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IMPROVING MULTIPLICATION FACT FLUENCY AMONG HIGH SCHOOL STUDENTS WITH LEARNING DISABILTIIES

A Thesis in

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ABSTRACT

Before students are able to solve complex mathematic problems, they must be fluent with their facts. Unfortunately, students with learning disabilities often rely upon inefficient retrieval strategies and can not rapidly produce answers to single-digit facts. This lack of automaticity prevents students from completing multi-step tasks because their time and energy is devoted to the recall of simple facts. The purpose of this study was to extend existing research on fact fluency using a technique known as detect, practice, and repair (DPR). A single subject AB design was used to determine the effectiveness of this method in improving students' recall of multiplication facts. Seven high school students with learning disabilities participated in this study. After six weeks of daily practice using DPR, all students showed improvement in their rate of response and recall of basic multiplication facts when given post-treatment assessments.

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CHAPTER 1

Introduction

Fluency is often equated with an individual's ability to complete a task both effortlessly and quickly. When considering mathematics, an individual must be able to recall facts rapidly and accurately while expending minimal effort (Poncy, Skinner, & Jaspers, 2007). Fluency with basic math facts is a critical piece of mathematics instruction. This knowledge is the building block of complex computational skills that are taught as students progress through school (Cooke & Reichard, 1996). When a student achieves fluency with math facts, these concepts are retained over time and can be applied to higher-level tasks.

Bley and Thornton (1995) recognize that students need to become more competent and fluent in their ability to solve addition, subtraction, multiplication, and division problems with whole numbers and decimals. The first step toward accomplishing this increased competency is through the mastery of single-digit number facts. The ability to meet success with advanced math concepts has a direct relationship to the effectiveness in which the most basic skills are performed (Hasselbring, Goin, & Bransford, 1987). Students who are able to complete basic math facts with speed and accuracy often have less anxiety when it comes to completing more advanced tasks because they require less effort and time to accomplish the skill resulting in a richer schedule of reinforcement (Carroll, Skinner, Turner, McCallum, & Woodland, 2006; see also Cates & Rhymer, 2003; Skiba, Magneusson, Marston, & Erickson, 1986; Skinner, 2002). Unless students are taught a way to effortlessly and automatically recall the basic facts, success with multi-step, complex problems will not occur. Unfortunately, when this happens, students are left without skills that are necessary for academic growth. In turn, this can lead to poor school performance and increased apprehension (Maccini & Hughes, 1997).

Cognitive processing theories propose the human mind has difficulty attending to multiple tasks simultaneously unless some of the tasks require a limited amount of time, effort, memory, and conscious attention (Poncy et al., 2007). By encouraging students to become fluent with their facts, their ability to concentrate on more complex tasks is enhanced. Basic math fact fluency requires substantial automaticity so that a student's attention is only required at a minimal level. Ultimately, this automaticity allows for a natural transition when students are expected to complete more complex operations (Garnett, 1992). As basic skills are practiced regularly, their execution requires less focused attention. Because distractions are minimized, and students no longer need to spend time using strategies to recall their facts, generalization across settings improves (Beck, Anderson, & Conrad, 2005). Students who have mastered their basic math facts can complete problems at an increased rate and will have multiple response opportunities in comparison to students who do not possess such skills. This leads to improved accuracy, fluency, and maintenance (Skinner, Bamberg, Smith, & Powell, 1993).

According to Gersten and Chard (1999), a lack of automaticity can lead to devastating effects because individuals are limited in their ability to process multiple pieces of information. Students who fail to learn basic math facts to automaticity usually have developed or learned inefficient retrieval strategies. When asked to produce the answer to a fact, students who lack fluency often use a slower "back-up" procedure such as counting on their fingers, making marks on their papers, or using manipulatives. While this may have been successful for students when performing addition or subtraction facts, these methods do not carry over to multiplication and division facts (Silbert, Carnine, & Stein, 1990). If too much energy is spent trying to recall the answer to 3 plus 8, understanding the concepts underlying multi-digit subtraction, long division, or complex multiplication is exhausting for students. If students can not automatically retrieve their facts and must rely upon strategies to do so, they often become frustrated when performing more complex computations because their energies are used up on simpler tasks. It is arduous to perform mathematic tasks when even the simplest of steps takes a concentrated effort. When examining work completed by students who do not know their facts, it often contains many careless errors. Students can either spend their time getting the facts correct or understanding the appropriate math procedure, but they can not focus on both tasks at the same time (Crawford, 2003). As a result, students who exhibit math difficulty disengage from the learning process, falling behind their peers academically.

Fluency is of additional importance as it is often an indication as to how well students may perform when given more sophisticated, multi-step problems. According to Skiba et al. (1986), students who develop the ability to rapidly and accurately respond to basic math facts are less likely to have learning difficulties in the future. Meeting success with higher level math skills has a direct relationship to the efficiency at which lower level processes (including basic math facts) are completed. Students who fail to develop such fluency at an early age struggle with mathematics as they continue through school. Without the mastery of basic skills, students are left with a flawed ability to develop strong math skills. This lack of proficiency can contribute to a student’s inability to advance both academically and vocationally (Mattingly & Bott, 1990). When students have learning disabilities in mathematics, this lack of advancement becomes more pronounced.

Between 5% and 8% of school-aged children exhibit some form of mathematic learning disability (Geary, 2004). When one considers that students are found to plateau in their mathematic ability during the fourth grade and continue to make inadequate progress over the years, it becomes even more crucial that students are taught the basic facts to mastery at an early age (McLeod & Armstrong, 1982). According to Garnett (1992), classroom teachers acknowledge that when students do not know their basic math facts, it is a barrier to the acquisition of upper-level math skills. In addition, this lack of knowledge has a distressing effect on the self-confidence of students with learning disabilities. Students with math disabilities often struggle to retain their math facts because they rely upon simplistic backup strategies to retrieve the answers to facts (Mabbot & Bisanz, 2008). These students often have weak associations between problems and answers and must use multiple retrieval strategies before the correct fact and its corresponding answer is produced. Because students with math disabilities are often inefficient at pulling needed information from their long-term memories, they take longer to respond and make more frequent errors when compared to their typically achieving, same-aged peers (Mabbott & Bisanz).

In a study conducted by Fleishchner, Garnett, and Shepherd (1982), sixth grade students with learning disabilities were no better at computing basic addition facts when compared to nondisabled third grade students. When considering one-minute timed assessments, fifth graders with learning disabilities completed one-third as many multiplication facts as their nondisabled peers. Surprisingly, all students demonstrated an understanding of how to perform the required math operation, but rather than use efficient retrieval strategies, students with learning disabilities often resorted to circuitous and immature methods (Garnett, 1992). Because these students were unable to develop effective memory strategies on their own, they labored over finding the correct answer and attempted to do so by counting on their fingers, making hash marks on their papers, or verbalizing counting strategies to themselves (Garnett, 1998). Such measures are too time-consuming and labor intensive to be effective.

Perhaps the greatest reason to emphasize the need for basic skill instruction and mastery of basic facts is the future implications this lack of skill acquisition has on students. While it is not hard to understand that students with math disabilities often have pervasive and long-term hurdles in school, it is important to note that such obstacles account for future differences in employment, income, and work productivity even after intelligence and reading ability have been considered (Fuchs, 2006). When students fail to master basic skills, instruction is compromised throughout their academic careers. According to Jones, Wilson, and Bhojwani (1997), secondary students with learning disabilities spend much of their time being instructed on very simple skills due to the fact they do not have the necessary prerequisite math skills needed for more difficult mathematic tasks. As a result of this continued rudimentary instruction, it is extremely difficult to motivate these students to attempt more complex tasks. Consequently, these students fail to acquire the necessary application and problem-solving skills needed to function independently. To suggest that students will somehow learn how to apply needed mathematical skills and concepts to their everyday lives when they lack proper instruction in basic skills is not just illogical, it is unsupported by empirical investigations (Jones et al.)

In order to become fluent with math facts, three stages must occur. These stages include activities for understanding, activities for relating, and activities for mastery (Stein, Silbert & Carnine, 1997). To begin, students must have procedural knowledge in order to determine the correct answer to each fact. If students are unable to correctly solve basic math facts when given an appropriate amount of time, they do not understand the process and can not begin to memorize math facts (Crawford, 2002). At this initial level of development, students must be provided with concrete demonstrations of each operation so the process is easier to understand

(Stein et al.). Once this procedural knowledge has been acquired, students then must develop strategies for remembering the facts and understanding the relationships between them.

During the second phase of fact mastery, students must comprehend numeric relationships, such as associating one problem to a related problem. This can be as simple as understanding if 3 + 4 = 7, then 4 + 4 must be 8. Students may also depend upon fact families, such as 6 + 7 = 13, 7 + 6 = 13, 13 – 7 = 6, and 13 – 6 = 7, in order to recall facts (Stein et al., 1997; Crawford, 2002). At this time, it is more important for students to be accurate than fast. Those students who meet success with remembering their basic facts often develop their own personal recall strategy where those students who lack such a strategy often guess and show less progress (Carnine & Stein, 1981; Thorton, 1978).

Lastly, students must develop automaticity in recalling their basic facts. Automaticity implies that students have learned facts to the point of mastery. Recalling basic facts does not require a student to rely upon previously learned strategies; rather the student has an automatic or immediate ability to produce the answer to the fact. Students at this level are not just accurate; they also demonstrate speed and ease of recall. According to Logan (1985), students who can perform facts to automaticity accomplish this task so well that their performance is fast, effortless, and not subject to distraction. Students at this level can complete any math fact without taking the time to stop and think about it. It is as if providing an answer is obligatory – the student can not help but respond when presented with the fact (Crawford, 2003).

When determining fluency, expectations are inconsistent. Studies report that automatic response times are most often between 400 and 900 milliseconds (less than one second) from the presentation of a visual stimulus to the response from a participant (Crawford, 2003). This would correspond to approximately 60 facts per minute when considering fact fluency. Mercer and Miller (1992) caution that when considering fluency, it is necessary to regard the student's age, academic skill, and motor ability. They propose 40 to 60 digits correct per minute (or 25 to 35 problems per minute) with no more than two errors to be appropriate. Howell and Nolet (2000) suggest 40 correct facts per minute, with adjustments being made for those students who write fewer than 100 digits per minute. Miller and Heward (1992) found that students who were able to calculate 30 to 40 facts per minute continued to accelerate their fluency rates as they encountered more difficult math tasks. However, students who were unable to complete at least 30 facts per minute showed a deceleration in fact progress when presented with more complex tasks. As a result, students should be expected to complete at least 30 to 40 correct facts per minute because this rate is the best indicator of success with complex mathematic tasks (Miller and Heward). Crawford advocates 40 facts per minute as a more appropriate goal because it is more likely to accelerate student progress than only 30 facts per minute. Further supporting the 30 to 40 facts per minute goal are Stein et al. (1997) who suggest students should be expected to complete problems at a rate that is 2/3 as fast as their writing speed with digits. Students who can write 100 digits per minute would then be expected to complete 67 digits per minute, or approximately 30 to 40 facts, within a one minute time period when accounting for both single and double digit responses (Crawford).

