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The Taped-Problems Intervention: Increasing Multiplication Fact Fluency Using a Low-Tech Time Delay Intervention

Elizabeth McCallum
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To the Graduate Council:

I am submitting herewith a dissertation written by Elizabeth McCallum entitled "The Taped-Problems Intervention: Increasing Multiplication Fact Fluency Using a Low-Tech Time Delay Intervention." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Education.

Christopher H. Skinner, Major Professor

We have read this dissertation and recommend its acceptance:

Robert L. Williams, Sherry K. Bain, John C. Malone

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Sherry K. Bain____________

John C. Malone___________

Accepted for the Council:

Anne Mayhew___________
Vice Chancellor and Dean of
Graduate Studies

(Original signatures are on file with official student records.)

THE TAPED-PROBLEMS INTERVENTION: INCREASING MULTIPLICATION FACT FLUENCY USING A LOW-TECH TIME DELAY INTERVENTION

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Elizabeth McCallum
August, 2006

DEDICATION

This dissertation is dedicated to my husband Scott for always making me laugh and to our son Maxwell, who has brought infinite joy to my life.

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I wish to thank everyone who helped me throughout these past five years of graduate school. Dr. Christopher Skinner in particular guided me through my practicum, coursework, and research. He served as a great advisor and role model and always encouraged me to think up and attempt new and different studies that might add to the school psychology literature base. I would also like to thank Dr. Robert Williams for being my teaching mentor throughout my four years of teaching at UT. Finally, I would like to thank Dr. Sherry Bain and Dr. John Malone for serving on my dissertation committee.

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Abstract

Fluency, the ability to respond both accurately and rapidly is a crucial step in skill development (Haring & Eaton, 1978). Fluency is important from a variety of theoretical viewpoints. A cognitive processing model suggests that being automatic with respect to a particular task allows one to free up cognitive resources (i.e., working memory) for more difficult aspects of the task. A behavioral approach suggests that fluency allows for more opportunities to respond within a given timeframe and therefore more opportunities to gain reinforcement. Finally, from a choice theory perspective, students are more likely to choose to engage in tasks that they find briefer and less difficult (i.e., tasks at which students have achieved fluency). The purpose of the current research was to introduce and evaluate a new method of increasing basic math fact fluency among elementary school students.

The current study was conducted to determine if the taped-problems intervention, a variation of the taped-words interventions (Freeman & McLaughlin, 1984), could be used to enhance multiplication fact fluency. This study used a multiple-probes-across-tasks design to determine if the taped-problems intervention increased the multiplication fact fluency of eighteen third-grade students from a general education class. During the taped-problems intervention, students were given lists of problems and instructed to attempt to complete each problem before its answer was provided by a recording from an audiotape player. Varying time delay procedures were used as intervals between the problems and their answers were adjusted. Initially, there was little time delay between problems and their answers. During each session, as the series of problems was repeated, the interval was increased and then reduced. Results of this study showed clear increases in multiplication fact fluency after the intervention was implemented. Furthermore, the enhanced performance appeared to be maintained. Discussion focuses on future research related to the taped-problems intervention.

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Chapter 1

Introduction and Literature Review

The National Center for Educational Statistics (NCES) recently released its *2003 Nation's Report Card,* an ongoing nationally representative study of America's education system, indicating student performance in a variety of subject areas. The most recent results showed that in 2003, only 32 percent of fourth-graders and 29 percent of eighth-graders were performing at or above the Proficient level in mathematics. The Proficient level indicates solid grade-level performance on a variety of math tasks including subject-matter knowledge, application of this knowledge to real-world situations, and appropriate analytical skills (NCES, 2003). Additionally, the 2003 data report that group averages for African-American, Hispanic, and American-Indian students at both the fourth- and eighth-grade levels were significantly lower than those for White and Asian students. Similarly, group averages for students meeting eligibility criteria for free and reduced-priced lunches (based on family income) were significantly lower than those for students not meeting these criteria. Although the national and most state averages had increased slightly since previous NCES studies (1992, 1996, 2000), these data still suggest large-scale improvements are warranted.

Basic Math Facts and the Skill Development Hierarchy

During elementary school, a large amount of mathematics instructional time is devoted to teaching basic mathematics computation facts (Fleischner, Garnett, & Shepherd, 1982). Basic mathematics computation facts include solving simple (e.g., one-digit by one-digit) addition, subtraction, multiplication, and division problems (Hasselbring, Goin, & Bradsford, 1987). Being accurate with respect to basic math facts is critical in the development of new skills and achievement in higher-level math (Ysseldyke, Thill, Pohl, & Bolt 2005). Because these basic computation skills are necessary for completing more complex computation problems, it may not be sufficient for students to merely acquire the ability to solve these problems; they should also be able to arrive at the correct answers *rapidly* (Deno & Mirkin, 1977; Haring & Eaton, 1978; Shapiro, 1996). Fluency, automaticity, and proficiency are terms often used to describe rapid and accurate responding (Skinner, 1998).

Haring and Eaton (1978) proposed a hierarchy outlining the steps necessary to develop a skill. The first level is acquisition, in which students build accuracy of a novel skill. Effective strategies for enhancing acquisition include drilling, modeling, and cuing. The next level of skill development is fluency (Haring & Eaton, 1978). Fluency is targeted once a student is capable of accurately responding to a task but lacks the ability to respond as quickly as desired. The goal of fluency development is for the student to respond both accurately and rapidly. Strategies used to enhance fluency include repeated practice and reinforcement or feedback.

Following the acquisition and fluency stages of the hierarchy, Haring and Eaton (1978) identified the third and fourth stages of skill development as generalization and application, respectively. Generalization is defined as performing a skill in response to a stimulus that was not present during initial instruction. Strategies for enhancing generalization emphasize responding to novel stimuli. The final stage of the hierarchy, application, requires the ability of a student to modify the skill in response to new problems. Strategies used to enhance application focus on creative problem solving and simulation of novel situations.

The importance of becoming fluent with respect to basic math computation facts cannot be overemphasized. From a cognitive processing perspective, those who can complete basic facts automatically may have more cognitive resources available to apply to learning more complex computation algorithms or concepts (LaBerge & Samuels, 1974; Wong, 1986). Additionally, the more rapidly students can complete the basic mathematics facts, the more quickly they can complete complex items (Skinner, Fletcher, & Henington, 1996). Thus, from a behavioral perspective, students receive more opportunities to practice these complex items, which can enhance generalization and discrimination skills and increase opportunities for reinforcement (Skinner & Schock, 1995). Finally, those who can complete basic facts both rapidly and accurately may find complex mathematics tasks less frustrating and have lower levels of mathematics anxiety than those who cannot complete basic facts automatically (Cates & Rhymer, 2003).

Student Choices

The ability to respond rapidly and accurately can also have an influence on whether students choose to engage in assigned mathematics work. Ultimately, whether or not a student completes an assignment is a choice made by the student. Successful students choose to complete tasks, their task completion is reinforced, and they continue to make this choice when faced with a variety of school tasks. Unsuccessful students often choose not to engage in given tasks. Instead, they choose other, sometimes inappropriate and even disruptive behaviors. These detrimental choices have been characterized as either *can't do* or *won't do* problems (Skinner, Pappas, & Davis, 2005). *Can't do* problems include logistical problems such as lacking the necessary materials or time to complete a given task. Sometimes *can't do* problems result from a student's lack of the prerequisite knowledge necessary to successfully complete an assignment. *Won't do* problems, on the other hand, stem from a variety of factors that include lack of perceived or actual reinforcement, lack of interest in the assignment, and perceptions that a task is too effortful (Billington, Skinner, Hutchins, & Malone, 2004).

The Principle of Least Effort suggests that when faced with a choice, an organism will choose the behavior that requires the least amount of effort on the organism's part (Billington & Ditommaso, 2003). Billington & Skinner (2002) suggested that this principle can also be applied to student choice behaviors. Because students always have a choice between complying with an assigned task and engaging in an infinite number of alternative behaviors, student perceptions of effort are crucial to their compliance with appropriate school tasks.

Both *can't do* problems stemming from a lack of prerequisite skills (i.e., failure to acquire skills) and *won't do* problems may be caused by failure to develop fluency. When faced with a task that a student *can* do, but not quickly, that student is more likely to choose not to do that task because it requires too much time and effort (Skinner, Pappas, & Davis, 2005).

Many advanced math concepts and tasks require the ability to do basic math computations (math facts). If a student is not fluent with respect to math facts, he or she often cannot perform higher level math algorithms within the given time period, a *can't do* problem. Additionally, when learning more complex tasks, a student who must expend large amounts of available cognitive resources (e.g., working memory) to perform basic tasks, may have insufficient resources available that are needed to acquire these complex concepts and tasks. Similarly, a student who is not fluent with respect to math facts may perceive math assignments requiring knowledge of math facts as too difficult and choose not to engage, a *won't do* problem. Achieving fluency is a possible solution to both of these problems. The student with the *can't do* problem who achieves fluency now *can* do the task requiring this prerequisite skill and *can* complete the task in the time allotted. The student with the *won't do* problem will be more likely to choose to engage in the assigned work if he or she can perform the task quickly and with less effort.

Procedures to Enhance Fluency

Numerous procedures have been used to increase automaticity or fluency with basic math facts (Greenwood, Delquadri, & Hall, 1989; Rhymer, Dittmer, Skinner, & Jackson, 2000; Skinner, Turco, Beatty, & Rasavage, 1989). Perhaps the most important shared characteristic of these procedures is that they occasion high rates of active, accurate responding (Greenwood, Delquadri, & Hall, 1984). Researchers have compared interventions and shown that interventions that occasion higher rates of accurate academic responding result in greater increases in fluency than those that occasion lower rates of responding (Skinner, Bamberg, Smith, & Powell, 1993; Skinner, Belfiore, Mace, Williams, & Johns, 1997).

