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Technology-Assisted Interventions to Improve Learning Outcomes for Students with Math Difficulties

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TECHNOLOGY-ASSISTED INTERVENTIONS TO IMPROVE LEARNING OUTCOMES FOR STUDENTS WITH MATH DIFFICULTIES

by

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Chapter I

INTRODUCTION

In the United States, 5-8% of all school-age children have deficits that greatly interfere with their ability to learn math (Geary, 2004). Some of these students have been identified with specific disabilities, whereas others are included among students who are described as struggling learners or students who are at risk for academic failure. National Assessment of Educational Progress (NAEP) (2013) data confirm that 45% of students with disabilities in the fourth grade were below basic levels in math, compared to 14% of their nondisabled peers. Eighth-grade results were more discrepant. These statistics point to the need to improve the math skills and learning outcomes for students with math disabilities.

Some researchers contend various technologies are effective in teaching mathematics to students with disabilities (Allsopp, McHatton, & Farmer, 2010; Funkhouser, 2003; Li & Ma, 2010; Maccini, Gagnon, & Hughes, 2002). The National Council of Teachers of Mathematics (NCTM, 2000) also acknowledged the importance of technology instruction when they identified technology as one of its six core principles and described how essential technology is to teaching and learning mathematics.

The purpose of this paper was to review the literature that examines the effectiveness of technology-assisted instruction for students with math difficulties. Although a multitude of both low- and high-tech devices and interventions are available for use by students with math disabilities, this paper focuses only on high-tech interventions. Calculators, iPads, and instructional software are examples of the high-tech interventions reviewed in this paper. Chapter I provides a description of these interventions as well as a description of the types of math deficits typically experienced by students with mild disabilities.

Historical Background

"Educators now have the opportunity to individualize instruction with many technological devices never before available in education" (Beard, Carpenter, & Johnston, 2011, p. 4). This opportunity is reflected in the NCTM's Technology Principle, which was adopted in 2000. This principle emphasizes that technology can enhance student learning by allowing the students to work at higher levels of generalization or abstraction. According to Woodward and Montague (2002), these newly adopted principles make specific reference to students with disabilities, whereas there was virtually no mention of students with disabilities in the 1989 NCTM principles.

By 2001, 49 states had adopted NCTM's 2000 standards and principles (Woodward & Montague, 2002). Currently, 45 states have built upon the NCTM's broad framework and adopted the Common Core State Standards (CCSS; National Governors Association Center for Best Practices, Council of Chief State School

Officers, 2010). The CCSS and NCTM's standards and principles are closely related in that they both emphasis technology. They differ in that NCTM has a specific principle addressing technology, and CCSS interweaves technology throughout their standards. Another area of difference is specifically addressing students with disabilities. For example, NCTM clearly addresses these specific concerns in their Equity Principle whereas CCSS provides limited guidance at best (Beals, 2014).

Technology is potentially an intervention that students can use to gain access to these standards and improve their learning outcomes in mathematics. The first legislation specifically addressing technology needs for individuals with disabilities was the Technology-Related Assistance for Individuals with Disabilities Act (P.L. 100-407), commonly call the Tech Act of 1988. The law provided funding for states to develop technology to improve the functional capabilities of individuals with disabilities. The Tech Act of 1998 was succeeded by or supplanted by the several pieces of legislation:

> Technology-Related Assistance for Individual with Disabilities Act of 1988 revised and extended programs in 1994 (P.L. 103-218).
>
> Telecommunications Act of 1996 (P.L. 104-104) provided for accessibility to the internet. For example, the law provided provisions for libraries to be connected to the internet. Specifically, the law provided guidelines for accessibility, usability, and compatibility of telecommunications.
>
> Assistive Technology Act of 1998 ended the Tech Act and helped states meet the technology needs of individuals with disabilities by awarding states grants to support capacity building and incorporating the Universal Design for Learning framework.
>
> Assistive Technology Act of 2004 redirected funding from states directly to individuals.

> Special education legislation was first passed in 1975 (P.L. 94-142), Education for All Handicapped Children, the landmark legislation that mandated free and appropriate public education and for all students with disabilities. Later, the 1990 reauthorization specifically mentioned that technology must be considered. The IEP team must consider assistive technology, and it must be provided if it will help the student more successful. Subsequent reauthorizations maintained support for technology use in addressing the specific needs of students with disabilities. (Beard et al., 2011, p. 4)

Lynn Fuchs has been researching the interactions between mathematics and technology since the 1980s. As early as 1988 and predating the legislation above, Fuchs stated that CAI and technology can improve student performance in mathematics. However, Fuchs also states that CAI is a supplement to teachers acting as managers while integrating technology with instructional variables (Fuchs, 1988).

Theoretical Background

Technology has been advocated as an instructional tool to help improve the mathematics performance of struggling learners (Fuchs et al., 2006; Funkhouser, 2003; Seo & Woo, 2010). However, the mere existence of technology does not guarantee positive learning outcomes (Clark 1983; Li & Ma, 2010). Rather, adherence to instructional principles and features in the technology will lead to positive results. Butzin (2001) and the NCTM (2000) emphasized that proper integration of technology is just as important as the design.

Funkhouser (2003) felt integration of technology should be based upon Piaget's approach. Funkhouser stated that active student involvement is needed for technology to produce positive results; technology should help students explore, discover, conjecture, and confirm their learning. In other words, these forms of active learning can be embedded in technology-assisted instruction and are consistent with Piaget's theory of cognitive development.

Technology-assisted instruction also has the potential to place this active learning in the student's zone of proximal development, which is based upon Vygotsky's theory. Vygotsky referred to the zone of proximal development as a student's instructional level, or the zone in which a student needs adult support to complete a task they cannot yet accomplish on his or her own (as cited in Harvey & Charnitski, 1998). Technology-assisted instruction should be provided while students are in their zone of proximal development in order to foster higher-level thinking and cognitive development.

Piaget and Vygotsky's theories support both NCTM standards and as well as technology-assisted instruction (Funkhouser 2003; Harvey & Charnitski, 1998; Mofeed 2011). The potential is there for technology-assisted instruction and interventions to help students engage with mathematics curriculum actively. However, the research is clear that integration and implementation are just as important as is the presence of the technology.

