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Effects of Digital-Based Math Fluency Interventions on Learners with Math Difficulties: A Review of the Literature

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Mathematical proficiency serves as a foundation for student success in the classroom and real world. One component of mathematical proficiency is fluency with basic facts. Frequently, students with mathematics difficulties struggle to become proficient and fluent in the four basic operations. Interventions are available to help develop and promote fluency for students. Digital-based interventions, such as programs on computers or tablet applications, are one avenue by which students are able to acquire and maintain fluency. These digital tools are becoming increasingly more common and available in today's classroom. Eight studies on digital-based fact fluency were identified through a systematic search of the literature and analyzed to determine their effects. Study participants were elementary aged students with mathematics difficulties. Results of this synthesis indicate that digital-based interventions are an effective instructional technique for increasing fact fluency with students demonstrating mathematics difficulties. Implications research and practice are discussed.

Keywords: math fact fluency; digital-based; math difficulties; and special education.

Mathematical proficiency serves as a foundation for student success in the classroom and real world. The National Center for Educational Statistics (NCES) determined that 22% of adults have not mastered enough mathematics skills past eighth grade necessary for success in many jobs (Geary, Hoard, Nugent, & Bailey, 2013). Quality of life and employment opportunities are negatively impacted without the necessary quantitative skills acquired (National Mathematics Advisory Panel (NMAP), 2008). In 2013, according to the National Assessment of Educational

Progress (NAEP), 42% of the nation's students in fourth-grade and 38% of the nation's students in eighth-grade performed at or above the Proficient level in mathematics (NCES, 2015). In 2015, 40% of the students in fourth-grade and 33% of the nation's students in eighth-grade met the proficiency criteria, a decline from the data collected in 2013 (NCES, 2015). In 2015, between 60-67% of students performed below the proficient level in mathematics (NCES, 2015). During the 2007-2008 school year, about 12.3% of students in public schools had a diagnosed

disability and Individualized Education Program (NCES, 2015). Additionally, it is estimated that approximately 10% of students in public schools have some form of mathematics difficulty (Berch & Mazzocco, 2007).

Mathematics, although always viewed a content, has become a larger focus in K-12 education with the introduction of the Common Core Standards (CCSS; Porter, McMaken, Hwang, & Yang, 2011). As the standards continue to rise, an increasing amount of pressure is placed on teachers and students alike (Porter et al., 2011). Most students, regardless of ability, should be able to become proficient with mathematics (Mathematics Learning Study Committee, 2001). However, many of the nation's youth are unable to meet the minimum mathematics standards set for proficiency.

While there are multiple factors contributing to poor mathematics performance, the inability of students to fluently solve basic mathematics problems plays a significant role (Bryant et al., 2015; Kanive, Nelson, Burns, & Ysseldyke, 2014). Students who struggle solving basic computational problems will in turn struggle with complex and higher level mathematic skills (Geary, Hoard, Nugent, & Bailey, 2013). Strong foundational fluency in computational skills predicts economic opportunities in the future (Geary et al., 2013). The connection between fluency in basic mathematics and the ability to become proficient in mathematics warrants further examination.

There are five mathematical strands required to reach proficiency identified by the Mathematics Learning Study Committee:

Mathematical proficiency involves five intertwined strands: (1) understanding

mathematics; (2) computing fluently; (3) applying concepts to solve problems; (4) reasoning logically; and (5) engaging with mathematics, seeing it as sensible, useful, and doable. (2002, p. 1).

The strands of proficiency are not independent of each other, but rather woven together to create a stronger understanding (Mathematics Learning Study Committee, 2001). First, students must develop conceptual understanding of the mathematical concepts and skills they are learning. Second, the students become accurate and build computational fluency through focused and purposeful practice. When students understand concepts, develop accuracy and strategic flexibility through strategies, and develop fluency their reasoning and ability to solve higher-level mathematics problems using those skills will improve (Mathematics Learning Study Committee, 2001). Without a strong conceptual understanding and foundational fluency, it is difficult to progress through higher levels of mathematics (Geary, 2014; 2011).

Executive Functioning

Mathematical proficiency involves three general types of knowledge with each playing a critical role in the developmental progression towards proficiency. (Goldman & Hasselbring, 1997). Declarative knowledge is represented as facts about mathematics (Goldman & Hasselbring, 1997). Procedural knowledge is denoted as rules or procedures used to solve mathematical tasks (Goldman & Hasselbring, 1997). Conceptual knowledge is defined as information that is connected, and the linking relationships are as important as the information itself (Goldman & Hasselbring, 1997). Declarative knowledge lays the foundational skills for computation and solving procedural and

conceptual problems, allowing for more time to be spent using the working memory for procedural and conceptual.