Cover, Copy, and Compare. An example of a procedure that occasions high rates of accurate academic responding is the Cover, Copy, and Compare (CCC) strategy. This intervention has been successfully used to increase math accuracy, fluency, and maintenance of math skills in elementary and secondary students (Skinner, Turco, Beatty, & Rasavage, 1989). CCC involves a student's looking at a problem and solution, covering the problem and solution, writing the problem and solution, and then comparing his or her response with the original problem and solution. Aspects of CCC that account for its success at increasing performance include the availability of immediate feedback, high rates of accurate academic responding, and topographically similar responses to those required during assessments. Immediate feedback is important for a variety of reasons. First, immediate feedback can prevent students from practicing incorrect responses when errors are made (Goldman & Pellegrino, 1987). Additionally, immediate feedback for correct responses can serve as powerful reinforcement, increasing the probability of future correct responses (Van Houten, 1984). Thus, immediate feedback can lead to higher rates of accurate academic responding which often result in greater increases in student performance (Skinner, Bamberg, Smith, & Powell, 1993; Skinner, Belfiore, Mace, Williams, & Johns, 1997).

The third component of effective CCC may be requiring responses during the intervention that are topographically similar to those required during assessment procedures. Greenwood, Delquadri, and Hall (1984) have suggested that this practice of matching intervention response types with assessment response types may encourage higher performance gains.

Taped-Words Interventions

An intervention that has been used to enhance rapid, accurate sight-word reading is the taped-words intervention (Freeman & McLaughlin, 1984). During this intervention, audiotapes are constructed that provide words in the same sequence as written lists. Students are provided with the lists and instructed to read the word lists along with the tape. Results have shown that this procedure is effective for enhancing word list reading fluency (i.e., words read correct per minute on word lists).

In Freeman and McLaughlin's study (1984), the audiotapes presented words at a rapid rate (80 words per minute) because neurological impress or modeling theories (Cunningham, 1979; Heckelman, 1969) suggested that rapid rates of presentation may enhance students’ reading rates. Subsequent studies confirmed the effectiveness of the taped-words intervention (Shapiro & McCurdy, 1989; Skinner, Johnson, Larkin, Lessley, & Glowacki, 1995; Skinner & Shapiro, 1989; Skinner, Smith, & McLean, 1994; Sterling, Robinson, & Skinner, 1997). However, in these studies, researchers altered word presentation rates or implemented experimental procedures designed to control for opportunities to respond embedded within the taped-words intervention. Results from these studies suggest that neither neurological impress nor students' modeling the rapid pace of the tape accounted for the increases in students' accurate reading rates. Rather, these studies suggested that the opportunities to respond embedded within the intervention and provided during assessment procedures caused the increases in reading fluency (Skinner, Logan, Robinson, & Robinson, 1997).

Time Delay

Time delay procedures have been used to enhance accurate responding with individuals with various degrees of learning disabilities and mental retardation (Ault, Wolery, Doyle, & Gast, 1989). Two types of time delay procedures, constant and progressive, have been used to enhance accurate responding. Both include multiple trials consisting of a) the presentation of an antecedent stimulus, b) an interval for students to respond to that antecedent stimulus, and c) an additional stimulus or prompt that follows the antecedent stimulus when a student fails to respond accurately. Table 1 depicts this process and provides examples of how the process would work when students fail to

Table 1

Graphic Depiction of a Constant Time Delay Procedure with 5 Second Response Intervals and Examples of Procedure when Student Fails to Respond within 5 Seconds, (i.e., 1), Responds Inaccurately within 5 Seconds (i.e., 2), and Responds Accurately within the 5 Second Response Interval (i.e., 3)

Stimulus	Interval	Prompt	Response
1. Natural Antecedent Stimuli--→ (7 × 6 = ___)	Response Interval--→ 5 Seconds and no student response	Artificial Prompt--→ instructor says "7 × 6 = 42"	Student Response student repeats, "7 × 6 = 42"
2. Natural Antecedent Stimuli--→ (7 × 6 = ___)	Response Interval--→ student provides inaccurate response within 5 seconds	Artificial Prompt--→ instructor says "no 7 × 6 = 42"	Student Response student repeats, "7 × 6 = 42"
3. Natural Antecedent Stimuli--→ (7 × 6 = ___)	Response Interval--→ Student responds accurately within 5 seconds	Feedback instructor says "Yes 7 × 6 = 42" as feedback for independent accurate response	

respond within the response interval, respond inaccurately within the response interval, and respond accurately within the response interval.

With time delay, the goal is to have the student respond accurately to the antecedent stimulus. Thus, for a multiplication fact, an antecedent stimulus may be a printed problem (i.e., 7 × 6 = __). Following the presentation of the antecedent stimulus, an interval is provided for the student to respond. If the student emits a correct response during this interval, then this response is typically followed by reinforcement or praise (see Table 1, example 3). If the student responds inaccurately or fails to respond during the designated interval, an additional artificial prompt is provided that is designed to occasion an accurate response (see Table 1 examples 1 and 2). For a multiplication fact, this additional prompt may merely be stating the problem with the correct answer (e.g., the teacher says "7 × 6 = 42").

Time delay procedures initially provide students with an opportunity to *independently* respond to the antecedent stimuli (e.g., 7 × 6 = __). However, when a student fails to respond or emits an inaccurate response to the natural antecedent stimuli, the additional artificial prompt is designed to occasion subsequent accurate responses. Thus, all trials typically involve a correct response and the student's last response is almost always an accurate response.

Initially students may fail to respond accurately to the natural antecedent stimuli in the given interval. However, after repeated trials, students often begin responding correctly to the natural antecedent stimuli prior to the delivery of the artificial prompt. Thus, stimulus control is transferred from accurate responding to the artificial prompts to accurate responding to the naturally occurring antecedent stimulus. Now the student is independently emitting desired responses to naturally occurring stimuli.

When using *constant time delay*, the time provided for students to respond independently (i.e., interval between the natural antecedent stimuli and artificial prompt) remains constant across trials. Although constant time delay procedures are abundant in the literature, a modified form of the second type of time delay, *progressive time delay,* was chosen for integration into the present intervention. Progressive time delay procedures involve providing progressively shorter or longer intervals between a stimulus and a response as trials progress (Wolery, Ault, Doyle, & Gast, 1986). For example, the stimulus is shown and an individual has a very brief amount of time to respond. As time delay trials continue, this time interval is gradually increased, allowing more time for responses. When the time delay is brief, students have little time to respond before the prompt is delivered. Thus, initially a no-time delay condition can prevent students from making errors. Gradually increasing the delay during subsequent trials then allows students to respond independently, before the artificial prompt is delivered.

In contrast, time delay trials can begin with large delays that are gradually decreased. The large delays may initially increase the number of errors, but also provide students with more time to independently emit accurate responses to the naturally occurring stimuli (McCurdy, Cundari, & Lentz, 1990; Wolery, Ault, Doyle, & Gast, 1986). Gradually reducing delays then can be used to occasion more automatic responding. The current study employed an adaptation of traditional progressive time delay procedures in which an initially brief interval is first increased and then decreased as trials continue. We termed this type of procedure a *varying time delay* procedure.

Progressive time delay procedures have been used effectively to promote accurate responding across tasks and learners. McCurdy, Cundari, and Lentz (1990) found a progressive time delay procedure to be more effective in teaching sight words to students with behavior disorders than both direct instruction and observational learning. Similarly, Browder, Hines, McCarthy, and Fees (1984) successfully used a progressive time delay procedure to teach sight-word recognition and daily living skills such as answering telephones and doing laundry to a group of adults with severe handicaps. Progressive time delay procedures also have been used effectively in teaching language skills (Halle, Marshall, & Spradlin, 1979), food preparation (Schuster, Gast, Wolery, & Guiltinan, 1988), and banking skills (McDonnell & Ferguson, 1989). Most of these studies have been conducted with students with moderate or severe handicaps.

Purpose

Math teachers continuously suggest that students' inability to rapidly complete math facts hinders their ability to perform higher level math tasks (Ysseldyke et al., 2005). They further report a lack of available instructional time to be spent re-teaching students these basic skills. Thus, there is a need for interventions that may quickly increase students' math fact fluency, thereby allowing them to continue on to learning grade-level mathematics skills.

The current study was conducted to determine if the taped-words intervention could be adapted to address mathematics multiplication fact fluency deficits. In this study, each basic multiplication fact was presented four times on an audiotape. Rather than being encouraged to respond with the tape (see Freeman & McLaughlin, 1984), students were asked to try to write the correct math fact answer *before* it was provided on the tape (to try to "beat the tape").

In addition to altering the target skill, we adapted the taped-words procedure by employing varying time delays in an attempt to occasion higher rates of accurate academic responding. In the current studies, we employed both forms of progressive time delay. In an attempt to reduce error rates, initially each problem was presented on the tape with a brief time interval or delay (e.g, 1-second) between the problem being read and its answer being read. These intervals were then increased (e.g., 4-seconds) to provide opportunities for independent responding (e.g., responding before the answers were read on the tape). This also allowed students to use the audio cues as feedback to reinforce accurate independent responding and prompt error correction when responses were inaccurate (Skinner, Turco, Beatty, & Rasavage, 1989). Intervals were then decreased to encourage more rapid or automatic responding. We termed this type of time delay a *varying time delay* procedure.

All shared aspects of previously successful math fact fluency-building interventions (Greenwood, Delquadri, & Hall, 1989; Rhymer, Dittmer, Skinner, & Jackson, 2000; Skinner, Turco, Beatty, & Rasavage, 1989) were incorporated into the taped-problems intervention. Specifically, repeated trials of each math fact allowed for numerous opportunities for accurate academic responding. Immediate feedback was given following each trial of each math problem. Responses to math probes were topographically identical to those responses required during the intervention.

We attempted the taped-problems intervention on a class-wide basis with all students from a general education third-grade class. The classroom was chosen because of the low number of students who were proficient with respect to basic math (specifically multiplication) facts.