While the importance of fact fluency is evident, the question of how to make students more automatic with their facts remains. Researchers have explored several different methods to improve student fluency. Some of these methods include direct instruction (Stein et al., 1997), drill and practice activities (Casey, McLaughlin, Weber, & Everson, 2003; Cooke, Guzaukas, Pressley, & Kerr, 1993; Cooke & Reichard, 1996; Fasko & Leach, 2006; Roberts, Turco, & Shapiro, 1991), game formats (Haught, Kunce, Pratt, Werneske, & Zemel, 2002), computer assisted instruction (Cates, 2005; Hasselbring, Goin, & Sherwood, 1986; Landeen & Adams, 1988; Wilson, Majsterek, & Simmons, 1996), peer tutoring (Calhoon & Fuchs, 2003; Fasko, 1994, 1996; Fuchs, Fuchs, & Kazdan, 1999), a technique known as Cover-Copy-Compare (CCC) (Carroll et al., 2006; Poncy et al., 2007; Skinner, Turco, Beatty, & Rasavage, 1989), taped problems (Carroll et al., 2006; McCallum, Skinner, Turner, & Saecker, 2009; Poncy et al., 2007), corrective feedback (Bennett & Cavanaugh, 1998; Codding, Eckert, Fanning, Shiyko, & Solomon, 2006; Skinner, Bamburg, Smith, & Powell, 1993; Struthers, Bartlamay, Bell, & McLaughlin, 1994), and a technique known as Detect, Practice, and Repair (DPR) (Poncy, Skinner, & O'Mara, 2006). However, despite the need for research based interventions designed to improve fluency, the amount of existing studies remains small. Maccini and Hughes (1997) refer to a review of academic interventions for students with learning disabilities conducted by Lessen, Dudzinski, Karsh, and Van Acker (1989). After reviewing articles from leading journals in special education, Lessen et al. found that less than 4% of the articles reviewed within a 10-year period contained academic interventions. Within those articles, specific suggestions and applications for classroom teachers were not present. Furthermore, only 22% (n=29) of those articles containing academic interventions were specific to secondary students with learning disabilities (Maccini & Hughes). The need for continued research in the area of math fact fluency is clearly evident.

This study is an extension of an existing study conducted by Poncy et al. (2006). It is designed to improve multiplication fact fluency among high school students with learning disabilities through the use of a metronome to assist students in understanding the speed at which they must complete each probe. The purpose of this study is to answer the following research questions: (a) Is Detect, Practice, and Repair (DPR) an effective intervention to use for improving math fact fluency among secondary students with learning disabilities? and (b) Does DPR help students maintain newly learned facts after the intervention has ended? This study will attempt to answer those questions and add to the existing body of research on validated instructional techniques used to improve student fluency in mathematics.

CHAPTER 2

Review of Literature

This chapter is a review of the research on different methods used to improve fluency among students with disabilities across all grade levels. Instructional techniques used to improve both mathematic and reading fluency are identified in this section. The research is organized into eight different methods: (a) direct instruction, (b) drill and practice, (c) games and computer assisted technology, (d) peer tutoring, (e) cover-copy-compare, (f) taped problems, (g) self-correction and performance feedback, and (h) detect, practice, and repair.

The need to improve basic fact fluency is an important step in enhancing advanced skill development and academic behaviors within students (Carroll et al., 2006). It is not difficult to understand why teaching more complex mathematic tasks is inefficient if students are unable to recall their basic facts. In fact, without the mastery of basic skills, all subjects, not just mathematics, can be cumbersome and difficult for students to comprehend. In comparison to reading, however, teachers have much less information about effective practices and interventions for students with math difficulties (Fuchs, Compton, Fuchs, Paulsen, Bryant, & Hamlet, 2005). This lack of information causes teachers to make guesses as to how to instruct students rather than make their decisions based upon sound research-based methods (Jones et al., 2007). In turn, students continue to struggle and make limited progress in their ability to perform mathematically.

While it is not difficult to recognize why fact fluency is important, the reasons why students do not master and retain their facts are often harder to pinpoint. Some possible explanations may be to attributed to reduced student expectations, a student’s prior experience with low achievement, and/or poor instruction where students are not expected to master basic skills before moving forward (Jones et al., 1997). When students are not provided with effective instruction, they struggle and eventually fail. If poor teaching methods continue and students do not meet success, their experiences with failure become pervasive. Students readily give up when faced with problems they are unable to solve due to lack of proper instruction (Jones et al.). As a result, they are left short-changed when asked to perform functional life skills. Balancing a checkbook, calculating a tip, reading a newspaper, and leaving a memo can prove to be emotionally and functionally debilitating (Maccini & Hughes, 1997). To prevent students from falling behind, it is essential to provide them with meaningful and effective instruction.

Direct Instruction

One of the leading evidence-based methods used to improve student achievement is direct instruction (di). Direct instruction can best be described as a method of instruction that is carefully scripted to help students obtain, maintain and transfer new information in the most efficient manner possible (Stein et al., 1997). What makes di unique is not just the prescribed teacher-directed instruction, but the emphasis on rigorous performance expectations through the use of carefully timed prompts, guided practice opportunities, and the use of reinforcement and corrective feedback to enhance student achievement (Jones et al., 1997). Overall, di takes complex skills and breaks them down into their component parts. During instruction, the teacher begins the lesson by reviewing previous instruction and stating the objectives of the lesson. Skills are first modeled by the teacher and then the students complete the task along with the teacher. The teacher monitors student performance and offers corrective feedback as the skill is practiced. Lastly, the teacher reviews the lesson and assigns independent work (Jones et al.). Direct instruction can be used with a variety of subjects and is effective with both elementary and secondary students (Stein et al.). Teachers of di are encouraged to elicit frequent responses from the students, maintain an upbeat pace of instruction, monitor accuracy and provide corrective feedback and positive reinforcement in order for instruction to lead to improved achievement (Jones et al.; Stein et al.).

Stein et al. (1997) have developed programs that promote the mastery of basic facts through the use of di techniques. Such programs should include a specific regimen and criterion for introducing new facts while also allowing sufficient time for practice with new and previously learned facts. Record-keeping and motivation systems embedded within the selected program are also critical to its overall success (Stein et al.). Fact fluency programs can be used with an entire class of students regardless of ability and individual differences. The teacher can determine if all students should work on the same set of facts or, if significant differences exist, different operations or sets of facts may be used. Students first are pre-tested to determine at which level instruction should begin. Teachers are advised to select a starting point slightly lower than the class average if all students will be grouped homogeneously.

During homogeneous instruction, students engage in a group drill where they orally respond to a set of practice facts located at the top of a teacher provided worksheet. The teacher provides a verbal prompt, waits two to three seconds for the students to determine the answer to the fact, then signals the students to respond in unison. This procedure continues for all facts in the first line of the worksheet. The teacher will repeat this line of facts until all students are responding in unison with only a two second pause between facts. The same technique is then used on the second and third lines of facts. Following oral practice, the students complete the bottom of their worksheets as a timed test. At the end of the time limit, the teacher scores the papers, records student progress, and makes a decision as to whether or not the class is ready to move on to a new fact family (Stein et al., 1997).

If students have varying abilities and there are a small number of students in class, a heterogeneous approach to instruction might be better to implement. As in the previous model, students are pre-tested to determine which facts they need to practice. Students are then paired up according to ability and act as tutors for one another. The teacher has one student read all the facts with the appropriate answers aloud as the tutor follows along. If the student makes an error, the tutor supplies the correct response. The students then switch roles until both students have had an opportunity to read the facts on their worksheets a total of two times. Following this practice, both students complete a timed test. When the test is over, the students (who have been supplied with answer keys) switch tests, correct each other's work, and record each other's progress (Stein et al., 1997). While heterogeneous testing may take more time to implement, students are able to practice specific facts or operations where they have the most difficulty. This is a more effective use of their time, as well as the teacher's.

Drill and Practice

Drill and practice techniques are probably one of the most well-known and easiest methods to implement in a classroom. Students become better at a desired skill given repetitive practice over multiple sessions. In the mathematics classroom, flashcards are commonly used to help students practice their facts. Teachers may opt to present students with facts by fact family, use a random assortment of selected facts, or pre-test students to determine which facts are not known fluently in order to create a set of practice facts (Cooke & Reichard, 1996). In order to make drill and practice activities more productive, research suggests that using known (maintenance) and unknown (acquisition) items together rather than focusing only on unknown items has been effective in increasing the rate at which students achieve mastery (Cooke &

Reichard). The question of which ratio of known versus unknown facts is most effective in reaching mastery is examined in the following studies.

To test which ratios are most effective in accelerating learning rates, studies with vocabulary words, spelling words, and math facts have been conducted. Fasko and Leach (2006) utilized a drill and practice program with a third grade student with a learning disability. A drill deck of flashcards that contained five known and five unknown addition facts was used on a daily basis. As the student mastered certain facts, new unknown facts were added to the drill deck in order to maintain the 50%-50% ratio. After seven weeks, the student had improved from a baseline of 9 facts to 19 facts per minute. In a more salient study by Roberts et al. (1991), 42 second to fifth grade students participated in a flashcard drill where they had to read various vocabulary words. Students were assigned to groups with varying ratios of known and unknown words. At the end of the 8-week intervention, students in groups that had ratios of 40%-60% or 50%-50% showed the greatest gains and moved through the material faster than those students in the other two groups. This may be attributed to the fact the students had more contact with the unknown materials rather than having them introduced slowly over time (Cooke & Reichard, 1996).

Additionally, Cooke et al. (1993) examined individual student progress in spelling, multiplication facts, and reading fluency when exposed to ratios of 30% (acquisition) – 70% (maintenance) or 100% acquisition. At the conclusion of the study, the only time students benefitted from being exposed to both known and unknown elements was when they were completing multiplication facts. Students who practiced known and unknown facts developed fluency faster than those students who only practiced unknown facts. The results of this study indicate that the ratios needed for optimal performance may be largely dependent upon the subject matter being taught (Cooke & Reichard, 1996).

Cooke and Reichard (1996) further explored the effects of different ratio conditions on student achievement. Six fifth-grade students with learning disabilities or behavior disorders were exposed to three different ratio combinations to determine which condition most improved their acquisition of facts and how well such facts were generalized to performance on multiplication or division probes. Four of the six students mastered new facts the fastest when exposed to the 70% (new facts) - 30% (known facts) ratio condition. When generalizing the facts from flashcards to actual paper and pencil probes, the same results were achieved. Because all students did not achieve the same results, the differences may indicate a greater need to consider students' individual abilities when selecting the optimal ratio of known and unknown facts during drill and practice activities.

A drill and practice technique known as "say all facts one minute each day shuffled" (SAFMEDS) with and without time limits was used with two elementary school students with learning disabilities (Casey et al., 2003). During the intervention, the students were exposed to two conditions – five minutes of practice on multiplication facts versus unlimited practice. After both conditions, the students were expected to complete a one minute probe of the practiced multiplication facts. The results showed both students performed better when given unlimited time to practice their facts. This study reinforces the importance of the repetition that is associated with drill and practice activities.

Games and Computer Assisted Instruction (CAI)

Sometimes, drill and practice activities easily lend themselves to game formats. Using games in the classroom is a way to stimulate curiosity, generate excitement, and increase motivation among students because they include a high degree of student involvement and engagement. Games are also effective classroom tools because they allow students to practice new skills while immediate feedback is provided. While there are numerous teacher-created games that can be used to reinforce the memorization of basic math facts, computers also provide invaluable drill and practice opportunities for students.

Haught et al. (2002) conducted a study using games and music to improve fact fluency among elementary aged students. In this study, students either played mathematic games or listened to commercially produced music reinforcing math facts for 10 minutes each day. Each week, the students were expected to complete a two-minute timed math probe of facts. After 13 weeks, all students made gains with fact fluency regardless of how old the students were and which intervention was selected.

According to Cates (2005), computer assisted instruction (CAI) is a way to use the computer to provide students with individualized instruction through the use of multiple learning trials with consequences to shape correct student responding. Students are provided with an antecedent, respond with a behavior, and then receive a consequence for such behavior (Cates). While clever animation, sound, and game activities may motivate students and maintain their attention, the immediate feedback that CAI provides is an excellent way to improve student learning. By letting students know if their answer is correct, they do not continue to practice the wrong skills. Additionally, most selected programs allow students to work at their own pace and have record keeping systems that log students' errors and progress (The Access Center, 2009). As a result, students do not move ahead to a new concept until they have fully mastered prerequisite skills.