Working memory plays a key role in fact fluency and mathematics skills overall. Working memory involves the ability to complete tasks through cognition (LeFevre, DeStefano, Coleman, & Shanahan, 2005). When students are able to recall a fact quickly and automatically, less working memory is used in order to develop the answer (LeFevre, DeStefano, Coleman, & Shanahan, 2005). Using less working memory allows the individual to focus on the more complex mathematical concepts, tasks, and the appropriate interpretation of numerical quantities.

Fact Fluency

Fluency is defined as performance that includes both accuracy and speed (Johnson & Layng, 1996). Students begin learning information through an acquisition phase (Burns, Coddington, Boice, & Lukito, 2010). During the acquisition phase, students require modeling, prompting with scaffolds, guided practice, and frequent feedback (Burns et al., 2010). After students develop a basic understanding, focused and purposeful practice is needed to become accurate. There are a variety of methods to teach basic facts and promote accuracy.

One method for teaching facts is through Incremental Rehearsal (IR; Joseph, 2006). IR introduces facts in groupings or chunks based on known facts to unknown facts (e.g. 4 known facts are paired with 1 unknown fact). The unknown fact is mixed with the known facts and presented until it becomes known (Joseph, 2006). Other empirically based interventions include detect-practice-repair (DPR), Cover Copy Compare (CCC), and taped problems (Musti-Rao & Plati, 2015). After students develop understanding and become accurate with a

fact, they then work towards fluency. Researchers have established students should reach a minimum of 80% accuracy with their facts before moving into fluency building activities (Rhymer, Skinner, Henington, D'Reaux, & Sims, 1998). Mathematics fluency interventions serve as opportunities for students to practice known facts until the facts are produced accurately and quickly (Burns et al., 2010).

Fact fluency is defined as the ability for students to accurately and rapidly answer facts in the four basic operations (Bryant et al., 2015; Duhon, House, & Stinnett, 2012; Musti-Rao & Plati, 2015). According to the CCSS, students should fluently add and subtract by the end of second-grade, and fluently multiply and divide by the end of third-grade (National Governors Association (NGA), 2010). NGA states the following standards:

CCSS.MATH.CONTENT.2.NBT.B.5:

Fluently add and subtract within 100 using strategies based on place value, properties of operations, and/or the relationship between addition and subtraction (NGA, 2010).

CCSS.MATH.CONTENT.3.OA.C.7:

Fluently multiply and divide within 100, using strategies such as the relationship between multiplication and division (e.g., knowing that $8 \times 5 = 40$, one knows $40 \div 5 = 8$) or properties of operations. By the end of Grade 3, know from memory all products of two one-digit numbers (NGA, 2010).

Given the documentation of students with mathematics disabilities struggling with fluency, and the emphasis within the CCSS, the What Works Clearinghouse (WWC) outlined specific parameters for effective fluency interventions. First, students should

practice fluency for approximately 10 minutes each day following instruction in the targeted facts (Gersten et al., 2009). Practice can occur using technology, flashcards, and other materials to facilitate automatic retrieval (Gersten et al., 2009). These practices should embed a cumulative structure and continue through middle school (Gersten et al., 2009). Students can and should learn strategies to assist with accuracy, but eventually build their way to automatic recall with limited strategy use (Gersten et al., 2009). Reaching automatic recall allows students to off-load their working memory and better maximize their processing capacity to devote to reasoning and problem solving tasks (Geary 2013).

Currently, a number of programs and practices are used to promote fact fluency. Some curriculum programs embed fluency practice within the content, while other programs encourage students to practice fluency outside of the curricula (NMAP, 2008). Many curricula however, do not provide sufficient practice (NMAP, 2008; Witzel & Riccomini, 2007). One way in which teachers promote fluency practice with facts is developing strategies through game play (Godfrey & Stone, 2013; Kling & Bay-Williams, 2015). These strategies vary and have limited documented effectiveness, but can involve practices such as counting on, memory songs, or using manipulatives or fingers (Godfrey & Stone, 2013; Kling & Bay-Williams, 2015). Evidence-based practices promote the use of a fluency programs for 10 minutes daily, but do not specify which programs (Gersten et al., 2009). In general, fluency practice should present a fact, provide appropriate wait time, allow for student response, focus on automatic recall, and provide corrective, immediate feedback (Gersten et al., 2009).