Chapter 2

Methodology

Students and Setting

Eighteen students from a general education third-grade classroom participated in this study. Eleven of the students were Caucasian, five were African American, and two were Hispanic. All students were either 8 or 9 years old. The students ranged in achievement and ability levels, however, none had been identified as needing special education classes. The classroom teacher reported that none of the students were fluent with respect to basic multiplication facts.

The current study was conducted in the students' general education classroom. During the sessions, the researcher(s), students, and the students' regular teacher were all present. Each session took approximately twenty minutes.

Materials

A tape recorder, cassette tapes, and stopwatch were used throughout this experiment. Baseline and intervention data were collected via experimenter-constructed multiplication fact probes. Basic multiplication facts 2-9 were divided into three sets (see Table 2) of 12 problems each. Multiples of one were excluded from the probes.

Twelve audiotapes were made, four for each of the three sets of problems. Tapes were constructed for each set by reading the 12 problems and their answers into the tape four times each. Problems were numbered and the number of the problem was read immediately preceding the reading of each problem. The order of problems was randomly sequenced for each of the four readings.

Table 2

The Three Sets of Multiplication Problems

Set A	Set B	Set C
3 × 3	2 × 2	2 × 4
2 × 5	2 × 7	6 × 2
2 × 8	4 × 3	2 × 9
5 × 3	3 × 6	3 × 3
3 × 8	9 × 3	3 × 7
4 × 4	4 × 5	6 × 4
4 × 9	8 × 4	4 × 7
6 × 5	5 × 7	5 × 5
6 × 7	9 × 5	5 × 8
9 × 6	6 × 6	6 × 8
7 × 7	9 × 7	7 × 8
9 × 8	8 × 8	9 × 9

All twelve tapes were constructed in the same manner based on a varying time delay format. Specifically, the series of 12 problems was read the first time through with no time delay between each problem and its answer. The second series was read with a 4-second time delay between reading each problem and reading its answer. The third series was read with a 2-second time delay between reading the problems and their answers. The final reading also included 2-second delays. Thus, each problem and answer was read 4 times. For each series, problem order was randomized.

Intervention sheets were constructed for each tape (see Appendix A for a sample intervention sheet). These sheets displayed each problem as heard on the tape and a space in which to write its answer (e.g., 7 × 6 = ____). Problems were numbered and provided in the same sequence as on the tapes.

Five different assessment packets were also constructed for each set of problems (see Appendix B for a sample assessment packet). Assessment packets contained the 12 problems with spaces provided for their answers. Each assessment probe consisted of all problems repeated four times for a total of 48 problems. This was necessary in order to ensure that students would not finish a probe before the minute was up. The problems were randomly sequenced across assessment probes, however, each problem was given once before any problem was repeated. The assessment packets were four pages long with each series of twelve problems occupying a separate page.

Dependent Measures, Experimental Design, and Conditions

A multiple-probes-across-tasks (i.e., sets of problems) design was used to evaluate the effects of the intervention (Cuvo, 1979; Horner & Baer, 1978). Percent correct (PC) and digits correct per minute (DCM) were the dependent measures used in this study. Both were measured during 1-minute timed assessment sessions. Percent correct was calculated by dividing the number of correct answers by the total number of problems answered and multiplying by 100. Unanswered problems were not scored when calculating accuracy.

Deno and Mirkin's (1977) scoring procedure was used to calculate digits correct per minute (DCM) for each assessment probe. To be scored as correct, a correct digit had to be written in the correct place. Thus for the problem $9 \times 5 =$ ____, an answer of 45 would be scored as 2 digits correct because both correct digits are in their correct places. Answers of 40, 15, or 4 would be scored as 1 digit correct and answers of 21 or 50 would be scored as 0 digits correct. Since one minute served as the time limit for all probes, digits correct per minute were calculated by totaling digits correct.

Each intervention day at 1:30 PM the primary and/or secondary experimenters entered the classroom for the intervention. This time was chosen by the teacher.

Assessment Procedures: Baseline, Probes, and Intervention. During the first three sessions (baseline phase), assessment procedures were run for each set of problems. The experimenter used a stopwatch to time each assessment for 1 minute. All students were given the three assessment packets one at a time in random order. They were directed to complete as many problems as possible in 1 minute. When the first minute was up, the students were instructed to put their pencils down and wait for the next assessment packet. The experimenter collected each set of assessment probes before providing the next set. No performance feedback was given. Instructions for all assessment probes were given verbatim as follows: "I will be timing you to see how quickly you can answer some multiplication problems. You will have one minute to complete as many problems as you can. You are not expected to finish all of the problems. Please start with problem number one and go in order. If you come to a problem you do not know, take your best guess and go on to the next problem. Try your best and I will tell you when to stop. Ready? Begin."

Following the initial three baseline sessions, the students' performance on the target set (i.e., the set of items being addressed with the taped-problems intervention) was assessed each session prior to the actual intervention (the tape). The non-target sets were not assessed on these days. Instead, assessments for these problem sets were probed (i.e., administered prior to the implementation of a new list). This intermittent assessment procedure was used to decrease the probability of students becoming frustrated by having to work on problems that were not being targeted during the current intervention phase (Cuvo, 1979). Probe procedures also allowed for the collection of maintenance data.

Intervention phases: Taped-problems intervention. Following the third baseline session, the first intervention session was run with Problem Set A. After the regular baseline assessment packets were collected, the students were given intervention sheets for the first tape of Set A. The packets listed the problems in the numbered order that they would be heard on the tape.

The students were told that they were going to listen to a tape-recorder. They were instructed to look at their intervention sheets and follow along with the tape that would supply the problems and answers. They were instructed to try to write the answer to each problem following its reading but before the reading of the answer. Thus, students were encouraged to try to "beat the tape". If they wrote an incorrect response, students were instructed to write a slash on the incorrect answer and write the correct response as heard on the tape. If they failed to beat the tape, they were instructed to write the correct answer after its reading. Specific instructions were given verbatim as follows: "You will be listening to a tape with multiplication problems and answers. Follow along on your sheet and try to write the answer to each problem before it is spoken on the tape. If you write a wrong answer, mark through it with a slash and write the correct answer as you hear it on the tape. If an answer is given before you can come up with it on your own, write the correct answer as it is said on the tape. Try your best to beat the tape but do not skip ahead. When the tape is over, I will collect the sheets. Ready? Begin." After students indicated that they understood the instructions (by raising their hands), the researcher began the tape. The researcher walked around the classroom and monitored the students during the intervention session. When the tape ended, the researcher stopped it and collected the follow-along sheets.

Following the tape, the students were given another assessment probe for the specific problem set they were working on (i.e. Set A). This probe was randomly selected from the various forms, with one exception: the probe given during the pre-intervention assessment that day was excluded from the selection process. The same timing procedures and directions used during baseline were used with this probe.

Data from probes following intervention sessions (listening to the tapes) were not the primary dependent variable for this study. Instead, these assessment probes were designed to allow students the opportunity to independently practice items just drilled. In summary, following the first intervention session, each session included a) assessment probe, used to collect data for the dependent variable, b) the taped-problems intervention, and c) another assessment probe to allow students to practice problems they had just been exposed to. Thus, the primary dependent variable was DCM on assessment probes that occurred at least 23 hours after each intervention sessions. See Table 3 for a complete chart of baseline, intervention, and assessment activities by session.

After four intervention sessions working on a set of problems, the tape was switched and similar procedures were run with the subsequent tape targeting the next set of problems. On most days, before beginning the taped-problems intervention, assessment procedures were run for only the set targeted. This allowed for a 23-hour delay between practicing with the tape and completing the probe which would serve as the dependent variable. However, the days before a new tape was begun, assessments were conducted for all three sets of problems (multiple-probes, see Cuvo, 1979). During the final session, all three sets were again assessed to check for maintenance of set A and B items.

Data Analysis and Procedures

Visual analysis of time-series graphs was used to evaluate the effectiveness of the taped-problems intervention by comparing the class's daily mean digits correct per minute (DCM) and percentage correct (PC) across baseline, intervention, and maintenance phases. Additionally, effect sizes were calculated by comparing baseline and intervention phase data (Busk & Marascuilo, 1992). Individual student mean data across phases is also reported and described.

Interobserver Agreement and Procedural Integrity

A second observer sat in the classroom and collected procedural integrity data during three of the 16 intervention sessions (19%). During these intervention sessions,

Table 3

Baseline, Intervention, and Assessment Activities by Session

Session	Activities
1-3	Assess Sets A, B, C: Baseline (Dependent Variable)
4	Intervention: Tape A Assess Set A (Not DV)
5-6	Assess Set A (DV) Intervention: Tape A Assess Set A (Not DV)
7	Assess Sets A, B, C (DV) Intervention: Tape A Assess Set A (Not DV)
8	Intervention: Tape B Assess Set B (Not DV)
9-10	Assess Set B (DV) Intervention: Tape B Assess Set B (Not DV)
11	Assess Sets B, C (DV) Intervention: Tape B Assess Set B (Not DV)
12	Assess Sets A, B (DV) Intervention: Tape C Assess Set C (Not DV)
13-15	Assess Set C (DV) Intervention: Tape C Assess Set C (Not DV)
16	Assess Sets A, B, C (DV)

the independent observer recorded the presence or absence of 16 experimenter behaviors (see Appendix C). Results showed 100% integrity. Additionally, during one baseline session, the observer recorded the experimenter completing steps 1-6 three consecutive times and step 16 at the end of the session. These data suggest strong procedural integrity.

The second experimenter also independently scored digits correct per minute and percentage correct for three sets of probes from one baseline session and two sets from two intervention sessions (5 sets or 19% of the probes). Interscorer agreement was calculated by dividing the number of agreements on digits correct by the number of agreements plus disagreements and multiplying by 100. Interscorer agreement on digits correct was 96%. Interscorer agreement for percentage correct was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100. Interscorer agreement for percentage correct was 98%.