<u>Research Question</u>

One research question guides this review of literature: Are technology-assisted interventions effective in enhancing the performance of students who experience learning difficulties in mathematics?

Focus of Paper

The review of literature in Chapter II includes 12 studies with participants who are identified as having a learning disability in math, or who are at risk for academic failure in math. My initial focus was solely on calculators and effectiveness as an accommodation for students with an identified disability. This narrow focus produced only six studies suitable for inclusion in Chapter II. For this reason, I expanded my search to include other high-tech devices and extended my search from 2000 to 2013. Studies were included if inferential or descriptive statistics were used to describe whether the technology enhanced students' mathematics performance.

I started the research using the Academic Search Premier, PsycINFO, and Advanced Google searches to comb the research literature. Various keywords and combinations of keywords were used to locate suitable and appropriate studies: *mathematics, technology, assistive, calculators, at-risk, struggling, special education, disabilities, computer,* and *interventions.* I also searched the tables of contents for the *Learning Disability Quarterly* and the *Journal of Research on Technology in Education* formerly *Journal of Research on Computing in Education* from 2000 to 2013.

Importance of the Topic

Woodward and Montague (2002) pointed out that trends in technology will have a considerable impact for students with LD and allow students to manipulate data at a higher level. However, Li and Ma (2010) argued this potential will not automatically produce positive outcomes. With only 26% of 12th grade students with

LD at or above basic math levels (NAEP, 2013), it is important that educators measure the effectiveness of technology-assisted instruction and interventions. By exploring technology and its effects on mathematics performance for students with LD, I hope to improve my instructional practices, which will in turn improve my students' mathematics performance.

Definitions of Terms

In the section, I define key terms used throughout this literature review to ensure understanding of unfamiliar language.

Computer-Assisted Instruction/Computer-Mediated Instruction. CAI or CMI in this paper commonly refers to computer software whether it is on a computer or tablet that provides instructional content using immediate and consistent feedback (Mautone, DuPaul, & Jitendra, 2005; Seo & Woo, 2010).

Curriculum-Based Measurements/Curriculum-Based Assessments. CBMs or CBAs are educator designed assessments drawn from students' curriculum. Assessments are short in duration and occur over time. Instructional and intervention decisions are evaluated and formulated from the results (Deno & Fuchs, 1991).

Effect Size. The effect size expresses the strength or weakness of the treatment in a numerical way. Generally, effect size is between 0.0 and 1.00. An effect size of 0.0 would mean the control group performed, on average, the same as the treatment group. An effect size greater than 0.0 means that the treatment group performed better, on average than the control group (Gay, Mills, & Airasian, 2012). Chapter II contains a negative effect size indicating that the control group performed better than the treatment group.

Long-Term Memory. Long-term memory refers to the location of information transferred from short-term memory to fairly permanent storage for later retrieval (Atkinson & Shiffrin, 1968).

Percentage of Non-overlapping Data (PND). PND is calculated by identifying the highest data point obtained in the baseline phase. During the treatment phase all data points above this identified data point are divided by the total number of data points in the treatment phase to obtain a percentage of treatment data points above the highest data point obtained in the baseline phase. Simply put, if 70% or more of data points obtained in the treatment phase are above the highest baseline data point, the treatment was effective to a certain degree (Scruggs, Mastropieri, & Castro, 1987).

Short-Term Memory. Short-term memory refers to the location of information that is stored temporarily and in small amounts. A commonly cited study conducted by Miller (1956) claimed the amount of information is made up of seven plus or minus two items.

Chapter II

REVIEW OF THE LITERATURE

In this chapter, I review the literature that examines the effectiveness of technology-assisted interventions to improve math outcomes for students with learning disabilities. Studies are organized in two sections: calculator use and computer-assisted instruction (CAI), and findings are presented in chronological order within each section.

Calculator Use

After synthesizing over 30 years of research, Ronau et al. (2011) concluded that calculators enhance students' understanding of mathematical concepts, orientation toward mathematics, and behaviors in mathematics. However, students with disabilities were not included in this review of literature. The studies in this section examine the effects of calculators on mathematical outcomes for students with learning disabilities.

Fuchs, Fuchs, Eaton, Hamlett, and Karns (2000) conducted a study to determine whether students with disabilities benefited differentially from extended time, calculators, reading text aloud, and encoding. A total of 373 students participated in this study: approximately half were students with learning disabilities

(LD) and half without disabilities. All students without LD were in fourth grade, 129 students with LD were in fourth grade, and 63 students with LD were in fifth grade. From the students identified with LD, 52% were male, 39% were African American, 55% were European American, and 6% were Asian American.

Researchers conducted a pilot session to develop data collection scripts. They then administered curriculum-based measurements (CBMs) under different accommodation conditions. Two of the three math areas incorporated assistive technology and are reviewed in this summary: concepts and applications and problem-solving domains. For concepts and applications, four CBMs were administered to each student: standard condition (6 minutes, not read, without calculators), extended time condition (30 minutes, without calculator), read condition (6 minutes, without calculator), and calculator condition (6 minutes, not read). For problem-solving, five CBMs were administered to each student: standard condition (20 minutes, not read, without calculator, not encoded), extended time condition (45 minutes, read, without calculator, not encoded), calculator condition (20 minutes, not read, not encoded), read condition (20 minutes, without calculator, not encoded), and encoded condition (20 minutes, without calculator, not read).

The researchers used a within-subjects analysis of variance to interpret the data from Phase I, and a statistically significant effect size was reported for differences between the calculator condition versus the standard condition in the concepts and applications strand ($p < .001$; ES = -.21). In other words, students with LD did worse on the CBM when using calculators. For standard versus calculator condition in the problem-solving domain, a weak and marginally significant difference was reported between conditions.

The authors concluded calculators had no statistical effect, and that they may have been detrimental as an accommodation in some cases. This has implications for special educators prescribing calculators as an accommodation for students with LD. However, it should be noted that the authors were not explicit about the students using calculators regularly during instruction or if students were trained in the use of calculators.

Bouck and Yadav (2008) implemented a study with 75 seventh-grade students with and without disabilities from two schools in the same Midwestern rural school district that encouraged calculator use for over a decade. The 75 participants were relatively evenly spread among four inclusive classrooms. Nineteen of the 75 students were identified with LD or diagnosed with Attention Deficit Hyperactivity Disorder (ADHD), or behavior disorder/emotional impairments.