Digital-Based Practices

With accessible technology become more widely available, educational practices are including more and more digital-based instructional tools. Digital-based instructional tools are programs involving practice through a computer or tablet. Although still developing, research conducted on the effects of technology to increase mathematics performance over the last three decades indicates positive outcomes and have confirmed technology-based practice programs can improve students' performance in mathematics (Hasselbring, 1988; NMAP, 2008). Additionally, the costs of technology have declined significantly, allowing for computers and devices such as tablets and iPads to become more common in the classroom (Lynch, 2013). Due to the increase in technology availability, teachers are turning towards digital educational programs and applications to teach and practice skills in and out of the classroom (Lynch, 2013).

There are some commonly cited benefits to using technology to practice facts such as increased time on task, immediate feedback, and increased student motivation (Burns, Kanive, & DeGrande, 2012; Duhon, House, & Stinnett, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014; Nordness, Haverkost, & Volberding, 2011; Musti-Rao & Plati, 2015; Stickney, Sharp, & Kenyon, 2012). There are also benefits to teachers and educators that are worth considering.

Many of the applications and programs are customizable and differentiated to meet the fluency needs of many students at a time. Some programs provide data tracking tools for both the student and the teacher to see how the student is progressing (Apple, 2016). The

cost of many of the programs and applications are low, ranging from \$500 for a district-wide intervention program to \$0.99 for a single application for a tablet (Apple, 2016). Despite the amount of technology available, minimal research investigating the effects of these digital-based interventions is available (Kroeger, Brown, & O'Brien, 2012). Due to the increase in available technology surpassing the amount of research being conducted, the research on this topic is undeveloped (Kroeger et al., 2012).

The purpose of this study is to examine the effects of digital-based interventions on the fact fluency of students with mathematics difficulties. The specific research questions addressed in this analysis are:

1. How are the programs structured for practice (i.e. computer or tablet, frequency and duration of intervention)?
2. How are the students practicing within the programs (i.e. operations used, response choices, wait time, and correction procedures)?

Method

Search Criteria

We examined peer-reviewed published experimental studies demonstrating the effects of interventions designed to enhance fact fluency of students with mathematics disabilities that met four conditions. First, studies included at least one participant with a disability or was at risk for disabilities (and had an IEP Goal in mathematics or teacher recommendation), or showed mathematics difficulty (performing below grade-level or requiring additional supports). Second, the study included students enrolled in an

elementary or middle school. Third, the studies included a dependent measure of single-digit fact fluency. Fourth, the intervention used some form of a digital-based fact practice (defined as computer software or internet based program for a computer, or application for a tablet).

Search Procedures

In order to conduct the review, two steps were used. First, combinations of the following terms were used: *special needs*, *students with disabilities*, *math difficulties*, or *Special Education*, and *math facts* or *math fluency* and *computer-based*, *computer learning*, *digital-based*, or *technology*. Key phrases were searched in titles and abstracts. The search included results dated as far back as was in the database, 1988 through 2016. Searches were completed using the ProQuest Education Journals Database, the EBSCO Host database, the PsycINFO database, and Google Scholar. Electronic database searches were followed by an ancestral search of the reference lists of relevant literature reviews and identified studies. A total of 257 articles were returned and abstracts read, six of which met the inclusion criteria. Second, in text citations and references of the 6 studies meeting the criteria were consulted and reviewed, yielding two additional studies. Eight studies meeting the criteria were identified and included in the analysis.

Results

Digital-based mathematics practice interventions on fluency have variables that impact their effects. Study designs, participant characteristics, fluency assessments, structure of the programs, and how the students practiced can impact fluency. It is important to consider these implications when discussing the efficacy of

these digital-based practice interventions. Table 1 displays participant characteristics, Table 2 presents a summary of the interventions from each study, and Table 3 displays the results of the interventions.

Design

There were two types of experimental research designs found in the eight studies. Four of the studies used a group design (Burns, Kanive, & DeGrande, 2012; Duhon, House, & Stinnett, 2012; Hasselbring, Goin, & Bransford, 1988; Kanive, Nelson, Burns, & Ysseldyke, 2014). Four studies used a single-case design. Three studies utilized alternating treatment design (Bryant et al., 2015; Musti-Rao & Plati, 2015; Wilson, Majsterek, & Simmons, 1996). Nordness, Haverkost, and Volberding (2011) used a multiple baseline design.