Chapter 3

Results

Digits Correct per Minute

Visual analysis. Figure 1 displays the class's daily average DCM data across phases and sets of problems. During the intervention phase, two sets of data are graphed: the class's daily average performance immediately following the intervention and the class's daily average performance the next day prior to the next intervention tape session (23-hour delayed DCM). The delayed DCM data served as the primary dependent variable for the current study.

Visual analysis of baseline data across the three sets of problems shows slightly increasing trends in DCM across the first two baseline sessions. On the third day of baseline, DCM slightly decreased for Set A. For Sets B and C baseline data show a slight increasing trend. However, for Sets B and C there was no evidence for an increase in DCM after the intervention was applied to the other sets of problems. These baseline data suggest that history effects (i.e., some other event that occurred concomitantly with the application of the intervention) did not confound treatment effects. Furthermore, these baseline phase data suggest that spillover effects (i.e., the treatment caused increases in DCM on items assigned to the untargeted sets) were controlled.

Visual analysis of performance on immediate assessments (open squares on Figure 1) shows an increase in DCM for each set of problems immediately following the application of the intervention. Additionally, immediate assessment data show an increasing trend for all three sets of problems during the four days of each intervention phase with DCM on the final day of treatment exceeding 16 DCM for all three sets of

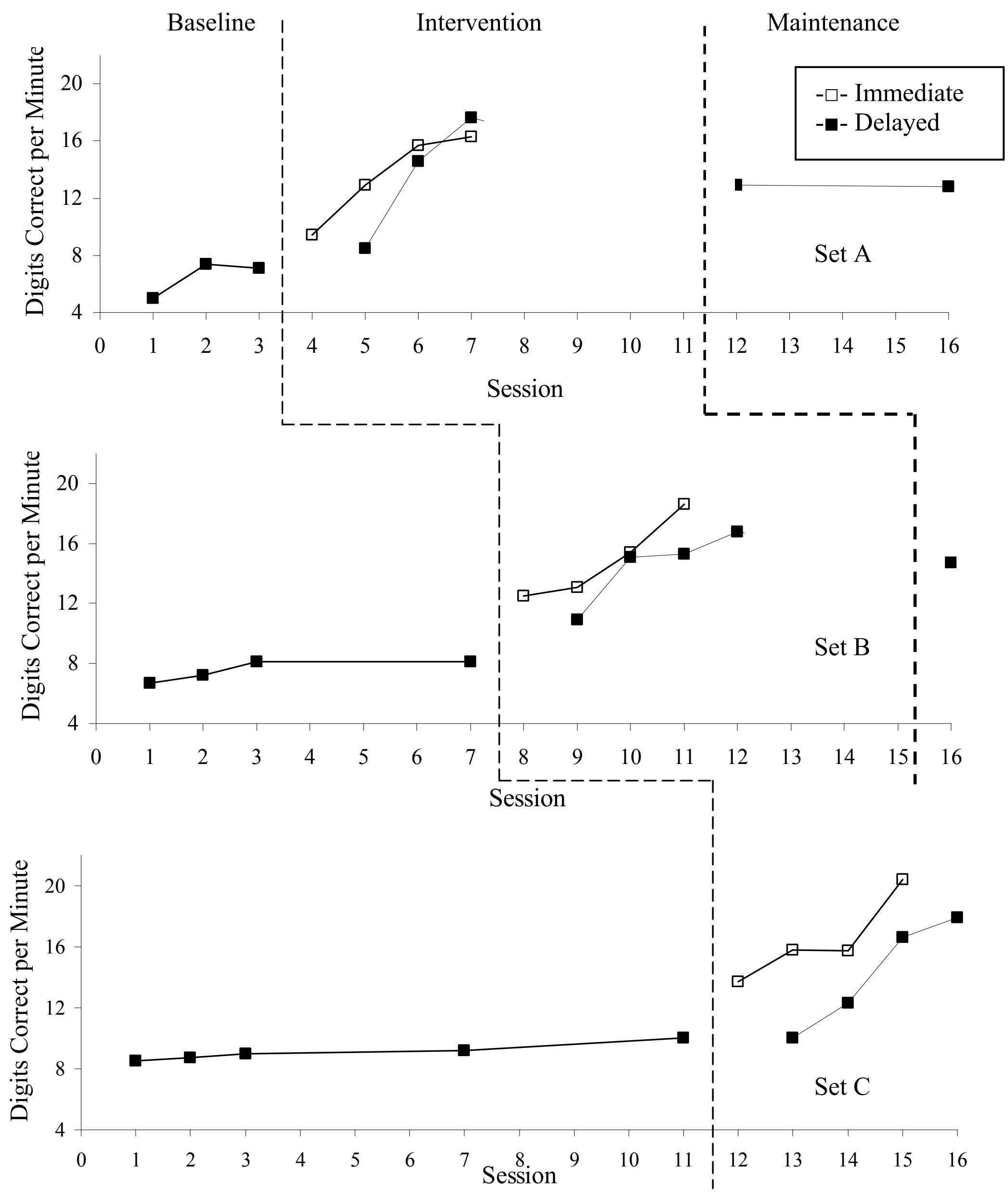

Figure 1: Mean DCM across Baseline, Intervention, and Maintenance Phases

These immediate assessment data suggest the intervention caused an increase in DCM.

The primary dependent variable for this experiment was DCM on probes collected almost 24 hours after the intervention was implemented (i.e., closed squares during the intervention and maintenance phases). Figure 1 shows that performance on these 23-hour delay probes showed a less immediate treatment effect than probes taken immediately following the intervention each day (open squares). Additionally, for all but one data point, the DCM increases were less for the delayed than the immediate probes. However, across all three sets of problems, the trend data for these 23-hour delay probes show steady increases in DCM over intervention phases.

Figure 1 shows a slight decrease (relative to the last intervention point) in DCM during maintenance checks for Problem Sets A and B. However, for both sets, maintenance data showed sustained increases in DCM over baseline performance.

Statistical Analyses. Tables 4, 5, and 6 display the phase means and standard deviations during baseline, intervention (both immediate and delayed), and maintenance phases for Sets A, B, and C respectively (no maintenance data for Set C). Effect size data comparing baseline with immediate and delayed intervention phase data is also presented in these tables. Effect sizes were calculated by taking the difference of the average mean DCM of baseline and intervention (including maintenance) phases and dividing by the mean baseline standard deviation.

Table 4 shows that for Set A, baseline data averaged 6.5 DCM. During the intervention phase, this average more than doubled for both the immediate assessments

Table 4

Problem Set A Mean Digits Correct per Minute and Effect Sizes Across Phases

	Baseline	Intervention		Maintenance
		Immediate	Delayed	
Mean	6.5	13.6	13.3	12.9
Standard Deviation	1.3	3.2	3.3	.1
Effect Size		5.5	5.2	

Table 5

Problem Set B Mean Digits Correct per Minute and Effect Sizes Across Phases

	Baseline	Intervention		Maintenance
		Immediate	Delayed	
Mean	7.5	14.9	14.6	14.7
Standard Deviation	.7	2.8	2.2	0
Effect Size		10.6	10.1	

Table 6

Problem Set C Mean Digits Correct per Minute and Effect Sizes Across Phases

	Baseline	Intervention	
		Immediate	Delayed
Mean	9.1	16.4	14.2
Standard Deviation	.6	2.8	3.7
Effect Size		12.2	8.5

(x = 13.6) and the 23-hour delayed assessments (x = 13.3). Maintenance data further show that these DCM increases could still be seen two weeks following the removal of the intervention targeting Problem Set A (x = 12.9). Effect sizes comparing baseline to immediate assessments show a large (according to Cohen, 1992) increase in DCM (ES = 5.5). Effect size data comparing baseline to the 23-hour delay data similarly show a large increase in DCM (ES = 5.2).

Table 5 shows that for Problem Set B, baseline data averaged 7.5 DCM. During the intervention phase, this average nearly doubled for both the immediate assessments (x = 14.9) and the delayed assessments (x = 14.6). Data taken 1 week after the intervention no longer targeted this set of problems show that increases in DCM were maintained (x = 14.7). Effect sizes comparing baseline to immediate and delayed assessment data show large DCM increases (ES = 10.6 and 10.1 respectively).

Table 6 displays Problem Set C data. No maintenance data is available for this set of problems. Baseline data for Set C averaged 9.1 DCM. During intervention, this average increased for both immediate (x = 16.4) and 23-hour delayed assessments (x = 14.2). Effect sizes comparing baseline with immediate and delayed assessment averages show large DCM increases (ES = 12.2. and 8.5 respectively).

During baseline, DCM class means were 6.5, 7.5, and 9.1 for Problem Sets A, B, and C respectively. Deno and Mirkin (1977) define the frustration level for third-graders as between 0 and 9 DCM, the instructional level between 10 and 19, and the mastery level above 20. Thus, all three Problem Set averages fell within the frustration level, indicating performance below that which would be expected based on grade level.

During the intervention phase, the class's average DCM increased across all three sets of problems to the instructional level (i.e., 13.3, 14.6, and 14.2 DCM for delayed assessments for Sets A, B, and C respectively). Additionally, ES data suggest that these increases were large.

Individual student performance. Table 7 displays the average baseline and delayed intervention data for the 18 students across all three sets of items for DCM and PC respectively. Included in these tables is an overall average baseline and delayed intervention mean for each student. These data were calculated by taking the means of each student's three baseline and delayed intervention scores (from the three Problem Sets). Using Shapiro's (1996) criteria for frustration, instructional, and mastery levels, each student's DCM is categorized for both baseline and delayed intervention means (represented by an F, I, or M following each DCM score).