The researchers used an assessment containing 28 open-response, problem-solving questions to measure the number and operation strand from the National Council of Teachers of Mathematics (NCTM, 2000). Students were randomly assigned at class level to one of two conditions and assessed at the end of two 4-week intervals. The 35 students in Condition 1 had access to a calculator during the first assessment but not the second. The 40 students in Condition 2 did not have access to a calculator on the first assessment but did on the second. A TI-82 calculator was used because students used these regularly and had training on proper use.

Researchers analyzed the effect of ability status (students with or without disabilities) and condition (calculator use) using an ANOVA. Results indicated a statistically significant effect for Condition 1 versus Condition 2 ($F_{(1,71)} = 26.118$, $p < .000$). This implies that students with access to calculators on the second assessment (Condition 2) showed greater gains between assessments than students that had access to calculators on the first assessment (Condition 2). Ability status was shown to not be statistically significant ($F_{(1,55)} = .904$, $p = .345$), which suggests that students with disabilities did not differ in their gains from students without disabilities.

In addition to the ANOVA, researchers conducted an independent *t*-test for each condition. Both Assessment 1 ($t_(33) = 2.453$, $p = .02$) and Assessment 2 ($t\ (38) = 2.508$, $p = .017$) results significantly favored students without disabilities. These results show that calculators are not an appropriate accommodation or intervention for students with disabilities because they do not benefit more than their nondisabled peers.

Overall, the study showed that all students benefited from the use of a calculator. More specifically, students with and without disabilities benefited on an assessment designed to measure number and operation skills with open-ended problem solving questions. However, this study supported the Fuchs et al. (2000) findings that calculators did not benefit students with disabilities more than students without disabilities. Moreover, it addressed the issue of prior training on tool used as an intervention.

Bouck and Bouck (2008) implemented a study to explore the performance of sixth-grade students on a mathematics assessment when given access to a calculator. The study included 89 students; 22 were identified with LD. The students were enrolled in six different classes from three schools in a Midwestern state, and each class had a different teacher.

Students were administered a 28-item problem-solving pre- and post-test matched for difficulty that measured the number and operation strand from the NTCM (2000). The pre-test, given 6 weeks prior to post-test, was conducted without the use of calculators. During the post-test, 49 students were in the access-to-a-calculator (basic four-function calculator) group and 40 students were in the no-access-to-a-calculator group. Students were randomly assigned to group at class level for the post-test.

The researchers used an ANCOVA to determine the effects according to ability status (students with LD and students without LD) and condition (access and no access to a calculator). Scores on the pre-test served as the control variable. Results were statistically significant for the group with access to a calculator regardless of ability ($F_{(1,84)} = 29.916, p < .000$). The interaction between condition and ability status was not statistically significant. Although students with disabilities scored lower in both the calculator condition and no-calculator condition than their nondisabled peers, they performed better when given access to a calculator (Table 1). The results of a one-way ANOVA were statistically significant ($F_{(1,20)} = 57.532, p = .03$) and favored the calculator condition. The authors did not conduct a one-way ANOVA for students without disabilities.

Table 1

Mean Scores by Students with LD and Students without LD

	CALCULATOR CONDITION		NO-CALCULATOR CONDITION	
Test	LD	Without LD	LD	Without LD
Pre-test	3.29	8.81	1.4	4.63
Post-test	7.46	11.78	4.71	6.08

The researchers asserted the results did not support the use of calculators as a valid accommodation for students with disabilities. When students with disabilities used a calculator, they attempted more questions and had fewer calculation errors. Even so, calculators did not help to close the gap between students with disabilities and students without disabilities. Calculators also did not improve conceptual understanding of mathematical problems (i.e., calculators did not help them understand what the question was asking).

In a 2009 study, Bouck examined the effects of a graphing calculator as an accommodation for students with and without disabilities on a mathematics assessment in an inclusive classroom. Forty seventh-grade students from a Midwestern state participated in the study; 13 students were identified with LD or diagnosed with ADHD or emotional impairment. The 40 students were randomly assigned to two classrooms that were co-taught by one special educator and one general educator.

The pre-post assessment used was aligned with NCTM's principles for school mathematics (2000) for numbers and operations skills and included 28 problem-solving questions. All 40 students completed the pre-assessment without the use of a calculator and completed the post-assessment 4 weeks later. The class that was randomly assigned to the access-to-calculator-group used a TI-82 graphing calculator.

Data were analyzed using an ANCOVA. Results revealed that regardless of ability status, students answered more questions correctly in the access-to-calculator-group ($F_{(1,40)} = 15.51, p < .000$). However, the gap between students with disabilities and students without disabilities was greater in the access-to-graphing calculator condition. This is evident in the results presented in Table 2.

Table 2

Mean Scores Across Ability and Condition with Difference in Mean Number Correct

	PRE-ASSESSMENT		POST-ASSESSMENT		DIFFERENCE IN MEAN # CORRECT
	M	*SD*	*M*	*SD*	
SWD No calculator	1.75	1.7	2.25	2.5	0.50
SWD Calculator	2.56	1.7	6.56	2.8	4.00
SWOD No calculator	7.20	4.6	6.93	3.5	-0.27
SWOD Calculator	4.33	3.0	10.75	4.4	6.42

These results confirmed that although calculators improved learning outcomes for students with disabilities, they did not close the gap between students with disabilities and their nondisabled peers. Rather, the use of calculators increased the gap between the two ability groups. The authors advised caution when interpreting the results, given the small sample size of 40.

Engelhard, Fincher, and Domaleski (2011) examined the effects of two accommodated conditions on a large-scale statewide assessment. Participants in this study were identified from a stratified random sample of schools in Georgia. A total of 947 students were in third and fourth grade: 488 students without disabilities and 459 with disabilities. A total of 997 students were in sixth and seventh grade: 567 students without disabilities and 430 with disabilities. Approximately 60% of the participants were female.