Participants

Number of participants ranged from 3 to 442 (total $n = 749$) and included both male (reported $n = 56$) and female (reported $n = 59$) students. The range of ages included 7–14 years of age and grades 2–5. The specifics of the number of participants, ages, and exceptionalities are presented in Table 1.

The types of disabilities varied among the studies. Four of the studies included participants with mathematics difficulties ($n = 576$), students scoring in the bottom 25% on standardized mathematics assessments or struggling in mathematics as deemed by their teacher, as their exceptionality (Burns, Kanive, & DeGrande, 2012; Duhon, House, & Stinnett, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014; Musti-Rao & Plati, 2015). Two studies included participants with learning disabilities ($n = 10$) as their primary exceptionality (Bryant et al., 2015; Wilson, Majsterek, & Simmons, 1996). Hasselbring, Goin, and Bransford (1988) used a

comparison of students with disabilities ($n = 80$) and students without disabilities ($n = 80$) to compare participation in the program. Nordness, Haverkost, and Volberding (2011) included students with learning disabilities ($n = 2$) and behavior disorders ($n = 1$).

Program Structure

The types of programs used in the intervention divided into two categories: (1) Internet-based programs or software programs used on the computer, and (2) tablet applications. Three studies examined the effect of the intervention delivered on an application using a tablet: Math Drills and Math Evolve (Bryant et al., 2015), Math Drills (Musti-Rao & Plati, 2015), and Magic Math (Nordness, Haverkost, & Volberding, 2011). Three studies used an Internet-based program: Math Facts in a Flash (Burns, Kanive, & DeGrande, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014), and a teacher-created online program (Duhon, House, & Stinnett, 2012). Two studies used computer software: Math Blaster (Wilson, Majsterek, & Simmons, 1996) and Fast Facts (Hasselbring, Goin, & Bransford, 1988).

Three tablet applications were used. Math Drills is an application from the Apple iTunes store costing \$1.99 (Apple, 2016). Math Drills allows for users to add students, track data, use the four basic operations, practice 10 timed problems, and test on 100 timed problems. Math Evolve is an application from the Apple iTunes store costing \$2.99 (Apple, 2016). Math Evolve has two modes: story mode where students play games with facts and practice mode where students can practice all four operations while they control the speed and number of questions being asked. Magic Math is an application from the Apple iTunes store costing \$0.99 (Apple, 2016).

Table 1
Description of Participants

Study	Participants	Age/Grade	Exceptionality
Bryant et al. (2015)	n= 6 4 male 2 female	Grade 4	Learning Disabilities
Burns, Kanive, & DeGrande (2012)	n= 442 DNP	Grades 3 – 4 295 third graders 147 fourth graders	Math Difficulties
Duhon, House, & Stinnett (2012)	n= 32 DNP	Grade 2 7.4 – 8.3 years old	Math Difficulties
Hasselbring, Goin, & Bransford (1988)	n= 160 DNP	7 – 14 years old	Students with disabilities and Students without disabilities
Kanive, Nelson, Burns, & Ysseldyke (2014)	n= 90 42 male 48 female	Grades 4 – 5	Math Difficulties (all), 26.7% identified with a special education disability
Musti-Rao & Plati (2015)	n= 12 5 male 7 female	Grade 3 8.2 – 9.1 years old	Math Difficulties
Nordness, Haverkost, & Volberding (2011)	n=3 2 male 1 female	Grade 2	Learning Disabilities (2) or Behavior Disorders (1)
Wilson, Majsterek, & Simmons (1996)	n= 4 3 male 1 female	9.2 – 10.10 years old	Learning Disabilities

Note. DNP = Data Not Provided

Magic Math uses the four operations to answer questions using pictures or without, and allows customization with the number of problems presented.

Four computer programs were used. Math Facts in a Flash is an Internet subscription program run by Renaissance

Learning. Math Facts in a Flash has the four basic operations as well as square numbers and fractions and decimals, assessments, practice sessions, and data tracking abilities. Fast Facts, now FASTT Math, is owned by Scholastic Inc. as an internet based program. Fast Facts had assessments that drive student practice, questions with

unlimited time to determine speed (latency), and data tracking abilities. Math Blaster was a computer software program when used in the study, but now is an Internet based program. Math Blaster would present an unknown fact and its corresponding answer, then mix it into known facts until it was learned. Students could also play an arcade-style game after completing practice sessions where they were timed. Gary Duhon, the first author of the study, created the final program. The program presented one subtraction problem at a time during a two minute timed practice.