In a study conducted by Cates (2005), four female elementary school students identified as having difficulty with mathematics were exposed to two different interventions – peer tutoring and CAI. During the peer-tutoring, student pairs practiced random addition facts for three minutes. During the CAI intervention, students were individually presented with computerized flashcard drills for the same amount of time. After 17 sessions, results were varied. The first pair of students showed the most gains with CAI while the second pair of students made more improvements with peer-tutoring. Cates proposes that differences in ages may have accounted for the variability in the results. The students who performed best with CAI were two and three years older than the students who responded better to peer tutoring. Perhaps the older students were more fluent in their understanding of addition facts and were at an advanced stage of learning in comparison to the younger students (Cates).

In a similar study comparing the effects of CAI and teacher-directed instruction (TDI), four elementary students with learning disabilities practiced their multiplication facts using MathBlaster® computer software and flashcards presented by a teacher (Wilson et al., 1996). During the CAI treatment, each student played three MathBlaster® games for a total of 10 minutes. During the TDI intervention, the teacher used flashcards to individually teach the students the facts for 10 minutes. After 21 days, the results showed students performed better with TDI than with CAI. While the students did make improvements in their fact acquisition during CAI, TDI was found to be more efficient and effective in improving student fluency. This may have been due to the fact the students had more opportunities to respond during TDI than with CAI.

Hasselbring et al. (1987) caution that while CAI may be an effective way to increase student engagement as they practice skills, it should only be used after specific prerequisite conditions have been met. When working on increasing fact fluency, only those facts that a student can retrieve from memory should be used in drill and practice activities via CAI. If a student does not have a strong association between a problem and its answer, time spent using CAI is wasted. In the end, there is little, if any, improvement within students who are exposed to CAI before they have some basic fact recall (Hasselbring et al.). In an earlier study conducted by Hasselbring et al. (1986), students with mild learning disabilities used drill and practice software to practice basic addition facts. Those students who began the study using counting strategies as a method to recall their facts showed no improvement in their ability to recall basic addition facts after 70 sessions on the computer. In fact, these students continued to use counting strategies as a way to recall their facts. However, those students who began the study able to recall their facts from memory, even if it was only slowly, were able to recall their facts to automaticity after 20 sessions on the computer. While CAI may be a way to improve student fluency, it should not replace teacher-directed instruction when students are first learning skills.

In addition, the use of a computer may not always be motivating for students. In a study by Landeen and Adams (1988), the use of paper and pencil activities versus computer-assisted drill and practice interventions were compared in their ability to improve student performance with basic math skills. The results of the study indicated it took three times as many sessions for the students to reach mastery with the computer-assisted program compared to the paper and pencil sessions. When asked which method the students preferred, more students favored the paper and pencil option. CAI did not improve student performance in this study. Landeen and Adams speculate this may have been due to the fact the students had limited familiarity with computers and the paper and pencil tasks did not take as long to complete. This is something educators should consider before implementing the use of CAI. Students should feel comfortable using the computer and the types of programs selected should be of high interest.

Peer Tutoring

Another method frequently used to reinforce basic skills and improve fluency is peer tutoring. In peer tutoring, students alternate between the roles of tutor and tutee. Because explaining a concept to another person helps to improve one's own learning, peer tutoring is an effective way for both students to better understand and master a concept (Steedly, Dragoo, Arafeh, & Luke, 2008). In a peer tutoring relationship, students can be of the same age or of differing ages. Students also may be of the same ability or high achieving students may be paired with lower achieving students. Since it has been effective in improving basic academic skills across environments, tasks, and students, peer tutoring is considered to be a feasible way to provide individualized instruction with little drain on educational resources (Cates, 2005).

While peer tutoring may be used with a variety of skills and subject areas, the emphasis of this literature review is to identify those studies that specifically utilize peer tutoring as a method to improve fluency. In a previously mentioned study by Cates (2005), students had better response rates with math facts when they participated in peer tutoring sessions rather than when they received CAI. Additionally, Stein et al. (1997) advocated the use of peer tutoring in their direct instruction program developed to improve fact fluency among students with varying skill abilities. The Peer-Assisted Learning Strategy (PALS) is a method of dyadic instruction that has been successful in teaching computational skills to students with disabilities. This method involves the use of structured activities, frequent exchanges with corrective feedback between tutors and tutees, and the reciprocity of tutoring roles (Fuchs et al., 1999). While PALS was first used to supplement existing math curricula, it also has been used in reading classrooms.

It has been found to be most effective when implemented two to three times per week as a way to provide students with extra individualized practice on skills which have not been mastered (Calhoon & Fuchs, 2003).

Calhoon and Fuchs (2003) examined the effects of using PALS and curriculum-based measurement (CBM) with 92 high school students with specific learning disabilities in mathematics. Students participated in PALS sessions two times per week for 30 minutes where the focus was on math computation and application skills. After 15 weeks, the students in the PALS groups performed better on computational skills than those students who did not participate in tutoring sessions; however no difference was shown between the groups on application concepts. These results may indicate that PALS is more effective in improving student performance with concrete skills rather than those that require abstract, higher-order thinking often associated with application problems.

In an earlier study, Fuchs et al. (1999) used PALS as a way to improve reading fluency and comprehension among high school students with significant reading disabilities. Students were to partner-read, summarize paragraphs, and make predictions during PALS sessions. After 16 weeks, the researchers found little difference in the PALS students' fluency rates and slight improvements in the area of comprehension when compared to a control group. In their discussion of the study, Fuchs et al. suggested the reason the students did not make better gains in their reading fluency may have been due to the fact the students were not paired with higher achieving, competent readers who may have served as better models for the tutee.

Additional studies with peer tutoring were conducted by Fasko (1994, 1996) who completed studies with math and reading fluency. In the math study, Fasko (1994) selected eight students from a fourth and fifth grade classroom who were unable to meet mastery on timed multiplication probes. Students drilled one another on multiplication facts for a duration of 15 minutes each day. At the end of the school year, six of the eight identified students improved their multiplication fluency by achieving mastery on all of their facts. In a second study, Fasko (1996) used peer tutoring as a means to improve sight word vocabulary and reading fluency. Four elementary students who demonstrated poor reading fluency were selected for the study. Similar to the aforementioned study, flashcards were prepared and contained all vocabulary words used in the reading-series text (257 total words). Again, students were paired and drilled one another on the selected words for 15 minutes each day. At the conclusion of the intervention, three of the four students showed improvement in their sight word recognition and all students showed improvement in their reading fluency. Peer tutoring appeared to be an effective intervention in encouraging students to improve their fluency with basic skills within these studies. Peer tutoring may be an effective way to improve performance when students do not master a skill through teacher instruction alone (Fasko, 1994).

When comparing the aforementioned studies and differences in results, the ages of the students must be considered. While all studies were conducted with students with learning disabilites, two of the studies were exclusive to secondary students while the other two studies were specific to elementary students. Those students at the elementary level, while having difficulty with basic skills, may have been more enthusiastic and willing to participate in a peer-tutoring situation than those students at the secondary level who have had years of failure and frustration when learning basic skills. Additionally, students at the elementary level are often working at a very concrete level, which is easier to model and correct. Students are the secondary level were not just working on basic facts and sight words; they were expected to grasp higher level concepts and apply basic skills, which may have caused the differences in the results. Because the research shows mixed results when using peer-tutoring to improve fluency, other methods that allow students to work independently should be considered. Cover-copy-compare is one such approach that allows students to work at their own pace and manage their results privately.

Cover-Copy-Compare

While the cover-copy-compare approach (CCC) was originally designed to assist students with their spelling rates, CCC has been shown to be an effective measure in enhancing math fact fluency with students in general education and special education settings (Carrol et al., 2006). This drill and practice technique includes the use of immediate corrective feedback as a way to improve fluency (Poncy et al., 2007). Cover-copy-compare is a 5 step intervention that is self-managed and provides several learning trials over a short period of time (Codding et al., 2007). When using CCC with mathematics, students are expected to focus on a math problem and answer, cover the problem, write the problem and answer, and then check the response against the original problem (Carroll et al.). If the student provides the correct response, he or she moves on to the next problem. If the student responds incorrectly, he or she must copy the problem and the correct answer three times. The repetition is used to promote accuracy by giving the student multiple opportunities to practice correct responses (Codding et al.).

Carroll et al. (2006) studied a twelve year old student with mild mental retardation and used the CCC approach to improve her performance with addition facts. After 11 sessions of using CCC, the student improved from a baseline of 15.33 digits correct per minute to 34.8 digits correct per minute (Carroll, et al.). Skinner et al. (1989) used the CCC approach with three students with behavior disorders to improve fluency with multiplication facts. All three students ended the study with maintenance levels higher than their baselines. Students began the study with an average baseline of 29 digits correct per minute and ended with maintenance levels of 56 digits correct per minute (Skinner, et al.). Additionally, Poncy et al. (2007) studied the effectiveness of CCC on improving addition fact fluency for a 10-year old student with mental retardation. After seven sessions using the CCC technique, the student improved from a baseline of less than 10 digits correct per minute to a maintenance level of 22 digits correct per minute. CCC was an effective means of improving fluency and accuracy in a short amount of time. The continued reinforcement and practice opportunities proved to be successful in improving fact fluency for the students in each of the studies.

Cover-copy-compare is a desirable intervention because it is easy to implement and does not require the attention of a teacher or another student. Because the students in the aforementioned studies were required to elicit numerous responses and immediate corrective feedback was available, students were given multiple opportunities to correctly practice their facts. CCC is also appealing because teachers can easily develop materials that are inexpensive and appropriate to their students' needs (Skinner et al., 1989).

Taped Problems

In the taped problems (TP) intervention, a student first listens to a taped recording of different math facts. Following this step, the student is told to write the correct answer to each fact before the answer is supplied by the tape recorder (Poncy et al., 2007). Students are told to correct any wrong answers or fill in any unknown answers on their papers when the tape supplies the correct response. The problems are repeated several times during a session to allow for practice. In addition, minimal delay exists between problems to prevent students from relying upon other strategies to recall their facts. The TP approach has been shown to be effective in improving students' accuracy and fluency with math facts when used in both individual and group settings (Poncy et al.).

McCallum et al. (2009) used the TP intervention with 18 third grade students to improve their fluency with multiplication facts. Students listened to a tape of 12 problems repeated four times with varying delays between problems. Following the TP session, the students completed a one-minute timed test of the same facts they had just practiced. Thirteen of the 18 students improved their fluency at the end of the intervention and maintained their performance over time (McCallum et al.).

Two previously mentioned studies also incorporated the use of TP to note its effect on improving fact fluency. In the study conducted by Carroll et al. (2006), not only did the subject participate in an intervention using CCC to improve her addition fluency, TP was also utilized as a comparison method. During baseline measures, the student had an accuracy rate of 49%, during the intervention, however, the student improved to 96.67% accuracy (Carroll et al.). When comparing the use of CCC versus TP, TP was more successful in increasing this student's fluency in this study. In the second previously mentioned study, Poncy et al. (2007) also compared CCC's effectiveness in improving fact fluency to that of TP. While the student was able to complete less than 10 digits correct during baseline, at the end of the intervention, the student had improved her rate of performance to 25 digits correct per minute at 100% accuracy. While both interventions were successful in improving the student's fluency, TP was noted as taking the student 30% less time to complete. This is an important consideration when selecting a method that will yield strong results in the shortest amount of time (Poncy et al.).

Self-Correction and Performance Feedback

A common theme that is inherent in the aforementioned studies is the use of corrective feedback and its importance in improving student performance. While feedback is essential to improving achievement, the timing of its delivery is even more critical. If students do not receive feedback in a timely manner, there is the risk that the students may continue to practice errors (Bennett & Cavanaugh, 1998). While the most common way for students to receive feedback on their performance is when a teacher provides error correction, teaching students to self-correct may prove to be an even more efficient and immediate way for students to improve their accuracy when performing tasks.