The researchers assigned participants to one of three conditions at school level. Students in Condition 1 used resource guides consisting of a single page (front and back) that had key definitions, examples, and graphics. Condition 2 participants were trained to use a basic calculator on the assessment. Condition 3 participants took the assessment standard administration. Condition 2 and 3 will be the focus of this review as Condition 1 does not involve a high-tech intervention. All students with and without disabilities took the standard format *Georgia Criterion-Referenced Competency Tests* in the spring of 2005 (grades 3 and 6) and then again in spring of 2006 (grades 4 and 7).

The authors employed a nonequivalent pretest-posttest group design and used ANCOVAs and descriptive statistics to interpret the results. The researchers found that students in third and fourth grade with disabilities had the statistically highest adjusted means when using calculators as an accommodation $M = 36.08$ ($F_{(2,455)} = 5.31, p = .01$). The adjusted mean for standard administration was $M = 35.18$. In sixth and seventh grade no statistically significant effect was found between conditions for students with disabilities. Regardless of ability status, the means were statistically higher for students in third and fourth grade in the calculator condition ($M = 42.34$) than the standard administration ($M = 40.83$) ($F_{(2,940)} = 5.85, p = <.01$). Student achievement in sixth and seventh grade decreased in all conditions from pretest to post-test except the calculator condition for students without disabilities.

Researchers found mixed results when calculators were used as an intervention for students with disabilities. They reported a small increase in mean scores for third and fourth grade, and a small decrease for mean scores for sixth and seventh grade. They also noted that students without disabilities had greater mean score increases than students with disabilities when using a calculator as an intervention. It can be concluded from this last point that calculators as an intervention were more effective at improving learning outcomes for students without disabilities than students with disabilities.

<u>Computer-Assisted Instruction</u>

A common use of CAI is for computation practice and immediate feedback. This instruction or intervention is regularly facilitated with computing devices such as computers or tablets. However, the effectiveness of this common and regular use of CAI is not completely understood with regard to students with learning disabilities (Allsopp et al., 2010). The seven studies in this section explore the effectiveness of CAI on mathematical outcomes for students with disabilities.

Martindale, Pearson, Curda, and Pilcher (2005) measured the effectiveness of a computer-based software application designed to improve student performance on the Florida Comprehensive Assessment Test (FCAT). Twelve schools were assigned to the experimental group that used the FCAT Explorer software application (Infinity Software Inc., 2004). FCAT Explorer was an interactive and benchmark based software program that could be accessed from anywhere with an internet connection. The other 12 were assigned to the control group. Each group had three schools each at four grade levels (grades 4, 5, 8, and 10).

The researchers obtained FCAT data from the Florida Department of Education for each school and at each grade level for the school years ending in 2001 and 2002. FCAT Reading scores were gathered for grade 4, and mathematics scores were gathered for the remaining grades and are the focus of this review. Data were also obtained from Infinity Software, designers of FCAT Explorer, to ensure that all experimental group students used FCAT Explorer and that all control group students did not. The researchers analyzed the data using an ANCOVA to examine treatment strength between program usage and non-usage.

For the fifth-grade mathematics FCAT, results were statistically significant between treatment and control group ($F = 4.46, p < .01$). The adjusted mean for

FCAT Explorer use was higher in both 2001 and 2002, but the effect size was moderate at best. For the eighth and 10th grade mathematics FCAT, differences between the treatment and control group were non-significant.

The findings from this study revealed that only students in fifth grade scored significantly higher on the mathematics FCAT when using the computer-based program. The authors indicated these findings may suggest that the FCAT Explorer program was more effective in elementary than secondary. However, given the low effect size for fifth grade, all conclusions should be interpreted with caution.

Mautone et al. (2005) examined the effectiveness of CAI on the mathematical performance and active engagement of students diagnosed with ADHD. Three students participated in the study: Greg was a 9-year-old fourth grader; Brian was an 8-year-old second grader; Chris was an 8-year-old third grader. All three participants were educated in public elementary schools. Brian was in a special education class for mathematics; Greg and Chris were both educated full time in a general education classroom.

The researchers used a single-subject design with a baseline and treatment phase. The baseline was established while the participants continued to receive typical classroom instruction that included small- and large-group instruction followed by individual seatwork. To measure mathematical performance and active engagement respectively, a 2-minute basic math computation probe after instruction was used to measure mathematical performance, and the *Behavioral Observation of Students in*

Schools (BOSS; Shapiro, 1996) was used during instruction. In accordance with the purpose of this paper, only mathematical performance is reviewed.

It took a minimum of four sessions for the baselines to stabilize for all participants. The treatment phase consisted of the participants using *Math Blaster Ages 6-9* (1997). At the beginning of each session teachers adjusted the program for each student's instructional level. Students earned points as they completed tasks correctly. Feedback was immediate, frequent, and individualized. When students accumulated enough points, they were rewarded with a 1-2 minute video game. The math tasks continued after the video game reward. Treatment phase data were gathered in the same way as the baseline phase (i.e., 2-minute probe).

To analyze the data, the authors used mean level of digits correct on the math computation probes, effect size, and Percentage of Nonoverlapping Data (PND). Increases in digits correct per minute from baseline to intervention were recorded for all three participants as measured by baseline and intervention mean. The last four sessions were used to determine the mathematical performance at the conclusion of the intervention, and effect size was calculated with these data.

Effect sizes for all three participants were over one but should be interpreted with caution given they are calculated for individual cases. PND results were not as positive as mean increases given that on two of three occasions the PND was below 50% indicating an unreliable treatment (Scruggs et al., 1987). Table 3 provides a summary of these results.

Table 3

Math Baseline and Intervention Performance Data

Participant	Mean Increase in Digits Correct		PND	Effect Size
	Baseline	Intervention		
Brian	*M*=1.75 *SD*=0.5	*M*=6.5 *SD*=3.2	1	1.45
Greg	*M*=11.54 *SD*=2.7	*M*=17.25 *SD*=5.3	0.474	1.72
Chris	*M*=8.25 *SD*=1.2	*M*=10.38 *SD*=2.0	0.455	1.15

The authors concluded from this study that CAI is an effective intervention and instructional model for students behind their peers in mathematical achievement. The authors stated that Greg and Chris showed gains above expected levels, and Brian's gains were only slightly less than expected. This is at odds with the PND data supplied.