Table 7 shows that for Problem Set A, all 18 students' mean DCM scores increased from baseline to intervention phases. For Problem Set B, 17 students' mean DCM increased and one remained the same across conditions. For Problem Set C, 15 students' mean DCM increased and three decreased from baseline to intervention phases. For Problem Sets A and B, while 16 and 14 students' baseline DCM means fell within the frustration level respectively, for both of these sets of problems, only 5 students' DCM means remained in the frustration level (Deno & Mirkin, 1977) following the implementation of the intervention. For Problem Set C, while 13 students' baseline DCM means fell in the frustration level, only 6 students remained at this level after the introduction of the intervention to this problem set. Overall baseline DCM averages across the three sets of problems placed 15 students at the frustration level and 3 at the

Table 7

Individual Student Baseline and Delayed Intervention Mean DCM Across Problem Sets and Overall

	Set A				Set B				Set C				Overall			
Student	Baseline		DI		Baseline		DI		Baseline		DI		Baseline		DI	
1	4.2	F	10.5	I	5.8	F	12.5	I	9.3	F	8.5	F	6.4	F	10.5	I
2	16.8	I	21.4	M	17.5	I	21.5	M	17.2	I	21.7	M	17.2	I	21.5	M
3	22.0	M	26.4	M	15.8	I	26.4	M	21.4	M	29.8	M	19.7	I	27.5	M
4	4.7	F	14.0	I	6.5	F	16.0	I	8.2	F	10.5	I	6.5	F	13.5	I
5	0.8	F	1.3	F	1.0	F	2.7	F	1.0	F	1.8	F	.9	F	1.9	F
6	3.5	F	5.8	F	2.8	F	4.3	F	3.4	F	4.5	F	3.2	F	4.9	F
7	6.8	F	36.0	M	10.3	I	10.3	I	12.5	I	6.3	F	9.9	F	17.5	I
8	4.5	F	5.8	F	4.3	F	7.8	F	6.8	F	5.3	F	5.2	F	6.3	F
9	5.8	F	17.0	I	7.0	F	17.8	I	8.0	F	19.3	I	6.9	F	18.0	I
10	3.3	F	13.0	I	3.7	F	24.2	M	8.3	F	12.5	I	5.1	F	16.6	I
11	3.3	F	11.8	I	7.5	F	13.8	I	6.8	F	16.8	I	5.9	F	14.1	I
12	4.0	F	8.0	F	7.0	F	9.8	F	8.8	F	10.8	I	6.6	F	9.5	F
13	7.3	F	12.0	I	8.3	F	15.6	I	13.2	I	29.5	M	9.6	F	19.0	I
14	1.3	F	3.0	F	4.8	F	5.7	F	2.2	F	5.5	F	2.8	F	4.7	F
15	8.0	F	11.5	I	5.5	F	16.3	I	9.8	F	14.8	I	7.8	F	14.2	I
16	6.0	F	11.4	I	9.0	F	14.3	I	8.8	F	20.3	M	7.9	F	15.3	I
17	9.0	F	17.6	I	13.3	I	21.3	M	11.5	I	19.0	I	11.3	I	19.3	I
18	4.0	F	12.6	I	4.0	F	13.8	I	3.0	F	13.5	I	3.7	F	13.3	I

instructional level. Overall delayed intervention DCM means place 5 students at the frustration level, 11 at the instructional level, and 2 at the mastery level.

Summary of DCM analysis. Visual analysis of Figure 1 suggests that the taped problems intervention caused an immediate and steady increase in the class's average DCM. Furthermore, these increases appear to be maintained over 23 hours and over weeks (e.g., see Set A and B final maintenance data points). Effect size data suggest that these increases were large. Finally, analyses of individual student data suggest that the intervention was effective for almost all students in the class.

Percentage Correct

Visual analysis. Figure 2 displays the class's daily average PC data across phases and sets of problems. During the intervention phase two sets of data are graphed: the class's daily average performance immediately following the intervention (immediate assessments) and the class's daily average performance the next day prior to the next intervention session (23-hour delayed assessments).

Visual analysis of baseline data across the three sets of problems shows an increasing trend in PC during Problem Set A's baseline phase. Set B had the most variable baseline PC data points, with a decrease following the first point and then an increase and another slight decrease. Set C showed an overall increasing trend for PC across baseline. Visual analysis of Figure 2 shows that following the first day of intervention (23-hour delay assessments or closed squares), PC decreased for each set of items. However, for all three sets of problems, there was an increasing trend in PC data (closed squares) immediately thereafter. Figure 2 shows a slight decrease in PC during

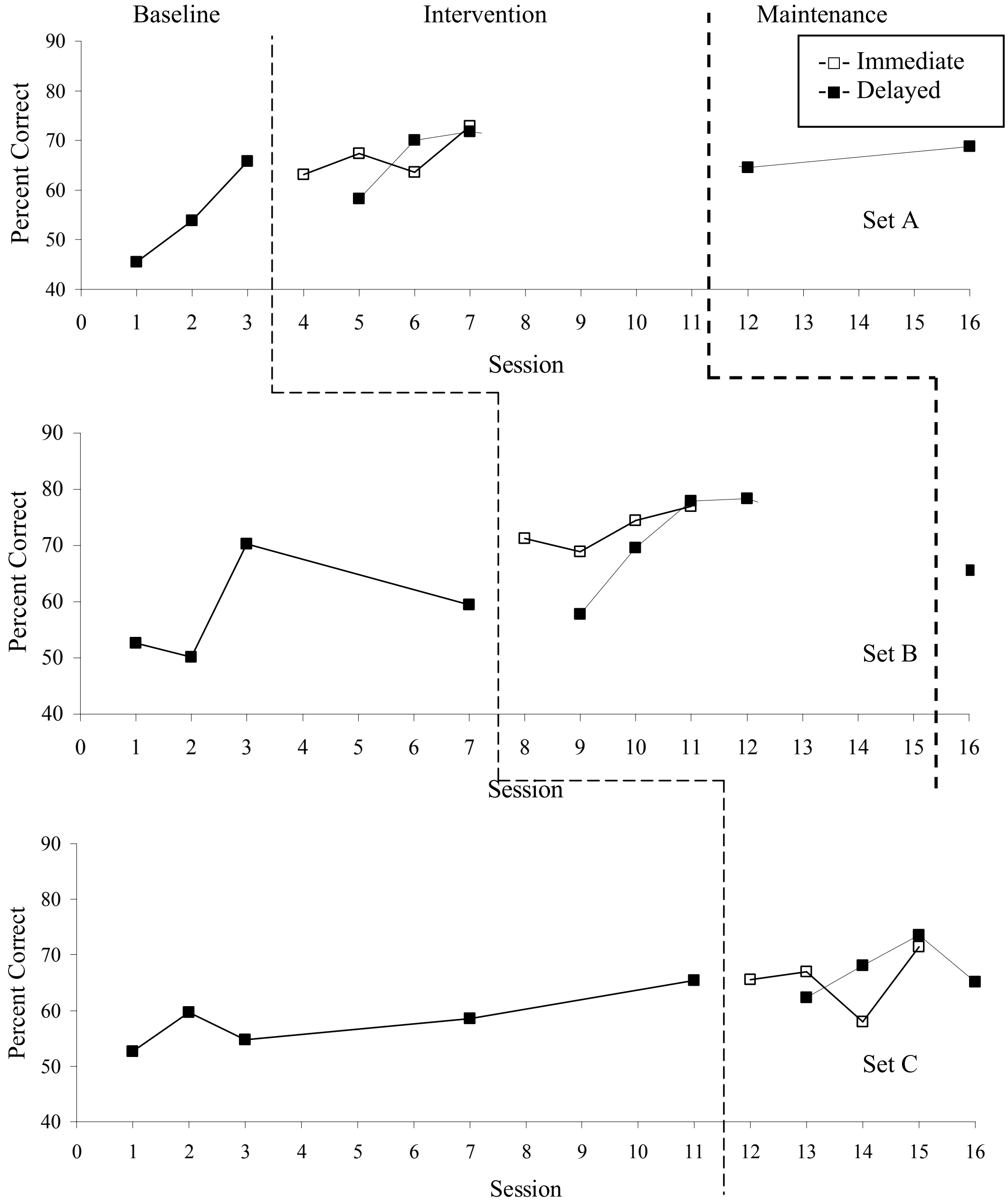

Figure 2: Mean PC across Baseline and Intervention Phases

maintenance checks for Problem Sets A and B. However, for both Sets, maintenance data showed sustained increases in PC over baseline.

Visual comparisons of immediate (open squares) and 23-hour delayed assessments (closed squares) indicate that for Sets A and C, immediate and delayed PC means were similar (much overlap among points). For Set B, immediate assessments showed a quicker and steeper increase in PC over baseline. These increasing trends in PC data during baseline prevent drawing conclusions regarding the effectiveness of the intervention for increasing accuracy. However, they do suggest that the intervention did not cause a decrease in accuracy.

Statistical Analyses. Tables 8, 9, and 10 display the class PC means and standard deviations for the three Problem Sets during baseline, intervention (both immediate and delayed), and maintenance phases for Sets A, B, and C respectively (no maintenance data for Set C). Effect size data comparing baseline with immediate and delayed intervention phase data is also presented in these tables.

Table 8 shows that for Set A, baseline data averaged 55.1 PC. During the intervention phase, this average increased for both the immediate assessments (x = 66.8) and the 23-hour delay assessments (x = 66.7). Maintenance data further show that these PC increases could still be seen 2 weeks following the removal of the intervention targeting Problem Set A (x = 66.6). Effect sizes comparing baseline to immediate assessments show a large (according to Cohen, 1992) increase in PC (ES = 1.2). Effect size data comparing baseline to the 23-hour delay data similarly show a large increase in PC (ES = 1.1).