Skinner et al. (1993) conducted a study where a student used the previously discussed CCC approach with performance feedback and goal setting. Originally, the student was unable to perform at mastery levels following nine sessions of CCC without feedback. With the addition of performance feedback and goal setting, the student was able to reach mastery levels on three different problem sets by the twelfth and thirteenth sessions. Also, Struthers et al. (1994) utilized public posting with spelling skills as a way to provide corrective feedback. Students received a star next to their names on a classroom poster when 80% of their words were spelled correctly. The classroom teacher noted that spelling skills improved for 7 of the 8 students and their level of accuracy in responding was 94%. In this instance, the feedback was reinforcing to the students and encouraged them to continue to engage in behaviors that were positively acknowledged (Struthers et al.). This led to better understanding and improved learning.

The effects of immediate self-correction, delayed self-correction, and no correction were compared in their ability to improve the acquisition and maintenance of multiplication facts by a fourth grade student with learning disabilities (Bennett & Cavanaugh, 1998). When practicing math facts, the student was 95% accurate (5 errors) when using immediate self-correction procedures compared to 76% accurate (24 errors) during delayed correction. When no correction procedures were used, the student was 88% accurate (12 errors) (Bennett & Cavanaugh). The use of immediate feedback may have prevented the student from practicing errors because she was expected to correct her paper as soon as it was completed. During delayed correction, the student may have written the wrong answer to a fact several times before she had an opportunity to realize her error and correct it.

Detect, Practice, and Repair

Detect, practice, and repair (DPR) is a technique that is similar to CCC. According to Poncy et al. (2006), DPR is an intervention that can be used in all classrooms to provide students with increased opportunities to respond to a stimulus, receive immediate feedback, and note their progress through self management techniques. In other words, DPR uses the best components of the previous interventions to create one overall program designed to improve fluency.

During DPR, the students begin with the "tap-a-problem" condition. While similar to the TP intervention, "tap-a-problem" involves the use of a metronome that has been set to a pre-determined number of beats per minute. Students are expected to write the answer to each presented fact on a worksheet each time the metronome sounds. If unable to do so, students leave the problem blank and move on to the next one. It is recommended that the metronome be set to a speed that does not allow students to use counting strategies, such as 1.5 seconds between problems (Poncy et al., 2006).

After the "tap-a-problem" phase, students identify those problems they did not solve correctly or ones they did not solve at all. The first five problems that are incorrect or blank become a practice set. Students then use the CCC approach to practice these facts. Students write and verbalize the facts multiple times in an attempt to internalize them and make recall easier. When this has been completed, the students are provided with a timed assessment to allow further practice and additional response opportunities with all the facts. Finally, the students graph their results. This serves as a visual representation of their progress and reinforces learning (Poncy et al., 2006).

Poncy et al. (2006) conducted a study to evaluate the effectiveness of DPR on student fluency. Fourteen elementary students used DPR to improve their fluency with subtraction facts. Students participated in DPR sessions for 15 minutes each day over a 6-week period. At the start of the study, the mean baseline of the participants was 21.7 digits correct in two minutes. At the conclusion of the intervention, the students were completing an average of 41 digits correct in two minutes. Thirteen of the 14 students in the study doubled the district norms for fluency by the end of the intervention and the class's average growth rate was six times greater than the district norm (Poncy et al).

Summary

Twenty-five empirical studies designed to improve student fluency in the areas of reading and mathematics were reviewed and evaluated to see which methods were most successful in maintaining results over time. While numerous methods are in existence, it is important to consider which features of each of these interventions offer the greatest degree of success with the least amount of time and resources. Although drill and practice activities, peer tutoring, computer assisted instruction, taped problems, and techniques known as CCC and DPR have their own unique characteristics, when multiple practice sessions were coupled with frequent response opportunities, students made significant gains with fluency regardless of which intervention was used. In addition, immediate corrective feedback and reinforcement improved students' recall and retention of learned facts. Because students are provided with immediate feedback, they are given the opportunity to correct mistakes before they become habitual. Additionally, when students are reinforced for their correct responses, there is a greater likelihood these responses will continue. Allowing students to record and monitor their progress was another common feature shown to be effective in providing students with the opportunity to see their growth as they moved forward through the intervention.

When selecting a method to use for improving student fluency, one must take into account the population of students being considered. While the age of the student is important, it is even more critical to know if certain prerequisite skills have been mastered. If students do not have knowledge of necessary concepts or pre-skills, it will not matter which intervention is selected. The students will not meet success because they do not know how to do the skills being assessed.

The use of DPR is of particular interest because it incorporates all of the previously identified successful components within one intervention. Students are given multiple response opportunities, immediate corrective feedback, and numerous practice sessions as they work at their own pace to improve mathematic fluency. While the study conducted by Poncy et al. (2006) showed promising results, little research is available. The purpose of this study is to extend the existing study and evaluate the effectiveness of DPR on improving multiplication fact fluency among secondary students with learning disabilities.

CHAPTER 3

Method

The purpose of this study was to evaluate the effectiveness of DPR in improving and maintaining fact fluency among high school students with learning disabilities. As students participated in this study, their speed and accuracy in completing sets of multiplication facts was recorded and evaluated over time.

Participants

The participants in this study included seven high school students. Six of the students were in the ninth grade and one of the students was in the twelfth grade. Of the ninth grade students, four students were 15 years old and two students were 16 years old. The twelfth grade student was 17 years of age. Five students were male (this includes the twelfth grade student) and two students were female. All students and their parents signed consent forms prior to the start of the study.

All seven students were identified as having a specific learning disability in the area of mathematic computation and problem-solving. All students were members of the same class and received mathematic instruction in the special education resource room. None of the students received instruction in the general education curriculum for mathematics at any time during the study. The students involved in this study received daily math instruction for 42 minutes in basic math skills such as whole number and decimal operations, as well as introductory fraction skills. All students were at lesson 30 in the "Level E" book of the *Connecting Math Concepts©* direct instruction series when the study began. This is approximately a fifth grade level.

All students in the study were given a code to protect their identity. Codes represented each student's current grade in school and gender. Each student was then assigned a letter of the alphabet to help differentiate one student from another. For example, 9FB represented a student in the ninth grade who is a female, while 9MC represented a ninth grade male. These codes are used in each chart and table when applicable in order to show individual performance as well as class means.

The decision to utilize multiplication facts rather than addition or subtraction facts was based upon the age of the students. According to Crawford (2003), students who have reached the fourth grade, yet still rely on compensatory skills to perform addition and subtraction facts, must be taught multiplication and division facts. Multiplication facts are needed for multi-digit multiplication and division problems, as well as fraction skills. The students' lack of fluency with multiplication facts was a source of frustration as they completed independent work during daily math instruction. Because the *Connecting Math Concepts©* program does not allow for calculator use (unless specifically stated); the students had to rely upon multiplication charts to assist them with their daily activities. This strategy was time consuming and did not seem to aid students in improving their retention of basic math facts.

The students in this study were selected by the first author of this study. This particular class of students was chosen based upon their post-secondary plans following high school. All students in the selected class hope to further their education at either technical schools or community colleges, therefore improving their math fluency was of increased importance. All students in the course (with the exception of the twelfth grade student) planned on taking Algebra 1 during the subsequent school year, therefore their ability to be fluent with their facts will make performing larger, more complex problems less cumbersome. Additionally, all students in the study had fact fluency as an IEP goal. Participation in the study by this group of students was viewed as non-disruptive to their current educational program because fact fluency was an activity that was frequently included during class instruction.

The intervention was conducted by the first author of the study, a female special education teacher with 14 years of experience teaching students with learning disabilities in mathematics. In addition to providing daily math instruction to the students, she was responsible for collecting baseline data and teaching the students how to use the "Detect, Practice, Repair" (DPR) technique. She also scored all of the students' math probes and collected post-intervention data.

Setting

The students in this study attended a suburban public high school located in southeastern Pennsylvania. The intervention took place in the students' classroom during daily math instruction. The classroom was an interior room with approximately 240 square feet of usable floor space. Ten student desks were arranged in three rows. Two rows contained three desks and one row contained four desks. Students were approximately two feet away from any neighboring desks. All desks faced the front of the classroom where a Promethean Board® was located. This piece of technology was the main source of instruction in the classroom. In addition, two teacher desks and a computer cart were located in the back of the classroom. No changes were made to any of the students' schedules who participated in the study. The intervention lasted a total of six weeks and took place on a daily basis for 15 minutes. Students continued to receive instruction in the *Connecting Math Concepts*© program following the 15 minute intervention.

Materials

The students in this study completed writing speed tests and addition and multiplication probes from the *Practicing Basic Skills in Math: Secondary Remedial*© manual by Sopris West Educational Services (Beck et al., 2004). Students completed both single and double digit writing speed tests prior to the start of the study. An addition probe of 80 sums from 0-18 was used only during the training phase with the students and did not impact the results of the study. The multiplication probes contained 90 problems each and were divided into the following fact arrangements for the students: Set A: X 1-2 (Answers of 0-18), Set B: X 3 (Answers of 0-27), Set C: X 1-3 (Answers of 0-27), Set D: X 4 (Answers of 0-36), Set E: X 1-4 (Answers of 0-36), Set F: X 5 (Answers of 0-45), Set G: X 6 (Answers of 0-54), Set H: X 1-6 (Answers of 0-54), Set I: X 7 (Answers of 0-63), Set J: X 1-7 (Answers of 0-63), Set K: X 8 (Answers of 0-72), Set L: X 1-8 (Answers of 0-72), Set M: X 9 (Answers of 0-81), and Set N: X 1-9 (Answers of 0-81).

Students used a “Detect, Practice, Repair” worksheet following the “metronome phase” of the study to identify incorrect or incomplete facts (see Appendix A for sample worksheet). They also used the worksheet during the “practice phase” of the study as a way to reinforce any unknown facts. Folders contained the appropriate multiplication probes for each student for the day. The first author scored each student probe and replaced the completed probes with new ones for the following day based upon each student’s performance. Completed probes were stored in separately coded file folders for each student and were placed in a locked file cabinet during the intervention.

A digital metronome was used to assist students with appropriate pacing during the intervention. The metronome was a Korg Metronome, Model MA-30. Students were also timed using a Control Company 1045 Stopwatch, Model CC1045 during the "repair phase" of the study. Students also used spreadsheets on Microsoft Office Excel 2007® to record and track progress.

Checklists were used to evaluate reliability and treatment integrity (see Appendix B for treatment validity checklist). Both the first author and the independent evaluator completed the checklist and compared results to verify results (see Appendix C for reliability checklist).

Procedures and Experimental Conditions

Baseline. The students in this study were first given a writing speed test where they had to copy random numbers onto a worksheet within a one minute time period. Students completed this activity twice. On the first occasion, they only copied single digit numerals. On the second assessment, they were required to copy double digit values. Students with poor fine motor coordination were not expected to complete as many facts per minute due to difficulty with handwriting. Evaluation of the writing speed tests were conducted by the first author. Digits were counted as correct if they were properly and fully formed and matched the original digit (or numeral) the student was required to copy. This information is displayed in Table 1.

An average number of digits was computed from both writing probes. If a student was unable to write 60 single digit numerals (one digit per second) or 40 double digit numerals in one minute (a total of 80 overall digits), modifications would have been made. These values were selected based upon the 40 facts per minute requirement recognized by the school district. Students who were able to write 60 single digits or 40 double digits per minute could still effectively meet this standard because they demonstrated the speed at which it is expected they should be performing their facts. Sixty single digits was used as a minimum rather than 40 because students were given a brief amount of time to process the fact on fluency probes in

Table 1

Writing Speed Test Results

Student	**Single Digit Probe**	**Double Digit Probe**	**Average Writing Speed (DPM)***
12MA	126	172	149
9FB	121	154	138
9MC	84	138	111
9MD	117	164	141
9FE	103	148	126
9MG	60	94	77
9MH	82	116	99
MEANS	**99**	**140.86**	**120.14**

Note. DPM = Digits Per Minute

comparison to simply copying a digit on the writing speed test. Forty double digits (a total of 80 single digits per minute) was selected as the minimum for double digit writing speed because students would not have to complete probes where a double digit answer is required for every problem. Again, a higher number of digits was expected during the writing speed test in comparison to the actual probes because students do need a moment to process the fact rather than simply copying a value that is already in existence.