It would have also been helpful in interpreting findings if the students not receiving the intervention were included in the data. The students not receiving the intervention were receiving the same typical classroom instruction but were excluded from the intervention. It is possible that the performance increases are the result of the participants meeting grade-level expectations and not from the treatment condition being more effective than the control condition.

Fuchs et al. (2006) evaluated the effectiveness of CAI to improve number combination and spelling skills for students at risk for math disability. The at-risk students were selected from nine first-grade classrooms in three Title 1 schools in an urban school system. The 33 participants were randomly assigned to math CAI

($n = 16$) and spelling ($n = 17$). Only the math CAI group results are discussed in this review. Fifty-six percent of the math CAI group were male, two were identified with LD, and two were English language learners.

The CAI software was designed to show a horizontal addition or subtraction problem (e.g., $1 + 2 = 3$ or $3 - 2 = 1$) for 1.5 seconds initially with time increasing by 0.3 seconds for every wrong answer. To produce a right answer a student had to type the correct number sequence after it disappeared from the screen. Correct answers were rewarded with tokens in a treasure chest. The researchers based this design on the assumption that repeated pairing of number combinations in the short-term memory would transfer to long-term memory for automatic retrieval. This study measured the effectiveness of CAI by the students' ability to transfer mastered number combinations to an arithmetic number combination skill test and a arithmetic story problem test.

Pre- and post-tests included an arithmetic number combination skill test and a story problem test. The number combination test included addition and subtraction subtests that each contained 24 problems with sums from 0 to 18, presented horizontally on one page. The story problem test contained 14 short story problems read aloud to students with sums of 0 to 9 involving either addition or subtraction. Students were given 30 seconds to respond verbally to the story problem.

ANOVA findings revealed that only math CAI had a statistically significant effect on addition fact fluency ($F = 5.14, p = .05$, ES = .82). The control group's mean was 1.88 ($SD = 1.87$) and the CAI group's mean was 4.19 ($SD = 3.73$).

With only math CAI showing strong effects on addition fluency, the researches theorized that this may be due to the design of the math CAI. Because of time constraints, students spent more time mastering addition combinations than subtraction combinations. Given more time, the researches felt students would also improve their subtraction fluency to a significant level. Having said that, the researchers did not feel the transfer of skills would be made to story problems even given more time.

Billingsley, Scheuermann, and Webber (2009) conducted a study to compare three mathematical instruction methods: direct teach, CAI, and a combination of both. The participants included one female and nine male special education students in grades 9 to 11. All participants received the mathematical instruction in a self-contained setting at a public high school. Participants ranged in age from 14-17 and included one African American, five Hispanic, and four White students. Nine of 10 students were identified with emotional disturbance (ED).

An alternating-treatments single-subject design was used to gauge which instructional method was most effective for students with ED. The teacher-designed curriculum-based assessments (CBAs), the dependent variable, targeted 10 math objectives identified by the *Wide Range Achievement Test-3* (WRAT-3; Wilkinson, 1993). The instructional method was assigned randomly across three groups for the first nine math objectives taught. The 10th math objective was taught using the identified best treatment. The CBAs were administered three times as a baseline, at the end of a 1-week intervention, and as a post-instructional probe. Each group received each instructional method three times.

Using the baseline mean of 13 for the 10 students and the condition mean across students (direct teach = 60.6, CAI =51.6, and combined method = 72.5) to interpret the data, the authors reported all three instructional methods were effective at increasing mean scores. The effect sizes for each condition across students fell between .83 and 1.00 except for one during CAI (-.72). Another student's effect size could not be calculated because the mean was zero. This indicated a strong effect for all treatments for eight of the 10 students.

Findings revealed no one method was better for all students, although the combined method was identified as the best treatment method because it was the most effective for seven out of 10 students. These findings should be interpreted while understanding the limitations. The alternating-treatment design could not implemented optimally because students missed treatments due to unexcused absences, school holidays, and refusal to participate. More exposure to treatments would have produced more sound results.

Mofeed (2011) conducted a study to determine if the I CAN Learn® (ICL) interactive computer-assisted program (JRL Enterprises, 2012) was more effective than traditional instruction ("Chalk and Talk") in teaching the Hickman Mills School District's eighth-grade mathematics curriculum in Missouri. The study included 589 students who used the ICL system and 363 students who received traditional mathematics instruction, for a total of 952 eighth-grade students. The students were randomly assigned to an instruction group and were further divided into four groups: male, female, special education, and low SES. All students were in one of two schools in the Hickman Mills School District in Missouri.

The ICL program is a computerized pre-algebra and algebra curricula designed to improve students' problem-solving skills through individualized instruction and is aligned with NCTM's (2000) principles for school mathematics. The *Missouri Assessment Program* (MAP) ("Missouri Assessment Program," 2013) was meant to align with the same principles and was used as the measurement tool for this study. The researcher used average MAP math scores to compare the effectiveness of the ICL system versus a traditional approach. Eighth-grade student scores for the 2006-07 and 2007-08 school years served as the dependent variable. The ICL group served as the treatment group, and the Chalk and Talk group served as the control group.

T-tests were used to determine a significant difference between MAP mean scores for students who used ICL and those who did not. The null hypothesis, "I CAN Learn is no different in effectiveness than Chalk and Talk, was rejected by the author when the *t* value was greater than the critical value of 1.96; this critical value was used because of the large sample size. Simply put, students using ICL scored higher than students who did not regardless of group. ICL had the strongest effect for females followed by low SES, special education, and males respectively. These results are presented in more detail in Table 4.

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Table 4

ICL Versus Traditional (trdl) for Identified Groups

	N	*M*	*SD*	*t*-value	*df*	Critical Value
ICL	589	678.32	37.79	4.955	950	1.96
trdl	363	665.29	41.97			
Male ICL	263	674.54	42.76	2.234	479	1.96
Male trdl	218	665.72	43.49			
Fem. ICL	326	681.38	33.00	4.766	469	1.96
Fem. trdl	145	664.63	39.72			
SpEd. ICL	34	654.41	30.90	2.448	115	1.96
SpEd. trdl	83	635.14	41.37			
Low SES ICL	429	674.41	34.37	4.235	688	1.96
Low SES trdl	261	661.98	41.89			

Despite these positive results for ICL, students in the special education group did not achieve on a level with their nondisabled peers. The mean of 654.41 for the special education group in the ICL condition was still lower than all other groups regardless of condition, but they had the greatest difference between conditions. In other words, although isolated ICL was effective in enhancing the performance of students with LD and narrowing the achievement gap, students with LD still performed lower than all groups without CAI.