The amount of time each participant spent on the programs varied from a total of 40 minutes to 675 minutes with an average of 267 minutes. Table 2 includes the frequency and duration of the interventions. The number of sessions ranged from 4 sessions to 49 sessions. The duration of each session ranged from 2 minutes to 30 minutes.

Practice Format

The practice format used in the studies' interventions were analyzed. Four distinct practice structures were identified: (a) type of operation used, (b) response choices available, (c) wait time given, and (d) correction procedure followed. See Table 2 for summary of practice formats.

Operations. The basic four operations (e.g. addition, subtraction, multiplication, and division) are typically measured when discussing fact fluency. The four types of operations used were analyzed. One study used mixed operations

of addition, subtraction, multiplication, and division (Burns, Kanive, & DeGrande, 2012). The remaining seven studies used a single operation for intervention practice. Four studies used multiplication facts (Bryant et al., 2015; Kanive, Nelson, Burns, & Ysseldyke, 2014; Musti-Rao & Plati, 2015; Wilson, Majsterek, & Simmons, 1996). Two studies used subtraction facts (Duhon, House, & Stinnett, 2012; Nordness, Haverkost, & Volberding, 2011). Hasselbring, Goin, and Bransford (1988) used addition facts.

Response choices. The response choices are described as how the student was expected to respond to the fact being asked. Two different choices were coded: multiple-choice and open-ended. Four studies used only open-ended responses where the student was asked to type the answer (Duhon, House, & Stinnett, 2012; Hasselbring, Goin, & Bransford, 1988; Musti-Rao & Plati, 2015; Wilson, Majsterek, & Simmons, 1996). Three studies used questions presented in multiple-choice format. Two interventions had three choices presented (Burns, Kanive, & DeGrande, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014). Nordness, Haverkost, and Volberding (2011) gave the students four choices for responding. The study conducted by Bryant et al. (2015) utilized two different intervention programs with two different response choices; Math Drills used open-ended questions while Math Evolve used multiple-choice format with four choices.

Table 2
Description of Digital-based Math Fact Fluency Interventions

Study	Name of program	Number of sessions	Duration of sessions	Total time (in minutes)	Type of facts	Presentation of facts	Wait time	Correction
Burns, Kanive, & DeGrande (2012)	Math Facts in a Flash (C)	3 per week for 8-15 weeks	5 - 15 min	120 - 675	Add, Sub, Mul, Div	Multiple choice: 3 choices	NS	Provides answer
Bryant et al. (2015)	Math Drills (T)	15 sessions	30 min	450	Mul facts of 4s and 8s	Open-ended	NS	3 attempts, provides answer, student must re-type answer
Bryant et al. (2015)	Math Evolve (T)	15 sessions	30 min	450	Mul facts of 4s and 8s	Multiple choice: 4 choices	3 – 20 seconds	Provides answer
Duhon, House, & Stinnett (2012)	Teacher-Created (C)	20 sessions	2 min	40	Sub facts up to 18	Open-ended	NS	No answer provided
Hasselbring, Goin, & Bransford (1988)	Fast Facts (C)	49 sessions	10 min	490	Add	Open-ended	3 seconds	Provides answer, student must re-type answer
Kanive, Nelson, Burns, & Ysseldyke (2014)	Math Facts in a Flash (C)	4 sessions	30 min	120	Mul	Multiple choice: 3 choices	NS	Provides answer
Musti-Rao & Plati (2015)	Math Drills (T)	8 sessions	10 min	80	Mul facts 2-9	Open-ended	NS	Provides answer
Nordness, Haverkost, & Volberding (2011)	Magic Math (T)	3 per week for 10 weeks	10 min	300	Sub facts up to 20	Multiple choice: 4 choices	No limit	2 attempts, provides answer
Wilson, Majsterek, & Simmons (1996)	Math Blaster (C)	13 sessions	10 min	130	Mul facts 0-9	Open-ended	2 – 6 seconds	2 attempts, provides answer

Note. T = Tablet Application, C = Computer, Add = Addition, Sub = Subtraction, Mul = Multiplication, Div = Division, NS = Not Specified

Wait time. Wait time is defined as the amount of time a student was provided to answer the question. The studies were analyzed to determine how much wait time was provided. After the problems were presented, four of the programs provided wait time before providing the student the answer if they were unable to respond. The program used by Wilson, Majsterek, and Simmons (1996) provided a range of two to six seconds of wait time; the amount of wait time was set by the teacher/monitor before practice began and was based on student performance. Bryant et al. (2015) had two programs as a part of their study, Math Evolve provided three to twenty seconds of wait time that the teacher controlled and Math Drills did not specify if wait time was provided. One study provided three seconds of wait time for each question (Hasselbring, Goin, & Bransford, 1988). Nordness, Haverkost, and Volberding (2011) used an intervention that gave the students untimed problems during practice to determine latency. Four studies did not specify the wait time given for each problem (Burns, Kanive, & DeGrande, 2012; Duhon, House, & Stinnett, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014; Musti-Rao & Plati, 2015).