Following the writing speed test, a math probe in multiplication was given to each student. This baseline probe contained 90 problems and was a mixture of all facts (0-9). Students were given one minute to complete the probe to determine their fluency. The first author told all students they had to complete the probe systematically. Students were required to attempt each problem in the order presented and provide a response. However, if students could not instantly recall the answer to a fact, they were told to skip the problem and move on to the next fact. The students completed this same fluency probe on three consecutive dates to achieve an average number of facts per minute per student.

Training. Prior to beginning the intervention, the students had two 42 minute class periods of training so they could understand the objectives of the study. The students engaged in all aspects of the intervention as the first author modeled expected behaviors and the classroom assistant monitored and offered corrective feedback to the students to improve the validity of the study. The following is a review of each phase and the expected behaviors that were to occur during the intervention.

Metronome Phase

To begin, the students needed to become familiar with the pace of the metronome. The metronome was set to sound at a rate of 40 beats per minute (or one “beep” every 1.5 seconds).

This pace was selected because the school district considers a student to be fact fluent when he or she can complete 40 facts in one minute. To help the students become accustomed to this pace and to the sound of the metronome, they were given a probe of 80 addition facts (sums 0-18) and were told to move from problem to problem with their index fingers at the sound of each "beep" rather than write actual values. The reason the addition probe was selected rather than the multiplication probe was to prevent the students from practicing their facts during the training and potentially inferring with the results of the intervention. During this phase of training, the first author noticed students were having difficulty hearing the tone of the metronome due to the ventilation system in the classroom. To compensate for this situation, she said the word "write" each time the metronome sounded.

After three practice sessions where the students achieved 100% accuracy, the students were then told to write the correct answers to each problem on this same addition probe at the sound of the metronome and the verbal cue "write." Students were told to write each answer quickly and move to the next problem at the tone / prompt. If the student did not know the answer, he or she was expected to move on to the next problem at the tone /prompt. The classroom assistant modeled the behavior for the students as the first author provided the verbal prompt. Following three trials, the students all ended together at the last problem on the probe. The students completed two extra addition probes during the metronome phase to strengthen the behavior. On both of these occasions the students performed to 100% accuracy.

Detect Phase

After the students completed the probe during the metronome phase, the first author told them to circle any problems they did not complete. Then, the first author provided the correct answers to the probe as the students made corrections. The students were then given a copy of the “Detect, Practice, Repair” worksheet and were told to write the first five facts they did not successfully complete on their probe next to each number in the left hand column of the worksheet. The investigator modeled this activity using the classroom Promethean Board®. If students did not have any incorrect problems, they were to copy the problems from the Promethean Board® onto their worksheets. This was done to make sure all students received the same training and understood each phase of the intervention.

Practice Phase

In the right hand column of the “Detect, Practice, Repair” worksheet, students were provided with five numbered spaces where they would reinforce their facts. Students wrote the correct fact one time and then silently said the fact to themselves five times in a row before writing this same fact a second time. Each fact that was identified in the “detect phase” was written five times with the silent recitation of the fact taking place five times after each writing. Overall, each incorrect fact was written six times (including the time it was written during the “detect phase”) and was orally recited 25 times. This was to provide multiple opportunities for reinforcement.

Repair Phase

During the “repair phase,” the students were given the same math probe for one minute and were told to complete as many facts as fact as they could. This time, they did not have the sound of the metronome to tell them when to move on. The reason for completing the probe again was to see if the facts had become more automatic and if the students improved the number of facts completed per minute. Students were timed using a stopwatch and the classroom assistant monitored the students to ensure all students started and stopped the probe at the given commands.

Intervention. Following the training, all students were given a folder containing multiple "Detect, Practice, Repair" worksheets and two copies of the first multiplication probe (Set A). The multiplication probes were replaced on a daily basis based upon individual student progress. Students began the intervention by first completing the metronome phase for a duration of 2 minutes and 15 seconds (the time it takes to complete 90 multiplication problems at a rate of 40 problems per minute). All students began this phase by removing one of the multiplication probes from their folders and placing it face up on their desks. Students were instructed to put the date and their assigned code at the top of the probe. Students put the tip of their pencils on the first problem. Next, the metronome was turned on. If a problem was not completed, the student was expected to move on to the next fact. The first author would say "write" and the students would complete the probe until the investigator indicated the end of the phase by stating "last one."

Next, the students circled all problems they did not complete. Following this step, the first author read the correct answers to the students and told them to make all appropriate corrections. The classroom assistant monitored the students to ensure they were attentive and making appropriate corrections. As the study progressed and students were no longer all completing the same set of multiplication facts, the first author read the correct answers to small groups or individual students.

After corrections were made, the students completed the "Detect, Practice, Repair" worksheet for the first five facts they did not correctly answer or omitted. Students were instructed to date and code these worksheets in the same manner they completed their probes. Some students did not always have five facts that required practice. In this case, they were permitted to only list those facts they did not correctly solve. If a student completed all facts to

100% accuracy during the metronome phase, he or she was exempt from completing the detect and practice phases. The first author and classroom assistant monitored the students and reminded them of the correct way to complete their worksheets and practice their facts as discussed during the training.

After all students completed their worksheets, they placed the worksheets in their folders and took out their second multiplication probe. Students placed this probe face down on their desks. They were asked to complete as many facts as quickly as possible when given the command to start. Given the cue “start now,” the students turned over their probes and completed them for one minute until the first author said “stop.” Students then dated and coded their probes appropriately. This was done following the one minute timing to prevent the students from looking ahead or wasting time writing their information on their papers. Students were then told to place the probes in their folders and the classroom assistant or first author collected them.

Probes were scored independently by the first author at the end of class. Students were considered to be fluent with a fact set when they could perform at least 40 facts per minute to 100% accuracy. This criterion was established by Don Crawford (2002) with the Otter Creek Institute and was held as a district requirement for fact fluency. Students were shown their results during the following class day. They used Microsoft Office Excel 2007® to chart their progress using a spreadsheet. While students saw their progress on a daily basis, they only entered their results on a weekly basis in an effort to minimize disruptions during class instruction.

Experimental Design and Measures

To adhere to the design of the original study conducted by Poncy et al. (2006), an AB design was used to evaluate the effectiveness of the DPR technique on multiplication fact fluency. The dependent variable was the math probes while the independent variable was the DPR technique. In the original study, students were evaluated based upon the number of correct digits they produced in a two minute time period when given a subtraction probe of 80 randomly generated problems. In this study, students were evaluated using the number of correct multiplication facts produced within a one minute time period.

During the baseline phase, all students were expected to complete the same multiplication fluency probe at the same time on three consecutive dates. This data was then used to find the mean number of facts, as well as the mean number of errors and omissions, the entire class completed each day during a one minute time period. This information served as pre-treatment data. None of the students had received instruction or training in DPR during the baseline phase. This information was used to compare student results before and after the intervention.

During the intervention phase, students were evaluated based upon the number of facts they completed during the repair phase. Performance on these probes was used to determine how effective the DPR technique was on improving fact recall and overall fluency. Again, students' individual performances were used to find the mean number of facts the entire class completed each day during a one minute time period. Data was collected for a duration of six weeks (30 dates). Mean fluency was calculated each day to determine if the students were improving their retention of facts. During this phase, a student was permitted to move on to a new fact set when he or she had reached mastery. Mastery was defined as: (a) 90 facts were completed to 100% accuracy within 1 day on the initial probe with the metronome or (b) 40 facts were completed to 100% accuracy within 1 minute on 3 consecutive days.

Lastly, students were given the same multiplication probe following the last day of the intervention. During this time, the students were not exposed to any component of the intervention; they were simply expected to complete the multiplication probe (facts 0-9) as quickly as possible for one minute. This probe was given on three consecutive dates to gain post-treatment data. Post-treatment data was then used to find the mean number of facts the entire class completed each day during a one minute time period. The results were used to determine if the intervention was effective and if there were gains from the students' original baseline scores.

Inter-rater Agreement

During the study, the first author scored all student probes on a daily basis. To gain reliability data, an independent evaluator scored 33% of the student probes during the baseline and post-treatment phases, as well as 33% of the probes from the intervention phase. The first author counted all probes from the intervention phase and selected every third probe to be reviewed. A total of seven probes from both the baseline and post-treatment phases, and 59 probes from the intervention phase, were reviewed. Each probe was numbered and listed on a spreadsheet. This spreadsheet had a column for total number of facts completed, total number of errors/omissions, and total number of correct facts. The evaluator was to count all completed facts and then count the number of incorrect responses. A fact was marked as incorrect if the answer was wrong, illegible, or incomplete. These two values were subtracted in order to produce the total number of correct facts per probe. Both the first author and the evaluator completed a spreadsheet and compared results. Inter-rater agreement was calculated for the baseline, intervention, and post-treatment phases of the study. Percentages were used to determine overall reliability. These values were calculated by taking the number of agreements and dividing this value by the sum of agreements and disagreements between the first author and the evaluator. Each value was multiplied by 100 in order to obtain a percentage.

Treatment Validity

To ensure the study was performed according to procedure, treatment validity took place intermittently throughout the six week intervention. The first author developed a checklist that listed all behaviors that were expected of both the students and the first author and gave this to the classroom assistant (see Appendix B for the treatment validity checklist). The first author modeled the expected behaviors for the classroom assistant by showing her the desired responses. This was done to ensure the classroom assistant understood each component of the checklist. Behaviors that deviated from the appropriate model were to be marked as a “no” response. The classroom assistant had the opportunity to indicate a behavior was “not observed” on the checklist. During the intervention, the classroom assistant used the checklist to verify the desired behaviors were occurring. She completed this checklist daily for the first week of the study. As students became more automatic in their actions, the classroom assistant evaluated student and first author performance two times per week during the remainder of the intervention.

CHAPTER 4

Results

Results are presented in sequence based upon each phase of the study: (a) baseline, (b) intervention, and (c) post-treatment. The results strive to answer the two identified research questions from Chapter 1. These questions are: (a) Is Detect, Practice, and Repair (DPR) an effective intervention to use for improving math fact fluency among secondary students with learning disabilities? and (b) Does DPR help students maintain newly learned facts after the intervention has ended?

Prior to conducting the intervention, the students' writing speed was assessed. The class mean for single digit writing speed was 99 digits per minute while the mean for double digit writing speed was 140.86 digits per minute. The average speed for the class was 120.14 digits per minute, which is beyond the established criterion. All students successfully met the established criteria for writing speed and did not require modifications.

Baseline data were collected over three consecutive days using the same multiplication probe (facts 0-9). In Table 2, each student's mean score (number of correct facts per minute) on the baseline probes was recorded and a daily class mean was also calculated. Additionally, the mean number of errors and omissions on the three baseline probes were calculated per student, as well as for the class. Data during the intervention were collected on a daily basis over a six week time period. Table 3 displays the mean number of facts completed per minute during the DPR intervention. Post-treatment data were gathered for three consecutive days immediately following the intervention. This information is displayed in Table 4 and lists individual student performance per day, as well as their mean performance, and includes class means.