Haydon et al. (2012) examined the effects of a worksheet condition versus an iPad condition on math fluency and active academic engagement. The study took place in a Midwest alternative public high school classroom during the 40-minute math instructional period. Three of the seven students in the classroom participated in the study, which was conducted over 15 lessons or periods. All three students' mathematical skills were well below grade level.

The three participants were identified as special education students with emotional disturbance (ED). Sue was a 17-year-old White student in the 11^{th} grade who had diagnoses of Bipolar Disorder, Pervasive Developmental Disorder NOS, and Anxiety Disorder. Jim was a 17-year-old White student who was enrolled in the 10^{th} grade. He had diagnoses of Conduct Disorder, Mood Disorder, and Reactive Attachment Disorder. Andy, the third participant, was an 18-year-old Black student enrolled in the 11^{th} grade. He was diagnosed with ADHD.

The research team developed procedures to target money, fractions, numerical patterns, and order-of-operations skills. Four iPad applications were selected in the iPad condition to target math skills: iTouch MATH Grade 5-LITE v. 2.1, Coin Math v. 3.0, and enVisionMATH: Understanding Fractions v. 1.1. In the worksheet condition, the worksheets were constructed in ensure the difficulty level was the same across conditions. Instructional time ranged from 26 to 40 minutes followed immediately by either the iPad condition or worksheet condition. Specifically, the authors used an alternating treatment design to compare the effects of the two instructional conditions on math fluency and academic engagement. Academic engagement was evaluated for each condition using a 10-s interval recording system. Engaged time was defined as writing, raising hand, participating in choral responding, reading aloud, talking to the teacher or peer about assignment, and placing and/or scrolling finger(s) on iPad.

Mean percentages for worksheet engagement were calculated for each student: Sue = 88.7, Jim = 86.2, Andy = 69.3, and the group = 81.4. Mean iPad engagement percentages were also calculated: Sue = 98, Jim = 98.6, Andy = 100, and the group = 98.9. Visual analysis of data revealed that for Andy, 100% of engagement data points for the iPad condition were above the worksheet condition.

Mathematical fluency was measured in correct responses per minute for each condition: Sue = 1.23, Jim = 0.75, Andy = 0.68, and the group = 0.89. The mean number correct per minute for iPads was much higher: Sue = 3.23, Jim = 3.93, Andy = 2.55, and the group = 3.24. For all three participants, all iPad data points exceeded data points for worksheets.

The authors concluded that this study demonstrated strong treatment effects for number of problems answered correctly while using the iPad. The results were also very promising for increasing active student engagement. However, the authors noted that results should be interpreted with caution given the low number of participants and the novelty effect of using iPads.

Leh and Jitendra (2012) compared the effectiveness of computer-mediated instruction (CMI) and teacher-mediated instruction (TMI) on problem-solving in mathematics. Twenty-five participants were included in the study. All 25 participants were in third grade and scored below the 50^{th} percentile for the Total Mathematics score on the *Stanford-10 Achievement Test-Tenth Edition* (Harcourt Brace & Company, 2002). The participants attended six classes in a suburban public elementary school in northeast United States.

Students were randomly assigned to either the CMI or TMI group. All students attended a 50-minute mathematics instructional period using school district curriculum. Students participating in the study received an additional 50-minute lesson using either CMI or TMI. The CMI group used the *GO Solve Word Problems* computer software (Tom Snyder Productions, 2005), and the TMI group used the *Solving Math Word Problems: Teaching Students With Learning Disabilities Using Schema-Based Instruction* curriculum (Jitendra, 2007). In total each group received 15 lessons.

The researchers used a pre-test-post-test control group design and also conducted a maintenance test. The problem-solving test was used immediately before and after intervention. The maintenance test was administered 4 weeks after the intervention had ended. The problem-solving test was untimed, and questions were read aloud as needed. Students received credit for the correct number sentence, correct computation, and appropriate labels.

The researchers analyzed the data using an ANCOVA to examine treatment strength between CMI and TMI. Results showed no statistically significant effect of the CMI group during the posttest or during the maintenance test. Analysis of means and standard deviation data revealed students performed comparably regardless of condition.

The researchers stated that their findings did not support CMI over TMI as an instructional or intervention tool. Additionally, they argued that the quality of instruction rather than the learning environment is more important. The three teachers facilitating the CMI and TMI together had 55 years of teaching experience and all possessed advanced degrees in education.

Chapter II Summary

In this chapter, I reviewed 12 studies to examine if calculator and computer-assisted instructional approaches improved the achievement of students with math disabilities. These findings are summarized in Table 5 and are discussed further in Chapter III.

Table 5

Summary of Chapter II Findings

AUTHOR(S)	STUDY DESIGN	PARTICIPANTS	PROCEDURE	FINDINGS
CALCULATOR USE STUDIES				
Fuchs, Fuchs, Eaton, Hamlett, & Karns (2000)	Quantitative • Causal-comparative • Inferential	373 grade 4 students; approximately half identified as LD.	CBMs were administered to measure computation, concepts and applications, and problem-solving. The effectiveness of the following types of accommodations were evaluated extended time, calculators, reading text aloud, and encoding.	• LD students did not benefit more from calculators than non-LD students. • Calculators did not allow for more valid expression of knowledge and had a negative effect on the concepts and applications and problem solving CBMs.
Bouck & Yadav (2008)	Quantitative • Nonequivalent control group design (pre-test and post-test) • Inferential	75 grade 7 students from a rural Midwestern school across four different inclusive classrooms.	Students were randomly assigned to two conditions: Condition 1: calculator use on assessment 1, no calculator on assessment 2 and Condition 2: no calculator on assessment 1, calculator use on assessment 2.	• Students who had access to a calculator on assessment 2, but not on assessment 1 (condition 2) showed greater gains than students who had access to a calculator on assessment 1, but no access on assessment 2. (condition 1) • Students without disabilities benefited more from calculator use than students with disabilities.