Correction procedure. The correction procedures were how the individual programs responded to student responses on an individual problem (e.g. correct or incorrect responses). Details of attempts allowed, providing the correct answer, and requiring the student to select the correct response before progressing are provided in Table 2. Three programs provided additional attempts for the students to correctly answer the problem, ranging from two to three attempts (Bryant et al., 2015; Nordness, Haverkost, & Volberding, 2011; Wilson, Majsterek, &

Simmons, 1996). Two programs provided the answer and asked the students to re-type the correct answer (Bryant et al., 2015; Hasselbring, Goin, & Bransford, 1988). Three programs provided the correct answer immediately after the first attempt was incorrect (Burns, Kanive, & DeGrande, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014; Musti-Rao & Plati, 2015). One intervention told the student that they missed the problem, but did not identify what the correct answer was or allow another attempt (Duhon, House, & Stinnett, 2012).

Effects and Progress

Each study showed results that the intervention yielded some improvement in mathematics fluency. The studies used a variety of assessments for pre- and post-intervention assessment. The specifics of the assessments and results are located in Table 3. Six studies used CBM in math (Bryant et al., 2015; Duhon, House, & Stinnett, 2012; Kanive, Nelson, Burns, & Ysseldyke, 2014; Musti-Rao & Plati, 2015; Wilson, Majsterek, & Simmons, 1996). Nordness, Haverkost, and Volberding (2011) used the N-ABLES assessment, Nebraska Abilities Math Test, which is a CBM. Two assessments used norm-referenced criteria to measure fluency and mathematics abilities. Burns, Kanive, and DeGrande (2012) used the Star Math assessment. Hasselbring, Goin, and Bransford (1988) used the Chronometric Assessment of Math. When reported, the timing of the assessments ranged from 2 minutes to a latency test using an unlimited amount of time.

Mastery Criteria. Each intervention used specific mastery criteria to consider if math facts had been mastered to meet fluency standards in the post-assessment. Two studies used the mastery criteria of

80% accuracy prior to the students beginning the fluency interventions (Bryant et al., 2015; Duhon, House, & Stinnett, 2012). The results of the interventions were reported in a variety of ways including dcpm, facts, percentage growth, and percentage growth using the normal curve equivalent.

Growth. Interventions using tablet-based applications stated growth in the following ways. One study reported growth in percentage, 17% on the N-ABLES (CBM) assessment (Nordness, Haverkost, & Volberding, 2011). Two studies presented growth in digits correct per minute: 9.8 dcpm (Bryant et al., 2015) and 31 dcpm (Musti-Rao & Plati, 2015). Interventions using computer-based applications stated growth accordingly. Two studies presented growth in digits correct per minute: 6.1 dcpm (Duhon, House, & Stinnett, 2012) and 7.3 dcpm (Kanive, Nelson, Burns, & Ysseldyke, 2014). Burns, Kanive, and DeGrande (2012) reported a mean growth in normal curve equivalent of 9.87% in third grade and 11.66% in fourth grade from the baseline scores. The additional two studies were reported as facts mastered using mastery criteria: 6.5 facts on average (Wilson, Majsterek, & Simmons, 1996), and 45 facts on average (Hasselbring, Goin, & Bransford, 1988).

Discussion

Researchers have established students with difficulties in mathematics frequently struggle solving basic arithmetic facts (Geary, 2014; 2013; 2004). This review

sought out to find the effects of digital-based interventions on the fact fluency of students with mathematics difficulties, how the programs structured practice, and how the students were practicing within the programs. Data from these studies provided initial evidence that digital-based fluency interventions can increase student fluency when implemented with students having mathematics difficulties. The structure of the programs, including computer versus tablet and time spent on the program, can impact student practice. Within each program, there are differing formats (i.e. operations, response choices, wait time, and correction procedures) that influence ways students practice facts.