Table 8

Problem Set A Mean Percentages Correct and Effect Sizes Across Phases

	Baseline	Intervention		Maintenance
		Immediate	Delayed	
Mean	55.1	66.8	66.7	66.6
Standard Deviation	10.2	4.5	5.4	3.0
Effect Size		1.2	1.1	

Table 9

Problem Set B Mean Percentages Correct and Effect Sizes Across Phases

	Baseline	Intervention		Maintenance
		Immediate	Delayed	
Mean	58.1	72.9	69.9	65.6
Standard Deviation	9.0	3.5	8.7	0
Effect Size		1.6	1.3	

Table 10

Problem Set C Mean Percentages Correct and Effect Sizes Across Phases

	Baseline	Intervention	
		Immediate	Delayed
Mean	58.2	65.5	67.3
Standard Deviation	4.9	5.6	4.8
Effect Size		1.5	1.9

Table 9 shows that for Problem Set B, baseline data averaged 58.1 PC. During the intervention phase, this average increased for both the immediate assessments (x = 72.9) and the delayed assessments (x = 69.9). Maintenance data taken 1 week after the intervention no longer targeted Problem Set B show that PC increases remained (x = 65.6). Effect sizes comparing baseline to immediate and delayed assessment data show large PC increases (ES = 1.6 and 1.3 respectively).

Table 10 displays Problem Set C PC data. No maintenance data is available for this set of problems. Baseline data for Set C averaged 58.2 PC. During intervention, this average increased for both immediate (x = 65.5) and 23-hour assessments (x = 67.3). Effect sizes comparing baseline with immediate and delayed assessment averages show large PC increases (ES = 1.5. and 1.9 respectively).

During baseline, PC class means were 55.1, 58.1, and 55.2 for Problem Sets A, B, and C respectively. All three of these averages fell within the failing range (below 60 percent) based on a traditional grading scale. During the intervention phase, the class's average PC increased across all three sets of problems to the passing range (i.e., 66.7, 69.9, and 67.3 percent for delayed assessments for Sets A, B, and C respectively).

Individual Student Data

Table 11 displays the individual student PC means for baseline and intervention conditions for all three Problem Sets and overall means. For Problem Set A, seven students' mean PC decreased from baseline to intervention while the other eleven students' means increased. Four student PC means decreased for Problem Set B while fourteen individual PC means increased. For Problem Set A, six PC means decreased from baseline to intervention phases while twelve means increased. Fourteen students'

Table 11

Individual Student Baseline and Delayed Intervention Mean PC Across Problem Sets and Overall

	Set A		Set B		Set C		Overall	
Student	Baseline	DI	Baseline	DI	Baseline	DI	Baseline	DI
1	44.3	41.8	58.0	69.3	53.3	59.5	51.9	56.9
2	75.7	86.0	68.5	78.3	68.6	79.7	70.9	81.3
3	90.7	93.8	81.3	93.4	96.8	96.3	89.6	94.5
4	29.3	90.0	48.1	97.6	69.8	100.0	49.1	95.9
5	8.3	3.3	11.3	11.7	6.3	8.0	8.6	7.7
6	28.7	19.8	20.0	41.8	5.6	7.5	18.1	23.0
7	54.3	89.0	76.5	43.3	54.3	21.3	61.7	51.2
8	21.5	7.2	6.3	41.8	26.8	8.5	18.2	19.2
9	100.0	97.3	86.8	94.8	92.6	96.3	93.1	96.1
10	50.0	92.0	64.0	96.2	67.0	84.5	60.3	90.9
11	19.2	97.0	74.0	92.3	67.0	100.0	53.4	96.4
12	27.0	66.3	59.7	77.0	73.0	75.5	53.2	72.9
13	48.0	48.8	79.5	54.8	79.4	72.5	69.0	58.7
14	38.0	62.8	35.6	29.0	17.0	97.3	30.2	63.0
15	66.7	76.3	82.5	78.3	79.6	84.0	76.3	79.5
16	50.0	78.2	69.0	70.3	81.0	72.8	66.7	73.8
17	100.0	81.6	77.7	84.3	77.0	52.7	84.9	72.9
18	67.0	55.4	29.0	58.4	7.7	63.8	34.6	59.2

overall PC means increased from baseline to delayed intervention while the other four decreased.

Summary of PC analysis. Effect size analysis suggests that the intervention caused an increase in accuracy. Additionally, analyses of individual student PC data suggest that this increase occurred for most of the students. However, these statistical procedures (e.g., analysis of mean differences across phases) do not take into account trend data.

Visual analysis of the graphed time series data show clear increasing trends in PC during baseline across each set of items. Because visual analysis allows for an evaluation of trends (e.g., what might have occurred if the intervention were not implemented), it can prevent research from drawing erroneous conclusions. In the current study, this visual analysis prevents us from concluding that the intervention was effective (based on statistics) for increasing student accuracy.

Student and Teacher Acceptability.

Table 12 reports student acceptability responses taken on the final day of the intervention. Students were given experimenter-written questionnaires and asked to read along as the researcher read the questions aloud. Students either marked yes, no, or maybe for each question.

The teacher also filled out an experimenter-written acceptability questionnaire (Table 13) 2 weeks after the intervention ended. This rating form used a six point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (6). The teacher answered ‘strongly agree’ to all questions except numbers 1 and 8 to which she answered ‘agree’.

Table 12

Children's Rating Form Results

	No	Maybe	Yes
1. Learning my multiplication tables with the tape was fun.	2	1	14
2. I became better at my multiplication tables.	1	2	14
3. I get more answers right now than I did before.	1	3	13
4. I am faster at my multiplication tables.	2	1	14
5. My friends would like learning math this way.	1	4	12

Table 13

Teacher Acceptability Rating Form

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
1. This intervention was an acceptable way to increase students' math fact accuracy and speed.	1	2	3	4	5	6
2. I would recommend this intervention to other teachers.	1	2	3	4	5	6
3. I noticed a positive change in my students' math fact knowledge.	1	2	3	4	5	6
4. I noticed a positive change in my students' math fact speed.	1	2	3	4	5	6
5. I would be willing to use this intervention again in the future.	1	2	3	4	5	6
6. This intervention is appropriate for a variety of students.	1	2	3	4	5	6
7. I liked the procedures used in this intervention.	1	2	3	4	5	6
8. The intervention will produce lasting improvements in the students' math fact skills.	1	2	3	4	5	6
9. The students enjoyed the intervention.	1	2	3	4	5	6
10. This intervention will not result in negative side-effects for the students' performance.	1	2	3	4	5	6
11. Overall, this intervention was beneficial to the students.	1	2	3	4	5	6
12. This intervention is a time-efficient way to work on math facts.	1	2	3	4	5	6

Chapter 4

Discussion

Students who can perform basic mathematics operations both rapidly and accurately may a) be more likely to choose to do additional mathematics tasks, b) learn advanced mathematics concepts and tasks more rapidly and with less effort, and c) be less likely to have mathematics anxiety than student who can perform basic operations accurately but slowly (Skinner, Pappas, & Davis, 2005, Cates & Rhymer, 2003). The current study was designed to determine if the taped-problems intervention would increase multiplication fact fluency in third-grade students. Both visual and statistical analyses of results suggest that this class-wide intervention caused rapid, large (see ES data), and sustained increases in fluency (i.e., DCM). Additionally, the teacher and the majority of the students rated the intervention favorably.

The current study supports the use of the taped-problem intervention for increasing student mathematics fact fluency. Additionally, the current findings and methodological limitations associated with this study suggest directions for future applied and theoretical research.

Internal Validity

Previous researchers have shown that the taped-words intervention is an effective procedure for enhancing word list reading fluency (e.g., Freeman & McLaughlin, 1984; Shapiro & McCurdy, 1989). In the current study, we modified the taped-words procedures to target third-graders' multiplication fact fluency and incorporated a form of progressive time delay we called varying time delay.

Traditional time delay procedures have employed either a constant or a progressive model of delivering stimuli, prompts, and opportunities for responses (Wolery, Ault, Doyle, & Gast, 1986). Constant time delay procedures do not alter the interval between the natural antecedent stimuli and the artificial prompt across trials. Progressive time delay procedures either gradually increase or gradually decrease the response interval as the trials progress. Gradually increasing the interval allows students more opportunities to independently respond to the stimulus before the prompt is given. Gradually decreasing the interval can encourage more automatic student responses.

During the current study, we employed a varying time delay procedure, starting with a brief delay, increasing the delay, and then decreasing the delay. We used an initial brief delay to reduce errors and gradually lengthened the delays to provide student opportunities to respond and immediate feedback on the accuracy of those responses. These procedures are fairly typical with progressive time delay, however we then reduced the delays to encourage and prompt automatic responding. This was done to prevent students from using strategies (e.g., finger counting) that often allow students to arrive at accurate answers but retard the development of automatic responding (Poncy, Skinner, & O'Mara, in press).

Although there are theoretical justifications for our varying time delay procedures, the effects of each component (i.e., shorter delay, longer delay, then shorter delay) were not assessed or measured in isolation. Future research should conduct component analysis studies to determine the effects of each time delay component and the interaction of these components. Treatment comparison studies should also be conducted to assess interaction effects and identify which sequence of delays is most effective.

Researchers have found that rate of word presentation during the taped-words intervention impacts learning. Specifically, in some instances the longer the delay between word presentations, the greater the number of words learned (Cunningham, 1979; Heckelman, 1969). However, because this procedure also lengthened the time required to complete the intervention, actual learning rates were depressed when the intervals between words were increased (Skinner, Belfiore, & Watson, 1995/2002). Thus, future research conducting treatment comparison and component analysis studies should include measures that take into account the amount of learning over more precise measures of instructional time as such studies will reveal the most efficient procedure for enhanced performance. For example, brief delays may enhance learning rates because they allow for more opportunities to respond.

Altering response topography may also enhance learning rates (Skinner, Belfiore, Mace, Williams, & Johns, 1997). In the current study, students wrote their responses. Future research should determine if altering the taped-problems responses to verbal or sub-vocal responses would be equally, or more effective (Skinner, Bamberg, Smith, & Powell, 1993) as such procedures would take less time.