Table 5 (continued)

AUTHOR(S)	STUDY DESIGN	PARTICIPANTS	PROCEDURE	FINDINGS
Bouck & Bouck (2008)	Quantitative • Nonequivalent control group design (pre-test and post-test) • Inferential	89 grade 6 students from rural Midwestern schools across two districts in six different inclusive classrooms.	Pre- and post-test were taken during 1 class period. No students had access to a calculator on the pre-test. The post-test had 2 conditions: access and no access to a calculator.	• All students regardless of ability status answered more questions correctly in the access to calculator condition versus the no access. • Results suggested that calculators are not a valid accommodation, nor are they a valid tool for knowledge expression.
Bouck (2009)	Quantitative • Nonequivalent control group design (pre-test and post-test) • Inferential	40 grade 7 students from a rural Midwestern school district.	Pre- and post-assessment design with random assignment at the class level. Tests were taken during one 50-minute class period. No students had access to a calculator on the pre-assessment. The post-assessment had two conditions: access and no access to a calculator.	• Results suggested that all students regardless of ability answered more questions correctly when they had access to a calculator • Students without disabilities performed statistically better than students with disabilities (caution low power).

Table 5 (continued)

AUTHOR(S)	STUDY DESIGN	PARTICIPANTS	PROCEDURE	FINDINGS
Engelhard, Jr., Fincher, & Domaleski (2011)	Quantitative • Nonequivalent control group design (pre-test and post-test) • Inferential	1,944 grade 3 and 6 students from three schools in Georgia.	Participants took the CRCT to measure six knowledge strands of mathematics. Schools were randomly assigned to one of three conditions: resource guides, calculators, or standard administration.	• Both students with and without disabilities benefited from the use of a calculator as an accommodation. • Students with disabilities gained more. • Calculators as an accommodation can eliminate construct-irrelevant variance for students with disabilities, but it does not close the gap between them and their nondisabled peers.
COMPUTER-ASSISTED INSTRUCTION STUDIES				
Martindale, Pearson, Curda, & Pilcher (2005)	Quantitative • Causal-comparative • Inferential	585 grade 4, 491 grade 5, 1379 grade 8, and 1505 grade 10 students from 24 schools in Florida.	12 schools with high usage of the Florida Comprehensive Assessment Test (FCAT) Explorer were used as the experimental group. The control group consisted of the other 12 schools that did not use the FCAT Explorer program. The FCAT Explorer is a computer assisted software program intended to improve student scores on the FCAT.	• For Grade 5, treatment produced higher scores than the control group. • Treatment did not produce higher scores than the control group for grades 8 and 10

Table 5 (continued)

AUTHOR(S)	STUDY DESIGN	PARTICIPANTS	PROCEDURE	FINDINGS
Mautone, DuPaul, & Jitendra (2005)	Quantitative •Single subject experimental •Baseline intervention design •Descriptive	Three students one in each grade 2nd to 4th and diagnosed with ADHD from public elementary schools.	Students were given basic math computation probes and behavioral observation assessments to establish computational performance and active engagement baselines. The intervention phase used Computer-assisted instruction (CAI), specifically Math Blaster software.	•CAI was effective in improving mathematics achievement •CAI was effective in improving active engagement
Fuchs, Fuchs, Hamlet, Powell, Capizzi, & Seethaler (2006)	Quantitative • One-group pre-test-post-test design • Inferential	33 at-risk students from three Title 1 schools across nine grade 1 classrooms	16 students were assigned the CAI math condition; 17 were assigned to CAI spelling condition and will not be discussed. Pre-post data were collected for Addition Fact Fluency, Subtraction Fact Fluency, and Story Problems.	• CAI was effective in promoting addition skills, but not subtraction skills • CAI was not effective in transferring learned skills to story problems

Table 5 (continued)

AUTHOR(S)	STUDY DESIGN	PARTICIPANTS	PROCEDURE	FINDINGS
Billingsley, Scheuermann, & Webber (2009)	Quantitative • Single subject experimental • Alternating treatment design • Descriptive	10 special education student in grades 9 to 11 from a self-contained urban setting	Students were in three different classes, and three different techniques were used at random for a week and then alternated. A pre-post curriculum-based quiz assessed mastery. Condition 1 - direct teach, Condition 2 - computer-assisted instruction, and Condition 3 - combination of both methods.	• All three conditions had positive results, although no statistically significant differences were reported between conditions. • A combined method was more effective but should be interpreted with caution.
Mofeed (2011)	Quantitative • Quasi-experimental Post-test-only control group design	952 grade 8 students from the Hickman Mills School District in the state of Missouri.	Mathematics achievement was measured using the Missouri Assessment Program (MAP). 589 students received math instruction using the "I Can Learn" computer program. 363 students received instruction using a traditional "Chalk and Talk" method.	Special education, female, male and low SES students who received the "I CAN Learn" instruction scored higher than respective students who received the "Chalk and Talk" method

Table 5 (continued)

AUTHOR(S)	STUDY DESIGN	PARTICIPANTS	PROCEDURE	FINDINGS
Haydon, Hawkins, Denune, Kimener, McCoy, & Basham (2012)	Quantitative Single subject experimental • Alternating treatment design • Descriptive	Three participants in a high school math class.	During 40-minute math lessons students either participated in the iPad condition or worksheet condition following instruction. Time spent in each condition varied based on time needed for instruction.	• All three participants answered more questions correctly in the iPad condition 100% of the time. • Engagement was greater in the iPad condition; all three participants were engaged close to 100% of the time.
Leh & Jitendra 2012	Quantitative • Pre-test-post-test control group design with a maintenance test • Inferential	25 grade 3 students with math difficulties randomly assigned to a condition of computer-mediated instruction (CMI) or teacher mediated instruction (TMI)	Students were randomly assigned to a condition of computer-mediated instruction (CMI) or teacher-mediated instruction (TMI). Each condition received 15 lessons of instruction. A researcher-developed word problem-solving test was administered for pretest, posttest, and maintenance measurements.	No significant differences were reported between the CMI and TMI condition.

Chapter III

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this paper was to examine the effectiveness of technology-assisted instruction for students with math difficulties. Chapter I laid the foundation by discussing the historical and theoretical perspectives as well as presenting the important pieces of legislation that have influenced technology in education. Chapter II included a review of 12 studies focusing on the effectiveness CAI on students experiencing mathematics difficulties. This chapter discusses the findings and presents recommendations for future research and current practice.