Table 2

Individual Student Performance and Class Means During Baseline

Student	# Attempted	# of Errors	# of Omissions	# Correct
12MA – 1	16	4	1	11
12MA – 2	30	1	9	20
12MA – 3	39	0	11	28
12MA - Means	**28**	**2**	**7**	**20**
9FB – 1	49	6	3	40
9FB – 2	45	3	3	39
9FB – 3	48	6	3	39
9FB – Means	**47**	**5**	**3**	**39**
9MC – 1	30	1	0	29
9MC – 2	45	2	0	43
9MC – 3	52	2	0	50
9MC – Means	**42**	**2**	**0**	**41**
9MD – 1	45	2	3	40
9MD – 2	30	3	3	24
9MD – 3	30	3	3	24
9MD – Means	**35**	**3**	**3**	**29**
9FE – 1	30	2	4	24
9FE – 2	34	2	4	28
9FE – 3	36	2	4	30
9FE – Means	**33**	**2**	**4**	**27**
9MG – 1	15	0	2	13
9MG – 2	16	1	1	14
9MG – 3	17	1	1	15
9MG – Means	**16**	**1**	**1**	**14**
9MH – 1	44	0	0	44
9MH – 2	48	0	0	48
9MH – 3	51	0	0	51
9MH – Means	**48**	**0**	**0**	**48**
CLASS MEANS	**35.71**	**2.56**	**3.67**	**31.14**

Table 3

Daily Class Means per Intervention Session

Intervention Session	Mean Number of Facts Per Minute (Rounded to Nearest Whole Fact)
Session 1	55
Session 2	54
Session 3	54
Session 4	54
Session 5	50
Session 6	51
Session 7	48
Session 8	47
Session 9	49
Session 10	46
Session 11	55
Session 12	43
Session 13	53
Session 14	46
Session 15	41
Session 16	48
Session 17	43
Session 18	44
Session 19	49
Session 20	43
Session 21	43
Session 22	45
Session 23	45
Session 24	48
Session 25	42
Session 26	38
Session 27	49
Session 28	42
Session 29	40
Session 30	53

Table 4

Individual Student Performance and Class Means During Post-Treatment

Student	Attempted	Errors	Omissions	Correct
12MA – 1	54	0	15	39
12MA – 2	49	0	11	38
12MA – 3	51	0	10	41
12MA - Means	**51**	**0**	**12**	**39**
9FB – 1	54	1	0	53
9FB – 2	47	1	0	46
9FB – 3	50	1	0	49
9FB – Means	**50**	**1**	**0**	**49**
9MC – 1	50	2	0	48
9MC – 2	39	0	0	39
9MC – 3	50	1	0	49
9MC – Means	**46**	**1**	**0**	**45**
9MD – 1	55	1	7	47
9MD – 2	49	1	3	45
9MD – 3	61	0	4	57
9MD – Means	**55**	**1**	**5**	**50**
9FE – 1	46	0	18	28
9FE – 2	28	0	4	24
9FE – 3	44	0	8	36
9FE – Means	**39**	**0**	**10**	**29**
9MG – 1	33	0	9	24
9MG – 2	31	1	6	24
9MG – 3	31	0	6	25
9MG – Means	**32**	**0**	**7**	**24**
9MH – 1	55	0	0	55
9MH – 2	55	0	0	55
9MH – 3	59	0	0	59
9MH – Means	**56**	**0**	**0**	**56**
CLASS MEANS	**47.19**	**1.13**	**8.42**	**41.95**

Table 5 summarizes individual student gains from baseline to post-treatment in chart form, while Figure 1 displays this information graphically. Figure 2 shows the class means during baseline, intervention, and post-treatment phases in graphic form.

Baseline

Baseline data were collected over three consecutive dates for all students. Data that were collected included the number of facts attempted, the number of errors produced, the number of facts omitted, and the total number of correctly completed facts in one minute. Each student's score was evaluated individually and a mean score was calculated for all of the aforementioned categories for each student. Then, a class mean was computed for each of these categories. During baseline, the class averaged a total of 35.71 attempted facts in one minute. They averaged 2.56 errors per probe and 3.67 omissions. An error was counted as a fact that was completed, yet incorrect. An omission was counted as any problem between the first fact and the last fact completed that was left blank. The class averaged a total of 31.14 correct facts per minute during the baseline phase. This is below the established district criterion of 40 facts per minute. Individually, only one student (9MH) consistently completed 40 facts per minute or greater on all three baseline probes. The remaining six students did not consistently perform at this level.

Intervention

All students were engaged in the intervention for six weeks or 30 class periods. The intervention results indicate that all students made gains in their fact fluency skills with multiplication. When reviewing Figure 3, the range of facts completed per minute following the use of the DPR technique went from a low of 38 facts per minute during session 26 to 55 facts per minute during sessions 1 and 11. Other than session 26, the class means were always above

Table 5

Individual Student Gains Comparing Mean Baseline to Mean Post-Test Scores

Student	Attempted	Errors	Omissions	Correct
12MA - Baseline	28	2	7	20
12MA - Post-Test	51	0	12	39
	+23	**-2**	**+5**	**+19**
9FB – Baseline	47	5	3	39
9FB – Post-Test	50	1	0	49
	+3	**-4**	**-3**	**+10**
9MC – Baseline	42	2	0	41
9MC – Post-Test	46	1	0	45
	+4	**-1**	**N/A**	**+4**
9MD – Baseline	35	3	3	29
9MD – Post-Test	55	1	5	50
	+20	**-2**	**+2**	**+21**
9FE – Baseline	33	2	4	27
9FE – Post-Test	39	0	10	29
	+6	**-2**	**+6**	**+2**
9MG – Baseline	16	1	1	14
9MG – Post-Test	32	0	7	24
	+16	**-1**	**+6**	**+10**
9MH – Baseline	48	0	0	48
9MH – Post-Test	56	0	0	56
	+8	**N/A**	**N/A**	**+8**

Figure Captions

Figure 1. Comparison of the mean number of facts each student completed during the baseline and post-treatment phases of the study.

Figure 2. Mean number of facts the class completed during the baseline, intervention, and post-treatment phases of the study. B = baseline and P = post-treatment phases of the study. Individual numbers represent each session during the intervention.

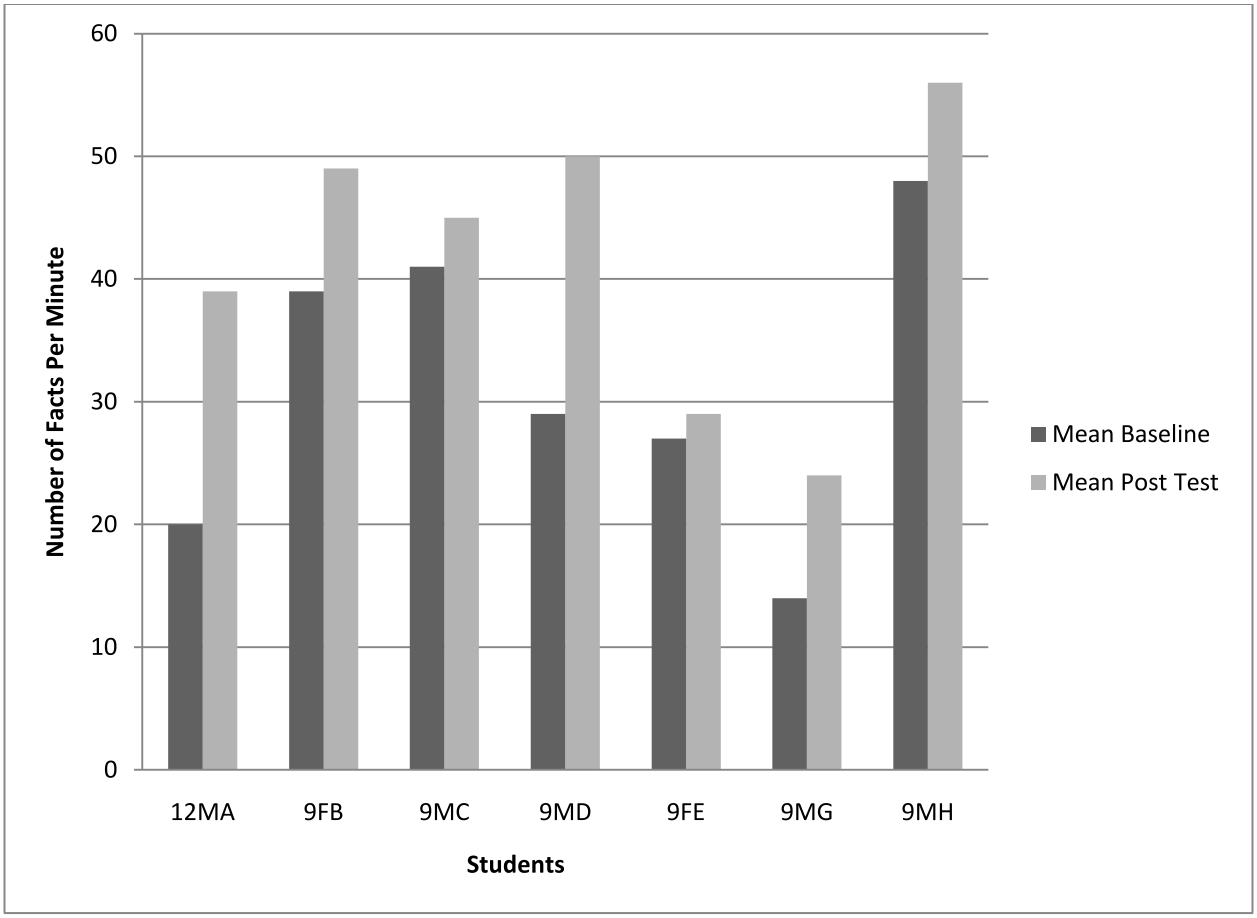

Figure 1: Graph of Individual Student Gains from Baseline to Post-Treatment

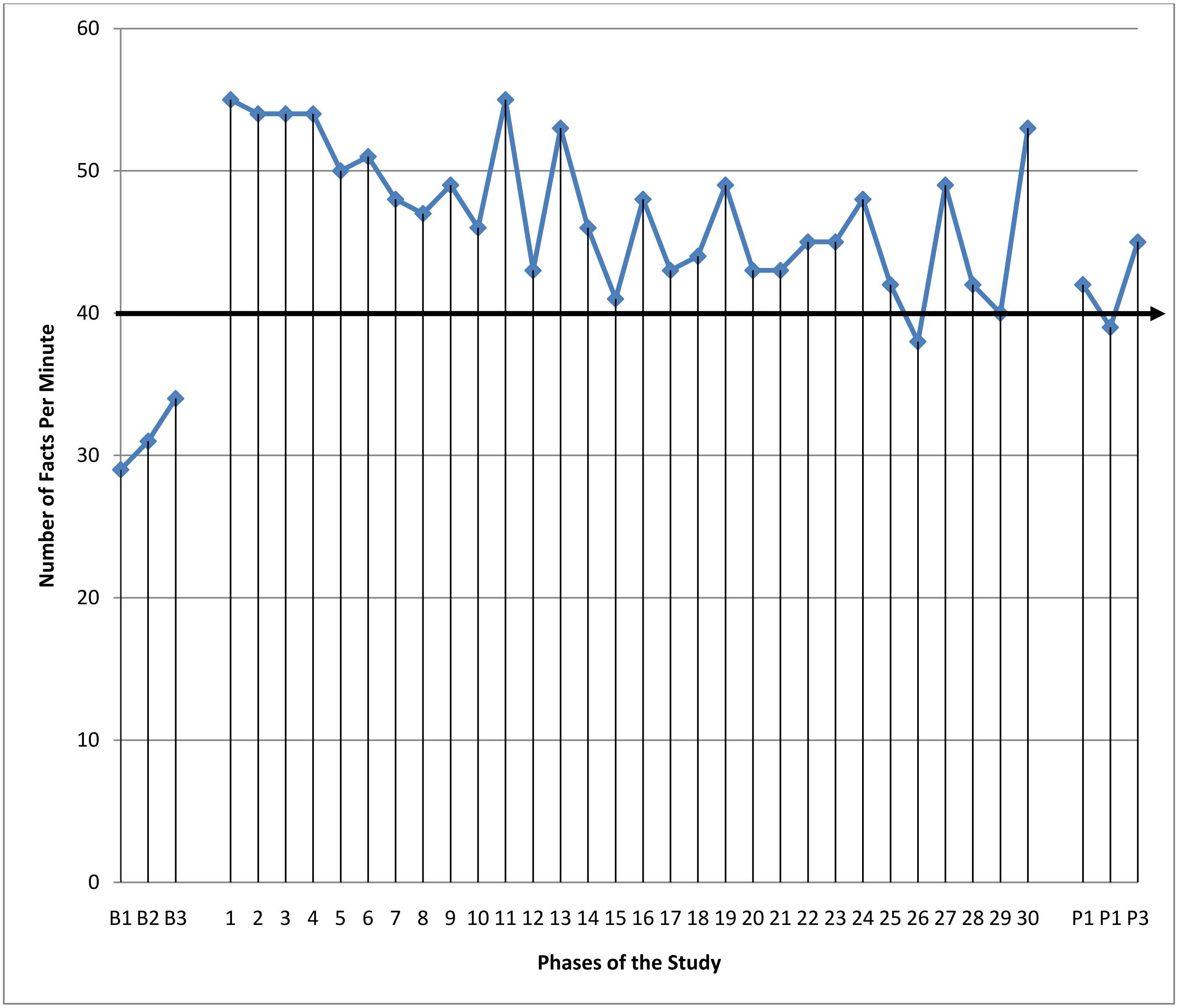

Figure 2: Graph of Class Means in Each Phase of the Study

40 facts per minute after the students practiced their facts using the DPR technique. All students increased the number of facts they completed accurately in one minute while reducing the number of errors produced.