Design

Single case and group design studies were included in this review. According to the WWC, single case experimental design has continued to grow in the field of special education (Kratochwill et al., 2010). As the standards have become more rigorous and published, researchers are using single case design to establish the effects of interventions with small numbers of individuals (Kratochwill et al., 2010). Group design has established effectiveness in the literature (Gersten et al., 2005). Group design allows for researchers to take interventions to large numbers of students to determine effects. (Gersten et al., 2005). Both single case and group design structures bring information to the field related to mathematical fluency.

Table 3
Description of Results of Fluency Interventions

Study	Program Used	Assessment Type	Length of Assessment	Mastery Criteria	Growth
Burns, Kanive, & DeGrande (2012)	Math Facts in a Flash (C)	SM – 24 problems	DNP	40 correct in 2 minutes (post)	3 rd grade – 9.87% in NCE 4 th grade – 11.66% in NCE
Bryant et al. (2015)	Math Drills (T) & Math Evolve (T)	CBM	2 minutes	80% accuracy (pre and post)	9.8 dcpm
Duhon, House, & Stinnett (2012)	Teacher-Created (C)	CBM	2 minutes	80% accuracy (pre and post)	6.1 dcpm
Hasselbring, Goin, & Bransford (1988)	Fast Facts (C)	CAMS – 100 problems	Unlimited - latency	Student can answer correctly in 1.5 seconds (post)	45 facts
Kanive, Nelson, Burns, & Ysseldyke (2014)	Math Facts in a Flash (C)	CBM – 40 problems	2 minutes	40 correct in 2 minutes (post)	7.3 dcpm
Musti-Rao & Plati (2015)	Math Drills (T)	CBM – 36 problems	2 minutes	31 dcpm (post)	32 dcmp
Nordness, Haverkost, & Volberding (2011)	Magic Math (T)	CBM (N-ABLES) – 100 problems	5 minutes	95% accuracy with all 100 facts (post)	17% growth
Wilson, Majsterek, & Simmons (1996)	Math Blaster (C)	CBM	DNP	Student can answer correctly in 3 seconds on 2 consecutive probes (post)	6.5 facts

Note. C = Computer, T = Tablet, CBM = Curriculum-Based Measure, SM = Star Math, CAMS = Chronometric Assessment of Math Strategies, DNP = Data Not Provided, NCE = Normal Curve Equivalent

Participants

The majority of the studies included students in elementary school. Mathematical facts and fluency are often topics that are typically mastered during elementary school (Mathematics Learning Study Committee, 2001). Therefore, this group is an appropriate population to consider when evaluating fluency programs. Due to the use of school-wide interventions, some of the studies used a population of students with 'mathematics difficulties'. This term can be used to describe both students with and without diagnosed disabilities. Using students with 'mathematics difficulties' have allowed researchers to reach a greater number of participants in their research, because they are more easily accessible. The implementation of Multi-Tiered Systems of Support encourages tiered interventions, such as fluency interventions, that can be implemented with students with and without disabilities (Gersten et al., 2009; Riccomini & Witzel, 2010). Furthermore, little is known about using digital tools as effective fluency interventions amongst specific and various populations.

Program Structure

With technology applications improving, digital-based programs are becoming more popular (Lynch, 2013). Some programs are available for use as software or Internet based programs on the computer, or tablet applications. These programs can allow the user with the ability to access the intervention in a combination of the categories. The studies outlined in this review used the programs only in a single format. No studies compared the same program on a computer against a tablet, but many programs are accessible on both computer and tablet applications. The costs of these programs vary based on

features, users, and data available to the instructor. Many programs offer customization for individual students and the ability for teachers to control problems presented, mastery criteria, and data reporting.

In most instances the teacher or instructor designates how much time is available for the students to practice the programs. The recommended amount of time for practicing fluency is 10 minutes daily (Gersten et al., 2009). Six of the eight studies had students practicing for at least 10 minutes during sessions, but they were not specific about sessions occurring daily. A fact fluency intervention should be implemented until the student shows mastery using pre-determined criteria of 20-40 dcpm depending on the standard and student selected (Burns, Coddling, Boice, & Lukito, 2010; Deno & Mirkin, 1977; Stickney, Sharp, & Kenyon, 2012).

Practice Format

The practice format is one of the essential elements to fluency building. The variables analyzed included operations used, response choices, wait time, and correction procedures. Some programs offer the potential for the teacher to alter the program variables to best suit their students' needs, while others have pre-set formats. The studies varied in the types of facts that the researchers used, however, many math-fact programs offer the potential to practice all four basic operations. The elements of effective practice methods are discussed.