In the current study, the immediate assessment procedures allowed for a clearer evaluation of treatment effects (i.e., immediate effects were not influenced by events that occurred during the 23-hour delay). However, because we were more concerned with occasioning sustained increases in fluency, the primary dependent variable was DCM 23 hours following each intervention session. Although the current data suggests that the taped-problem intervention caused the increases in DCM, the immediate assessment procedures may have contributed to this increased performance (Greenwood, Delquadri, & Hall, 1984). Future research evaluating these and similar procedures should determine if providing opportunities to respond independently immediately after the intervention enhances the effectiveness of the intervention.

External Validity

Future research studies designed to evaluate the external validity of the current findings should also be conducted. Specifically, research studies designed to assess generalizability across settings, dependent variables, and students are needed.

Although researchers were present throughout the intervention, the taped-problems intervention is designed so that students need little if any assistance implementing the intervention. As is, the intervention requires little teacher involvement beyond starting and stopping a tape recorder and distributing and collecting math sheets. Thus, future research studies should be conducted under conditions that may be more reflective of typical educational environments (i.e., teacher implements all procedures). Additionally, acceptability studies following these interventions to better gauge teachers' willingness to implement the taped-problem intervention are needed.

The taped-problems procedure can be modified for use by individual students. The procedure can target specific items (e.g., math problems) for each student, allowing students to work on different sets of items depending on their individual skill levels. When working individually, students could use headphones to avoid disturbing their classmates. Thus, future research should determine if the taped-problems intervention would be effective when used in learning centers where students work independently.

The current intervention offers a low-tech means for increasing multiplication fact fluency that can be modified to require little or no teacher involvement. Computer software could be developed to enhance the effectiveness and efficiency of the program. Specifically, intervals could be altered based upon a student's pattern of responding to specific items. A student who responded rapidly and automatically to a specific item for three trials would have a short delay the next time the item was provided. However, for the same student, the delay may be longer for a particular item (e.g., math problem), which he/she responded to inaccurately over the last few trials. More advanced technology (e.g., computers) could quickly alter the delay interval on an item-by-item basis dependent upon the student's previous pattern of responding. Future research should determine if such modifications could enhance the effectiveness of the taped-problems procedure and other time delay interventions.

While the primary goal of the current study was to increase math fact fluency, a secondary goal was to increase accuracy. Visual analysis of baseline phase data showed that the class's mean PC was increasing before the intervention was introduced. Even though statistical analyses indicated significant gains in PC, these increases could not be attributed to the intervention because of the baseline increasing trends. Therefore, conclusions about the effectiveness of the current intervention at increasing accuracy cannot be drawn from the current data. Future research might evaluate the taped-problems intervention's ability to improve math fact accuracy.

Enhancing basic computation fluency may reduce math anxiety, enhance the probability of students choosing to engage in mathematics tasks, and reduce the time and effort required to learn and complete more advanced mathematics tasks (Skinner, Pappas,

& Davis, 2005). Future longitudinal studies should be conducted to determine if the taped-problems intervention can be used to enhance fluency and prevent future problems related to mathematics achievement.

Time delay procedures have been shown to be effective for increasing accurate responding across a variety of tasks. Future research is needed to determine if the taped-problems intervention could be used to increase learning in other areas including letter and number identification, phonemic awareness skills, word learning, other basic math facts, and geography.

In the current study, analyses of individual student data suggested that most students learned, but some did not. Future research should attempt to identify why this occurred in order to a) identify procedures that allow educators to determine which students are most likely to benefit from the taped-problem intervention, b) modify the intervention so more students benefit, and/or c) supplement the intervention so all students benefit. For example, future research should determine if specific procedures are more effective with specific students depending upon each student's level of skill development.

In the current study, the majority of students reported that they liked this method of learning math facts. A few, however, reported that they did not find this method acceptable. These acceptability data may be useful in matching appropriate interventions with individual students. Because students may be less likely to perform desired behaviors when they find an intervention unacceptable (Skinner & Smith, 1992), these acceptability studies may prove critical for developing effective self-managed learning procedures such as the taped-problem intervention. Thus, future research should assess student acceptability to identify interventions that are acceptable to the greatest number of students (Turco & Elliott, 1986).

Research should also assess the effects of the taped-problems intervention across students with learning problems (e.g., students with learning disabilities, mental retardation, ADD). Researchers may find that adaptations to the procedure could enhance learning across different types of students. For example, students who have difficulty sustaining their attention may learn more when the time delays are reduced. However, students who tend to respond slowly, but have little difficulty sustaining their attention may learn best when the delays are longer.

Summary

School psychologists have been charged with preventing and remedying student problems through the application of empirically validated interventions (Kratochwill & Stoiber, 2002; Stoiber & Kratochwill, 2000). The current study showed that the taped-problems intervention was an effective procedure for enhancing the multiplication fact fluency of students in a general education third-grade class. Researchers should continue to contribute to the development of effective interventions by conducting additional studies designed to increase the effectiveness and efficiency of the taped-problems interventions and assess the external validity of this intervention. Via such efforts, school psychologists can help prevent and remedy student problems.

References

References

Ault, M. J., Wolery, M., Doyle, P. M., & Gast, D. L. (1989). Review of comparative studies in the instruction of students with moderate and severe handicaps. *Exceptional Children, 55,* 346-356.

Billington, E. J., & Ditommaso, N. M. (2003). Demonstrations and applications of the matching law in education. *Journal of Behavioral Education, 12,* 91-104.

Billington, E. J., & Skinner, C. H. (2002). Getting students to choose to do more work: Evidence of the effectiveness of the interspersal procedure. *Journal of Behavioral Education, 11,* 105-116.

Billington, E. J., Skinner, C. H., Hutchins, H. M., & Malone, J. C. (2004). Varying problem effort and choice: Using the interspersal technique to influence choice towards more effortful assignments.

Browder, D. M., Hines, C., McCarthy, L. J. & Fees, J. (1984). A treatment package for increasing sight-word recognition for use in daily living skills. *Education and Training of the Mentally Retarded, 19,* 191-200.

Busk, P. L. & Marascuilo, L. A. (1992). Statistical analysis in single-case research: Issues, procedures, and recommendations, with applications to multiple behaviors. In T. R. Kratochwill & J. R. Levin (Eds.), *Single case research design and analysis* (pp. 159-185). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cates, G. L., & Rhymer, K. N. (2003). Examining the relationship between mathematics anxiety and mathematics performance. An instructional hierarchy perspective. *Journal of Behavioral Education, 12,* 23-34.

Cohen, J. (2003). A power primer. In A. Kazdin (Ed.), *Methodological issues &*

strategies in clinical research (pp. 427-436). Washington, D.C.: American Psychological Association.

Cunningham, J. W. (1979). An automatic pilot for decoding. *The Reading Teacher, 32*, 420-424.

Cuvo, A. J. (1979). Multiple-baseline design in instructional research: Pitfalls of measurement and procedural advantages. *American Journal of Mental Deficiency, 84*, 219-228.

Deno, S. L., & Mirkin, P. K. (1977). *Data-based program modification: A manual*. Reston, VA:Council for Exceptional Children.

Fleischner, J., Garnett, K., & Shepherd, M. (1982). Proficiency in arithmetic basic fact computation of learning disabled and nondisabled children. *Focus on Learning Problems in Mathematics, 4,* 47-56.

Freeman, T. J., & McLaughlin, T. F. (1984). Effects of a taped-words treatment procedure on learning disabled students' sight-word reading. *Learning Disability Quarterly, 7*, 49-54.

Goldman, S. R. & Pellegrino, J. W. (1987). Information processing and elementary mathematics. *Journal of Learning Disabilities, 20,* 23-32.

Greenwood, C. R., Delquadri, J., & Hall, R. V. (1984). Opportunity to respond and student academic performance. In W. L. Heward, T. E. Heron, J. Trap-Porter, & D. S. Hill (Eds.), *Focus on behavior analysis in education* (pp. 58-88). Columbus, OH: Charles Merrill.

Greenwood, C. R., Delquadri, J., & Hall, R. V. (1989). Longitudinal effects of classwide peer tutoring. *Journal of Educational Psychology, 81*, 371-383.

Halle, J. W., Marshall, A. M., & Spradlin, J. E. (1979). Time delay: A technique to increase language use and facilitate generalization in retarded children. *Journal of Applied Behavior Analysis, 12,* 431-439.

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

Hasselbring, T. S., Goin, L. I. & Bradsford, J. D. (1987). Developing automaticity. *Teaching Exceptional Children, 1*, 30-33.

Heckelman, R. G. (1969). A neurological-impress method of remedial-reading instruction. *Academic Therapy, 5*, 277-282.

Horner, D. R., & Baer, D. M. (1978). Multiple-probe technique: A variation of the multiple-baseline. *Journal of Applied Behavior Analysis, 11*, 189-196.

Kratochwill, T. R., Stoiber, K. C. (2002). Evidence-based interventions in school psychology: Conceptual foundations of the procedural and coding manual of division 16 and the society for the study of school psychology task force. *School Psychology Quarterly, 17,* 341-389.

LaBerge, D., & Samuels, S. J. (1974). Toward a theory of automatic processing in reading. *Cognitive Psychology, 6*, 293-323.

McCurdy, B. L., Cundari, L., & Lentz, F. E. (1990). Enhancing instructional efficiency: An examination of time delay and the opportunity to observe instruction.

Education and Treatment of Children, 13, 226-238.

McDonnell, J. & Ferguson, B. (1989). A comparison of time delay and decreasing prompt hierarchy strategies in teaching banking skills to students with moderate handicaps. *Journal of Applied Behavior Analysis, 22,* 85-91.

National Center for Educational Statistics (NCES). (2004). *The nation's report card: Mathematics highlights 2003.* Washington, DC: U.S. Department of Education.

Poncy, B. C., Skinner, C. H., & O'Mara, T. (under review). Prompt, practice, and repair (PPR): The effects of a class-wide intervention on elementary students' math fact fluency.