Conclusions

The studies reviewed in the paper used varied data collection methods and interpretations. Most of the studies had students with and without disabilities. Disability type was seldom given.

Calculator use studies. Five calculator use studies were reviewed in this paper. Results were mixed with regard to the effectiveness of calculators on the mathematics performance of struggling students. Only the Engelhard et al. (2011) showed positive

Engelhard et al. (2011) showed that students with disabilities gained more than their nondisabled peers when using a calculator. This was also partially true in the three studies with mixed results. Students with disabilities performed better in mathematics when they had access to a calculator; however, they did not gain more than their nondisabled peers. In the Fuchs et al. study (2000), it was clear that calculators hindered the students with disabilities. In fact, this study actually showed students performing worse when they had access to a calculator in certain knowledge strands (e.g., concepts and applications). While in other knowledge areas, such as calculations, there were gains by students with disabilities when using a calculator, students without disabilities gained more. This was similar to three studies with mixed results. In four of the five studies reviewed, calculators did not narrow the learning gap between students with disabilities and their nondisabled peers. In some case it actually increased the gap.

Computer-assisted instruction studies. Seven CAI studies were reviewed in this paper. Results were again mixed, but the findings were more positive than the calculator use studies. Four studies showed positive results (Billingsley et al., 2009; Haydon et al., 2012; Mautone et al, 2005; Mofeed, 2011) for the effectiveness of CAI on enhancing mathematics performance for students with learning difficulties in mathematics.

Two CAI studies showed mixed results (Fuchs et al., 2006; Martindale et al., 2005), and Leh and Jitendra (2012) showed no difference between CAI and the more traditional approach of teacher-assisted instruction. Positive outcomes were reported specifically for the use of CAI in promoting addition skills (Fuchs et al., 2006), and overall mathematics skills in elementary students (Martindale et al., 2005).

Recommendations for Future Research

"As computers become ubiquitous tools for learning and instruction, an important question is to what extent CT impacts student mathematics learning" (Li & Ma, 2010, p. 231). If we accept Li and Ma's statement about CAI being ubiquitous tools, it becomes more difficult to separate the effects of CAI on student learning. Is it due to the delivery method or novelty effect?

Delivery method. Some studies tried to ensure content and delivery method were comparable (Billingsley et al., 2009; Fuchs et al., 2006; Haydon et al., 2012; Leh & Jitendra, 2012; Martindale et al., 2005), and one explicitly stated that achievement gains could have been the results of quality instruction and teacher experience rather than delivery method (Leh & Jitendra, 2012). The calculator studies by design where able to control for instructional delivery, and the novelty effect was less. This made it easier to evaluate the effectiveness between treatments.

I believe that future research studying the effects of CAI should focus on aligning content before judging the impact of CAI on mathematical outcomes. This will prove to be difficult. For example, no teacher can give the immediate feedback CAI is capable of in an inclusive classroom. On the other hand, the CAI that was reviewed here cannot adjust to the individual needs or differentiate the way quality and experienced teachers can.

The novelty effect. Li and Ma (2010) found more positive effects for CAI when the instruction or intervention lasted less than 6 months. Nine of the 12 studies reviewed here had treatment phases of less than 6 months (Billingsley et al., 2009; Bouck, 2009; Bouck & Bouck, 2008; Bouck & Yadav, 2008; Fuchs et al., 2000; Fuchs et al., 2006; Haydon et al., 2012; Leh & Jitendra 2012; Mautone et al., 2005). The three remaining studies were unclear because data were obtained in way that made time spent in the instructional environment unknown (Engelhard et al., 2011; Martindale et al., 2005; Mofeed, 2011).

To eliminate the novelty effect, I believe future research on CAI needs to be more longitudinal. However, this will be difficult given the nature of schools. For example, the longest treatment (18 weeks) was found in Fuchs et al. (2006) study. This is traditionally half a school year. The studies in which the instructional environment was known were 9 weeks or less. This indicates that the researchers likely conducted their studies within a traditional school quarter. Having to consider the school calendar will prove difficult when addressing this gap in research.

Implications for Current Practice

Given the prevalence of technology in educational settings (e.g., one to one laptop or tablet schools), it is important that educators do not lose focus of what is vital. As far back as 1988, Fuchs cautioned educators that CAI "… fails to represent a viable alternative to direct teacher instruction and planning" (p. 294).

For mathematics within the field of special education the focus should be on content and the quality of instruction. A calculator cannot replace the value of a student learning the ability to manipulate numbers. This was demonstrated when students using a calculator did not generalize computation skills to concepts and applications (Bouck & Bouck, 2008; Fuchs et al., 2000). Although the temptation is there to use technology as a time-saving method of delivering instruction, the novelty and quality of instruction and long-term gains should be considered first.

This lack of consideration is evident in my current practice and setting. It is easy to obtain technology whether it is a calculator, iPad, or downloaded software. However, it is not easy to attract highly qualified and trained teachers to Lusaka, Zambia. Even when highly qualified and trained teachers are available, training on the specific technology to be used is often lacking. The consequences of putting technology before quality content and instruction play out in a number of ways. For example, the school has a class set of tablets that cannot function within the classroom effectively because of network issues. This prevents the technology from even becoming the medium let alone an effective method to deliver instruction. It is evident that in my particular teaching situation, that without access to both, it is unlikely my school or any other will see desired outcomes in mathematics.

Summary

In all the studies reviewed in Chapter II it is difficult to determine how the quality of instruction impacts the positive—or negative—effects of CAI. Clark (1983) used an analogy that expresses this concept well:

> The best current evidence is that media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries cause changes in our nutrition. Basically the choice

> of vehicle might influence the cost or extent or distributing instruction, but only the content of the vehicle can influence achievement. (p. 445)

Although the potential is there for CAI to be an effective method of boosting student performance, it should not create more barriers nor can it be a replacement of quality teaching. Li and Ma (2010) put it very succinctly, "Successful and effective use of technology for the teaching and learning of mathematics depends upon sound teaching and learning strategies that come from a thorough understanding of the effects of technology on mathematics education" (p. 216).

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