When comparing the post-treatment data to the baseline data, the class attempted an average of 47.19 facts per minute. This is an improvement of 32.15% from the baseline results. Students averaged 1.13 errors per probe (a decrease of 55.86%), however the number of omitted facts increased to 8.42 per probe (an increase of 129.43%). When the intervention was completed, the class average for the number of correct facts completed per minute increased to 41.95. This is an average of 1.80 facts per week, or a gain of 10.81 facts over the course of the intervention. This was an improvement of 34.71% over the course of the intervention.

When reviewing individual student performance during the intervention, all students made gains with the number of facts accurately completed per minute. Substantial gains (10 or more correct facts per minute over the course of the intervention) were made by students 12MA, 9FB, 9MD, and 9MG. Student 12MA improved from 20 to 39 correct facts per minute following the intervention. He reduced his number of errors from 2 to 0, however he made more omissions following the treatment. During baseline, he made an average of 7 omissions, but during the post-treatment probes, he made an average of 12. Overall, he made a gain of 19 facts in 6 weeks, or an average of 3.17 new facts per week. Student 9FB improved her fact completion by 10 facts following the intervention (from 39 to 49 correct facts per minute) or 1.67 facts per week. She reduced her number of errors from 5 to 1 and reduced her number of omissions from 3 to 0. Student 9MD made a gain of 21 facts (29 to 50 correct facts per minute) or 3.5 facts per week. While reducing his number of errors from 3 to 1, he increased his number of omissions from 3 to 5. Finally, student 9MG improved his fluency by 10 facts at the end of the intervention (14 to 24 facts per minute) or 1.67 facts per week. While this did not meet the 40 fact per minute requirement set forth by the district, the personal gains the student made were noteworthy. He reduced his number of errors from 1 to 0, however he did increase his number of omissions from 1 to 7.

Students who made gains, but did not improve more than 10 facts during the course of the intervention, were 9MC, 9FE, and 9MH. Student 9MC improved from a baseline of 41 facts to 45 facts at the end of the intervention. This averaged to .67 newly acquired facts per week. While the overall gain was not as strong as some of the other students, 9MC had already acquired more than the district requirement for fact fluency during two of the baseline probes. The same is true of student 9MH. This student improved from 48 to 56 facts after the intervention. This is a gain of 1.33 new facts per week. Both students did not omit any facts during the probes in the baseline and post-treatment assessments. Student 9MH did not make any errors during both phases, while student 9MC reduced his errors from 2 to 1. Student 9FE began with a total of 27 facts per minute during the baseline phase and ended with 29 facts per minute at the end of the intervention. This is an average of .33 new facts per week. This student reduced her number of errors from 2 to 0, but increased her number of omissions from 4 to 10.

Reliability

Reliability data were collected through the use of checklists. The first author selected 7 baseline, 59 intervention, and 7 post-test probes to be scored by an independent evaluator. These numbers account for 33% of all student data collected during each phase of the study. On the baseline probes, the first author and evaluator met 100% agreement across all categories on all seven probes. The same results were true of the post-test probes. On the intervention probes, 96.61% accuracy was met between the first author and the evaluator when comparing the total number of completed facts and the number of errors (57 of the 59 probes). When comparing the total number of correct facts, agreement was found 93.22% of the time (55 of the 59 selected probes). Treatment reliability was also 100%.

CHAPTER 5

Discussion

The purpose of this study was to determine if DPR is effective in improving and maintaining fact fluency with secondary students with learning disabilities. While the original study conducted by Poncy et al. (2006) focused upon elementary aged students in the general education classroom setting and targeted the operation of subtraction; this study involved seven high school students with specific learning disabilities in mathematics and used the operation of multiplication during the intervention. The students participated in this study for six weeks. The intervention consisted of daily practice with multiplication facts using a method known as "Detect, Practice, Repair" (DPR). Students were expected to detect facts they did not know to automaticity, practice these facts multiple times in both written and oral forms, and repair these unknown facts on follow-up multiplication probes.

The school district where this study took place previously established the criterion of 40 facts per minute to indicate appropriate fluency with a math operation. This standard is supported by research that suggests students who are held to a standard of 40 facts per minute often have an easier time with more complex mathematic tasks (Crawford, 2003; Howell & Nolet, 2000; Miller & Heward, 1992; Stein et al.,1997). Prior to the implementation of this intervention, students in the classroom were receiving minimal instruction on their basic facts. While they were expected to recall their facts during class instruction, the students often relied upon the use of a multiplication chart or would ask their peers for assistance rather than recall their facts independently. During fluency probes, the students were able to review their facts for five minutes prior to taking the probe, but no corrective measures were ever implemented to help them. The students were not provided with the opportunity to correct those facts they did not know to automaticity which never allowed them the chance to learn the correct facts. In turn, this lack of correction may have reinforced and perpetuated the students' incorrect recall of their facts. Unfortunately, the teachers within the selected school district were trained to allow practice time, administer the probe, and share progress with the students when administering fluency probes. While students are shown which facts they did not complete correctly and are given the correct answers to these facts, they are not provided with activities to reinforce these facts. Because all teachers at every building level received the same set of instructions, this may explain why students at the high school level still have not achieved mastery of their basic facts. If students have never had proper instruction or never have had the ability to make corrections to their incorrect assumptions about what a fact may truly represent, then it is not hard to understand why they continue to struggle with basic fact knowledge.

All students who participated in the study made gains using the DPR method. While all students did begin the study with some fact knowledge, none of the students were the same in their recall of these facts. The DPR technique allowed for individualization and let students practice those facts that were exclusive to their needs. This prevented students from needlessly practicing facts they already knew. In addition, students were able to move ahead at their own pace rather than have to wait for the entire class to master a fact set. This may improve motivation as students are directly responsible for their own progress.

Because DPR allows for individualization, its implementation in the classroom can easily be achieved. All students are expected to participate in the same activities, so the classroom teacher can easily monitor and engage all students during each phase of the intervention. The difference is that during these phases, the teacher may have several different probes being administered at the same time based upon prior student achievement. In addition, because all students are engaged in the same task, implementation of DPR is fast. It only takes 10 minutes to complete once students are trained and understand what to do. This training can easily be achieved because the teacher can easily model and explain each phase of DPR to the entire class at one time. Furthermore, because each student is working at his or her own pace, absences from school do not require the teacher to make special accommodations for the student. Students simply continue where they left off during the previous class, which reduces the demands on the teacher.

When reviewing student performance in comparison to district criterion, five of the seven students successfully met and maintained the requirement of 40 facts per minute after the intervention had ended. This may be a strong indication that the use of DPR was effective in helping students retain and maintain their facts over time. While the other two students in the study did show improvement with the number of facts completed per minute, they did not reach the established goal of 40 facts per minute. This may be attributed to the students' low baseline scores and overall difficulty recalling multiplication facts. These two students struggled to produce the correct answers to each fact during the metronome phase of the study which resulted in more than five facts that needed to be practiced when completing the "Detect, Practice, Repair" worksheets. These two students had the most difficulty retaining their facts and were unable to understand the concept of fact families. For example, the students may know that 7 X 2 = 14, but did not know that 2 X 7 = 14. This caused the two students to struggle significantly when completing the math probes.

While the overall results of the DPR method are promising, some limitations must be considered. To begin, the participants in the study were only exposed to the intervention for six weeks and came to the class with varying ability levels. While the original study also only lasted for six weeks, it would have been interesting to see if the two students who experienced difficulty reaching the 40 facts per minute criterion could have done so given more time. Also, given the short amount of time devoted to the intervention, not all of the students progressed through the full set of facts. Of the seven students, only one managed to complete all of the multiplication sets. Many of the students needed more time before they could achieve mastery with a set of facts.

When reviewing the class means during the intervention, it is important to note that not all students practiced the same sets of facts at the same time, which may have accounted for either an inflated or deflated score. For example, during the first session, with only one exposure to the practice of DPR, the students achieved a class mean of 55 facts per minute. At this time, all students were working on the same fact set, which were the “times 1” and “times 2” facts. This is an accurate measure of the entire class working at the same level. However, while some students may have had to stay at this fact set for a short time, others quickly moved on. As a result, the class mean may have been based upon nearly seven different fact sets rather than just one. As the students progressed through the fact sets and encountered more difficult multiplication facts, the class average began to decrease. This was particularly true during session 26, when the class mean dropped to only 38 facts per minute – a value below the established criterion for this study.

Another possible limitation of this study was the size of the population. Only seven students participated in this study, which makes it hard to generalize to a larger population of students. Additionally, the students in this study had learning disabilities with mathematics. None of the students had diagnoses that more severely impeded their cognitive functioning.

Consequently, it may be difficult to know whether or not the DPR technique is effective with students who have more significant academic needs.

While treatment reliability and inter-rater reliability was conducted, internal validity was not conducted in a formal manner. Throughout the study, the first author would ask the students if they were pleased with their progress and if they believed the DPR technique was the reason behind their success. While the students responded positively and favorably to the questions, they were not asked to complete a formal checklist or questionnaire regarding their feelings about the study. Additionally, even though the students were able to note their progress on a daily basis by seeing which fact set had been placed in their folders, they did not formally chart and view their progress until the end of the week when they had computer access to input their scores. This may have been too much of a delay for the students because performance feedback was not immediate.

In conclusion, after reviewing the literature, DPR contains many features that have been successful in improving student fluency. In this study, instruction was delivered in a very structured manner with multiple practice opportunities for the students. Corrective feedback was provided immediately and students were given the opportunity to reinforce such corrections through the “practice” and “repair” phases of the intervention. Students were able to work at their own pace and note their progress as they advanced through each fact set while being held to a standardized criterion. As a result, all students improved their fluency not just on a daily basis, but over time as shown by the post-test data.

If such fluency interventions were used consistently and were explicitly followed with students in the primary grades until mastery was achieved, the need for fluency programs at the secondary level may not be needed. When one takes the time to consider the number of skills students need to be successful in their everyday lives, the time that could be devoted to such tasks dramatically increases. Even though DPR only took 10 minutes to implement, one needs to look at the bigger picture. Ten minutes per day leads to 50 minutes per week, 200 minutes per month, 450 minutes per nine week quarter, and 1800 minutes in a full school year. In one school year, 30 additional hours of instruction could be spent on advanced concepts rather than rudimentary skills. If teachers of students in the elementary grades are instructed in the use of DPR and students master their facts before entering the middle school (seventh grade), this is 180 hours of additional instructional time – or an additional school year that could be devoted exclusively to mathematics. We can not deny the implications of what evidence-based practices can do for our students. While teachers frequently state they do not have time to implement such measures, consider the time that could be saved by using a technique such as DPR early in a student's academic career. Ignoring what research tells us is best practice will cost us much more than time in the long run.