Rhymer, K. N., Dittmer, K. L., Skinner, C. H., & Jackson, B. (2000). Combining explicit timing, peer-delivered immediate feedback, positive-practice overcorrection and performance feedback to increase multiplication fluency. *School Psychology Quarterly, 15,* 40-51.

Schuster, J. W., Gast, D. L., Wolery, M. & Guiltinan, S. (1988). The effectiveness of a constant time-delay procedure to teach chained responses to adolescents with mental retardation. *Journal of Applied Behavior Analysis, 21,* 169-178.

Shapiro, E. S. (1996). *Academic skills problems: Direct assessment and intervention* (2nd ed.). New York: Guilford Press.

Shapiro, E. S. & McCurdy, B. L. (1989). Effects of a taped-words treatment on reading proficiency. *Exceptional Children, 55*, 321-325.

Skinner, C. H. (1998). Preventing academic skills deficits. In T. S. Watson & F. Gresham (Eds.). *Handbook of child behavior therapy: Ecological considerations in assessment, treatment, and evaluation* (pp. 61-83). New York: Plenum.

Skinner, C. H., Bamberg, H., Smith, E. S., & Powell, S. (1993). Subvocal responding to increase division fact fluency. *Remedial and Special Education, 14,* 49-56.

Skinner, C. H., Belfiore, P. J., Mace, H. W., Williams, S., & Johns, G. A. (1997). Altering response topography to increase response efficiency and learning rates. *School Psychology Quarterly, 12,* 54-64.

Skinner, C. H., Belfiore, P. B., & Watson, T. S. (1995/2002). Assessing the relative effects of interventions in students with mild disabilities: Assessing instructional time. *Journal of Psychoeducational Assessment, 20,* 345-356. (Reprinted from *Assessment in Rehabilitation and Exceptionality, 2,* 207-220, 1995).

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

Skinner, C. H., Johnson, C. W., Larkin, M. J., Lessley, D. J., & Glowacki, M. L. (1995). The influence of rate of presentation during taped-words interventions on reading performance. *Journal of Emotional and Behavioral Disorders, 3*, 214-223.

Skinner, C. H., Logan, P., Robinson, S. L., & Robinson, D. H. (1997). Myths and realities of modeling as a reading intervention: Beyond acquisition. *School Psychology Review, 26,* 437-447.

Skinner, C. H., Pappas, D., & Davis, K. (2005). Enhancing academic engagement: Providing opportunities for responding and influencing students to choose to respond. *Psychology in the Schools, 42,* 389-403.

Skinner, C. H., & Schock, H. H. (1995). Best practices in mathematics assessment. In A. Thomas & J. Grimes (Eds.), *Best Practices in school psychology (3rd ed)* (pp. 731-740). Washington, D.C.: National Association of School Psychologists.

Skinner, C. H., & Shapiro, E. S. (1989). A comparison of a taped-words and drill interventions on reading fluency in adolescents with behavior disorders. *Education and Treatment of Children, 12*, 123-133.

Skinner, C. H., Smith, E. S., & McLean, J. E. (1994). The effects of intertrial interval duration on sight-word learning during constant time delay. *Behavioral Disorders, 19*, 98-107.

Skinner, C. H., Turco, T. L., Beatty, K. L., & Rasavage, C. (1989). Cover, copy, and compare: An intervention for increasing multiplication performance. *School Psychology Review, 18,* 212-220.

Sterling, H. E., Robinson, S. L., & Skinner, C. H. (1997). The effects of two taped-words interventions on sight-word reading in students with mental retardation. *Journal of Behavior Education, 7,* 25-32.

Stoiber, K. C. & Kratochwill, T. R. (2000). Empirically supported interventions and school psychology: Rationale and methodological issues-Part I. *School Psychology Quarterly, 15,* 75-105.

Turco, T. L. & Elliott, S. N. (1986). Assessment of students' acceptability ratings of teacher-initiated interventions for classroom misbehavior. *Journal of School Psychology, 24,* 277-283.

Van Houten, R. (1984). Setting up performance feedback systems in the classroom. In W. L. Heward, T. E. Heron, J. Trap-Porter, & D. S. Hill (Eds.), *Focus upon applied behavior analysis in education* (pp. 114-125). Columbus, OH: Charles Merrill.

Wolery, M., Ault, M. J., Doyle, P. M., & Gast, D. L. (1986). *Comparison of instructional strategies: A literature review.* Lexington, KY: University of Kentucky Press.

Wong, B. Y. L. (1986). Problems and issues in definition of learning disabilities. In J. K. Torgesen & B. Y. L. Wong (Eds.), *Psychological and educational perspectives on learning disabilities* (pp. 3-26). New York: Academic Press.

Ysseldyke, J., Thill, T., Pohl, J., & Bolt, D. (2005). Using MathFacts in a Flash to enhance computational fluency. *Journal of Evidence-Based Practices for Schools, 6,* 59-89.

Appendices

Appendix A

Sample Intervention Sheet

Tape A: Form 2 Name ____________________________

1. $8 \times 3 =$ _____
2. $7 \times 7 =$ _____
3. $2 \times 5 =$ _____
4. $6 \times 9 =$ _____
5. $9 \times 4 =$ _____
6. $3 \times 5 =$ _____
7. $7 \times 6 =$ _____
8. $3 \times 3 =$ _____
9. $5 \times 6 =$ _____
10. $4 \times 4 =$ _____
11. $8 \times 2 =$ _____
12. $8 \times 9 =$ _____
13. $7 \times 7 =$ _____
14. $6 \times 9 =$ _____
15. $3 \times 5 =$ _____
16. $3 \times 3 =$ _____
17. $4 \times 4 =$ _____
18. $8 \times 9 =$ _____
19. $8 \times 3 =$ _____
20. $2 \times 5 =$ _____
21. $9 \times 4 =$ _____
22. $7 \times 6 =$ _____
23. $5 \times 6 =$ _____

24. $8 \times 2 =$ ______

25. $2 \times 5 =$ ______

26. $7 \times 6 =$ ______

27. $6 \times 9 =$ ______

28. $8 \times 2 =$ ______

29. $3 \times 3 =$ ______

30. $9 \times 4 =$ ______

31. $8 \times 3 =$ ______

32. $7 \times 7 =$ ______

33. $4 \times 4 =$ ______

34. $8 \times 9 =$ ______

35. $3 \times 5 =$ ______

36. $5 \times 6 =$ ______

37. $3 \times 3 =$ ______

38. $9 \times 4 =$ ______

39. $6 \times 9 =$ ______

40. $4 \times 4 =$ ______

41. $7 \times 6 =$ ______

42. $7 \times 7 =$ ______

43. $2 \times 5 =$ ______

44. $8 \times 9 =$ ______

45. $5 \times 6 =$ ______

46. $8 \times 3 =$ ______

47. $8 \times 2 =$ ______

48. $3 \times 5 =$ ______

Appendix B

Sample Assessment Packet

Set C: Form 3 Name ___________________________

1. $4 \times 2 =$ ______
2. $2 \times 6 =$ ______
3. $9 \times 2 =$ ______
4. $4 \times 6 =$ ______
5. $6 \times 8 =$ ______
6. $7 \times 4 =$ ______
7. $5 \times 5 =$ ______
8. $9 \times 9 =$ ______
9. $3 \times 3 =$ ______
10. $8 \times 5 =$ ______
11. $8 \times 7 =$ ______
12. $7 \times 3 =$ ______

13. $7 \times 4 =$ ______

14. $2 \times 6 =$ ______

15. $3 \times 3 =$ ______

16. $6 \times 8 =$ ______

17. $4 \times 2 =$ ______

18. $8 \times 7 =$ ______

19. $5 \times 5 =$ ______

20. $8 \times 5 =$ ______

21. $7 \times 3 =$ ______

22. $4 \times 6 =$ ______

23. $9 \times 2 =$ ______

24. $9 \times 9 =$ ______

25. $8 \times 7 =$ ______
26. $9 \times 2 =$ ______
27. $3 \times 3 =$ ______
28. $2 \times 6 =$ ______
29. $5 \times 5 =$ ______
30. $4 \times 6 =$ ______
31. $9 \times 9 =$ ______
32. $8 \times 5 =$ ______
33. $7 \times 3 =$ ______
34. $6 \times 8 =$ ______
35. $4 \times 2 =$ ______
36. $7 \times 4 =$ ______

37. $9 \times 2 =$ ______

38. $8 \times 7 =$ ______

39. $5 \times 5 =$ ______

40. $6 \times 8 =$ ______

41. $3 \times 3 =$ ______

42. $7 \times 3 =$ ______

43. $9 \times 9 =$ ______

44. $4 \times 2 =$ ______

45. $7 \times 4 =$ ______

46. $2 \times 6 =$ ______

47. $8 \times 5 =$ ______

48. $4 \times 6 =$ ______

Appendix C

The Treatment Integrity Checklist

1. ____ Place probes face-down on students' desks.
2. ____ Set timer to zero.
3. ____ Read assessment instructions aloud.
4. ____ Start timer.
5. ____ When timer reaches 1 minute, say "time's up" and stop timer.
6. ____ Collect probes.
7. ____ Place appropriate Follow-Along packets and blank pieces of paper on students' desks.
8. ____ Read intervention instructions aloud.
9. ____ Start tape.
10. ____ When tape ends, collect Follow-Along packets.
11. ____ Place next set of probes face-down on students' desks.
12. ____ Set timer to zero.
13. ____ Reread assessment instructions aloud.
14. ____ Start timer.
15. ____ When timer reaches 1 minute, say "time's up" and stop timer.
16. ____ Collect probes.

Vita

Elizabeth McCallum was born in Louisville, Kentucky on July 4, 1978. She was raised in Knoxville, Tennessee and graduated from Bearden High School in 1996. She attended Cornell University in Ithaca, New York where she received a B.A. in psychology in 2000. Elizabeth is completing requirements for a Ph.D. in Education with a concentration in School Psychology. She currently works as an intern with the Tennessee Internship Consortium and Cherokee Health Systems.