Oklahoma State
University School Psychology Graduate Organization; Psi Chi.