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Appendix A

Detect, Practice, Repair Worksheet

Code: ________________________________ Date:______________

Fact	**Practice Space**
	1. 2. 3. 4. 5.
	1. 2. 3. 4. 5.
	1. 2. 3. 4. 5.
	1. 2. 3. 4. 5.
	1. 2. 3. 4. 5.

Appendix B

Treatment Validity Checklist

Date of Observation: ___________________

Behavior	Yes	No	N/O
METRONOME PHASE			
1. All students have a writing utensil.			
2. All students have a math probe face up on their desks, properly dated and coded.			
3. All students place the point of their pencils on the first fact.			
4. All students begin completing the probe when the teacher says, “Write” and the metronome sounds.			
5. Students move at the pace of the metronome and teacher prompt – students are not moving ahead or lingering on problems.			
6. All students stop writing when the teacher says, “Last one.”			
DETECT AND PRACTICE PHASES			
1. All students circle any problems they have omitted.			
2. The students make corrections as the teacher reads the correct answers aloud.			
3. The students list the first 5 facts (if that many are present) on their DPR worksheets.			
4. The students write the each fact and silently repeat it to themselves 5 times before writing the fact a second time.			
5. The students complete the DPR worksheet using the properly taught methods of the DPR technique.			

Treatment Validity Checklist

Date of Observation: ___________________

Behavior	**Yes**	**No**	**N/O**
REPAIR PHASE			
1. All students have a writing utensil.			
2. All students have placed their DPR worksheets and metronome probes back into their folders.			
3. All students have a math probe face down on their desks.			
4. All students are watching the teacher.			
5. All students turn over their probes and immediately start working when the teacher says, "Start now."			
6. The teacher starts the stopwatch at the same time she says, "Start now."			
7. The students complete the given probe systematically, moving from problem to problem.			
8. The students complete the probe for only 1 minute.			
9. The teacher adheres to the 1 minute deadline and stops the watch while telling the students, "Stop."			
10. All students stop working.			
11. The students code their probes with the correct date and proper code.			
12. The students place the probes in their folders.			
13. The teacher collects the folders.			

Appendix C

RELIABILITY CHECKLIST

Name:___________________________ Role: ______________________

Probe Type (B, I, PT)	Probe Number	Total Facts Completed	Number of Errors / Omits	Total Correct Facts

B = Baseline Probe **I = Intervention Probe** **PT = Post-Test**

Appendix D

Informed Consent Form for Social Science Research
The Pennsylvania State University
Parent Version

Title of Project: *Improving Math Fact Fluency*

Principal Investigator:
Holly Lorchak
Sharp Ave. and Frances St.
Reading, PA 19605
lorchakh@mail.muhlsdk12.org
610-921-8078, ext. 4174

Advisor:
Dr. Mary Catherine Scheeler
30 E. Swedesford Road
Malvern, PA 19355
mcs13@psu.edu
610-648-3272

Purpose of the study:
This study will try to improve your son's or daughter's memory of multiplication facts in two ways: 1) It will use a metronome to help your son or daughter understand the speed at which s/he must complete each math probe and 2) It will encourage your son or daughter to practice those facts s/he does not know so they become more familiar and automatic.

Procedures to be followed: In this study, the following events will occur:
First, your son or daughter will be given a test where s/he must copy a series of random numbers onto a chart. This is to find his/her writing speed. Next, your son or daughter will be given a math probe in multiplication. The probe is a worksheet of 90 multiplication facts which will be like a pre-test. This pre-test will contain a mixture of all the multiplication facts (0-9). Your son or daughter will be given one minute to complete the probe to see how many facts s/he can complete in one minute. This same step will be completed on two more dates to get an average number of facts s/he is able to complete in 1 minute.

Next, your son or daughter will have a class period where s/he will become familiar with the pace of the metronome. To start, s/he will move from problem to problem with his/her finger rather than solve the problems. The teacher will watch your son or daughter to make sure s/he understands what to do. Once the teacher is sure your son or daughter is comfortable with the speed of the metronome, s/he will complete an addition probe of 80 math facts from 0-10. S/he will write the answers to each of these problems at the sound of the metronome. This will give your son or daughter more practice with the metronome. S/he may practice this skill more than one time to make sure s/he feels comfortable with this task. Once the teacher has decided your son or daughter is completing the practice probes correctly with the metronome, s/he will complete an actual probe of 90 multiplication facts.

In a 2-minute and 15 second time period, your son or daughter will write the answers to each multiplication fact on his/her worksheet when s/he hears the beep of the metronome. If s/he does not know the fact automatically, s/he will move on to the next fact at the sound of the metronome. At the end of two minutes and 15 seconds, your son or daughter will hear the answers to the probe. S/he will make corrections on the worksheet. Next, s/he will write the first five facts s/he did not successfully complete on a special worksheet. An example of this worksheet is provided for you. S/he will write each fact 5 times. After each fact is written, your son or daughter will quietly say the fact to his/herself. Following this short practice section, s/he will be given the same math probe for 1 minute. This time, s/he will not have the sound of the metronome to tell him/her when to move on. The reason your son or daughter will complete the probe again is to see if the facts have become more automatic and if s/he improved the number of facts completed per minute.

Your son or daughter will move on to a new set of facts if 90 facts are completed to 100% accuracy on the metronome probe or if s/he completes 40 facts per minute to 100% accuracy three days in a row. Your son or daughter will chart his/her progress by keeping a folder of the probes and recording progress on a graph.

Duration / Time:
Your son or daughter will be a part of this study for eight weeks. S/he will complete multiplication fluency probes on a daily basis for the first 10 minutes of class for eight weeks.

Statement of Confidentiality:
All of the information that your son or daughter will be providing is private. His/her name will not be used anywhere. Only Mrs. Holly Lorchak (the classroom teacher), Dr. Mary Catherine Scheeler (the advisor), and Mr. Michael Herb (the research assistant) will know your son or daughter's identity and will see the math probes. The information (data) from the math probes will be stored and secured in Holly Lorchak's classroom and home office in a locked file cabinet. Your son's or daughter's results and progress will be stored on Holly Lorchak's home computer in a password protected file. Nothing s/he does will be discussed with anyone outside of the research team. Your son or daughter may quit the study at any time and s/he will not face any negative consequences for doing so. All information (the math probes and logs of progress) will be destroyed by August of 2014. In the event of a publication or presentation resulting from the research, no personally identifiable information will be shared.

Right to ask questions:
Please contact _Holly Lorchak_ at (610) 921-8078, ext. 4174 with questions or concerns about this study. Or, please e-mail Holly Lorchak at the following address: lorchakh@mail.muhlsdk12.org.

Voluntary Participation: Your son's or daughter's decision to be in this research is voluntary. S/he can stop at any time. His/her refusal to take part in this study or withdrawing from this study will not involve a penalty or any negative consequences.

If you agree to allow your son or daughter to take part in this research study as outlined above and will allow his/her multiplication fact fluency probes to be released to the research team, please check the appropriate boxes and sign your name and fill in the date below. Also, please print the name of your son or daughter below.

You will be given a copy of this form for your records.

☐ I agree to allow my son/daughter to participate in the described research study.

☐ I DO NOT agree to allow my son/daughter to participate in the described research study.

☐ I agree to allow my son/daughter's completed multiplication fact fluency probes from his/her basic mathematics course to be released to the principal investigator and the research team of this study for the purpose of seeing if the previously described methods (detect, practice, and repair) have been successful. Fact fluency probes will be studied to see if there is an increase in the number of facts completed and if there is improvement in the level of accuracy on each probe.

☐ I DO NOT agree to allow my son/daughter's completed multiplication fact fluency probes from his/her basic mathematics course to be released to the principal investigator and the research team of this study.

____ ____________________
Parent's Signature Date

____ ____________________
Parent's Name (please print) Date

____
Son's or Daughter's Name (please print)

____ ____________________
Principal Investigator's Signature Date

Informed Consent Form for Social Science Research
The Pennsylvania State University
Student Version

Title of Project: *Improving Math Fact Fluency*

Principal Investigator:
Holly Lorchak
Sharp Ave. and Frances St.
Reading, PA 19605
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610-921-8078, ext. 4174

Advisor:
Dr. Mary Catherine Scheeler
30 E. Swedesford Road
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This study will try to improve your memory of multiplication facts in two ways: 1) It will use a metronome to help you understand the speed at which you must complete each math probe and 2) It will encourage you to practice those facts you do not know so they become more familiar and automatic to you.

Procedures to be followed: In this study, the following events will occur:

First, you will be given a test where you must copy a series of random numbers onto a chart. This is to find your writing speed. Next, you will be given a math probe in multiplication. The probe is a worksheet of 90 multiplication facts which will be like a pre-test. This pre-test will contain a mixture of all the multiplication facts (0-9). You will be given one minute to complete the probe to see how many facts you can complete in one minute. This same step will be completed on two more dates to get an average number of facts you are able to complete in 1 minute.

Next, you will have a class period where you will become familiar with the pace of the metronome. To start, you will move from problem to problem with your finger rather than solve the problems. The teacher will watch you to make sure you understand what to do. Once the teacher is sure you are comfortable with the speed of the metronome, you will complete an addition probe of 80 math facts from 0-10. You will write the answers to each of these problems at the sound of the metronome. This will give you more practice with the metronome. You may practice this skill more than one time to make sure you feel comfortable with this task. Once the teacher has decided you are completing the practice probes correctly with the metronome, you will complete an actual probe of 90 multiplication facts.

In a 2-minute and 15 second time period, you will write the answers to each multiplication fact on your worksheet when you hear the beep of the metronome. If you do not know the fact automatically, you will move on to the next fact at the sound of the metronome. At the end of two minutes and 15 seconds, you will hear the answers to the probe. You will make corrections on the worksheet. Next, you will write the first five facts you did not successfully complete on a special worksheet. An example of this worksheet is provided for you. You will write each fact 5 times. After each fact is written, you will quietly say the fact to yourself. Following this short practice section, you will be given the same math probe for 1 minute. This time, you will not have the sound of the metronome to tell you when to move on. The reason you will complete the probe again is to see if the facts have become more automatic and if you improved the number of facts completed per minute.

You will move on to a new set of facts if 90 facts are completed to 100% accuracy on the metronome probe or if you complete 40 facts per minute to 100% accuracy three days in a row. You will chart your progress by keeping a folder of your probes and recording progress on a graph.

Duration / Time:
You will be a part of this study for eight weeks. You will complete multiplication fluency probes on a daily basis for the first 10 minutes of class for eight weeks.

Statement of Confidentiality:
All of the information that you will be providing is private. Your name will not be used anywhere. Only Mrs. Lorchak, Dr. Scheeler, and Mr. Herb (the research assistant) will know your identity and will see the math probes. The information (data) from the math probes will be stored and secured in Mrs. Lorchak's classroom and home office in a locked file cabinet. Your results and progress will be stored on Mrs. Lorchak's home computer in a password protected file. Nothing you do will be discussed with anyone outside of the research team. You may quit the study at any time and you will not face any negative consequences for doing so. All information (the math probes and logs of progress) will be destroyed by August of 2014. In the event of a publication or presentation resulting from the research, nothing that can identify you with the study will be shared.

Right to ask questions:
Please contact _Mrs. Lorchak_ at (610) 921-8078, ext. 4174 with questions or concerns about this study. Or, please e-mail Mrs. Lorchak at the following address: lorchakh@mail.muhlsdk12.org.

Voluntary Participation:
Your decision to be in this research is voluntary. You can stop at any time. Your refusal to take part in this study or withdrawing from this study will not involve a penalty or any negative consequences.

If you agree to take part in this research study as outlined above, please sign your name and fill in the date below.

You will be given a copy of this form for your records.

____ _____________________
Participant’s Signature Date

____ _____________________
Participant’s Name (Please print) Date

____ _____________________
Principal Investigator’s Signature Date