Response choices. The use of different response choices can be scaffolded to assist students at their level of need and support while first learning a topic. When practicing fluency, the goal is for a student to recall a fact automatically without hesitation, within 2-3 seconds

(Burns, Coddling, Boice, & Lukito, 2010; Stickney, Sharp, & Kenyon, 2012). Consideration should be taken for both of the skills involved in answering a multiple choice and an open-ended question using a tablet or computer. If a student has a slow reading speed, they may struggle on multiple-choice questions, due to the necessity of reading their choices. If a student has poor keyboarding skills, asking them to type the response will delay their results. If a student knows the fact, then the best way for them to improve the speed in which they can identify it, would be to use open-ended response (Kling & Bay-Williams, 2015). This is due to the student needing to use automatic recall instead of having scaffolded prompts from which to select their answer. However, if a student does not know their facts well, multiple-choice may provide an opportunity for them to have options to select the correct answer building accuracy.

Wait time. When discussing fluency, it is important to clarify that for a student to be considered fluent, they must be able to state the answer to the fact accurately and quickly after being presented with the fact. With the established criteria of 2-3 seconds of wait time, only one study used this criterion throughout their intervention. Because these studies were interested in measuring students' fact fluency, the interventions should have involved an element of time. The amount of time given for student response was not provided in five of the studies. Some of the programs provided the teacher the ability to control how long the student had to respond before another prompt or the correct answer was given. This is helpful for students who are working towards fluency. For example, if a student could answer a fact in 5 seconds but not 3 seconds, over

time the teacher would reduce the time available to answer the question to progress the student towards mastery in fluency.

Correction procedure. There were an assortment of correction procedures found within the eight studies. Seven of the studies gave students the correct answer; and of those, three provided the student another opportunity to respond. One intervention did not provide any feedback, but rather moved onto the next question, revealing the scores at the end of the session. The feedback needs to provide the student the correct answer, so the student is able to retain the correct response for the future. Research has established that providing immediate feedback allows students to learn and retain more (Epstein et al., 2010). Using digital based programs with immediate feedback allow for the students to receive instant feedback instead of relying on a teacher to have the time to check on their work. This allows students to receive support when they are in large groups, or at times when teacher supervision is minimal (e.g. independent work time or time spent at home). The teacher is then able to monitor student progress and provide feedback after the intervention has taken place, with the use of data monitoring systems.

Effects and Progress

There were a variety of methods used to collect pre- and post-intervention data. Because of the lack of packaged resources (i.e. norm referenced math assessments on particular topics) in mathematics assessment, many teachers have relied on curriculum based measures to evaluate fluency. Other studies used a variety of assessments to collect information. Because these assessments are not universally the same, it is difficult to

compare the strength of the effects of the interventions.

Mastery Criteria. Mastery criteria were pre-determined for the post-assessment in each study. Only two studies used appropriate pre-assessment criteria. Research has established that students should be 80% accurate before beginning a fluency intervention (Rhymer, Skinner, Henington, D'Reaux, & Sims, 1998). According to best practices, students should be able to answer a fact accurately between 2-3 seconds (Burns, Coddling, Boice, & Lukito, 2010; Deno & Mirkin, 1977; Stickney, Sharp, & Kenyon, 2012). Five studies used mastery criteria upheld by these standards while three studies used criteria that were not explicit enough to meet the mastery criteria.

Growth. It is encouraging that all of the studies reported growth in fact fluency in one form or another. Difficulty lies in the fact that the studies represented growth in a range of measures: percent growth, correct digits per minute, and facts mastered. When discussing fluency, researchers have established that the appropriate and reliable measure is digits correct per minute (Deno & Mirkin, 1977). This range of effects makes it difficult to compare which of the interventions were more effective than others. Two of the studies juxtaposed teacher directed instruction against digital practices; the remaining studies did not mention any type of teacher training or education prior to beginning the studies. All of the studies used interventions that required additional time outside of the curriculum.

Implications

Digital-based fluency interventions show promise to promote fluency in students with mathematics difficulties.

Review of the eight studies showed growth in fluency using various types of digital-based programs. As technology continues to play a larger role in society and in the classroom, digital-based programs are becoming a helpful tool for reaching many students at a time. Digital tools can provide immediate feedback and require less organization than paper and pencil interventions do.

There are numerous implications for teachers. The opportunity for teachers to have multiple students on various levels practicing fluency at the same time, is an advantage of using digital-based interventions and can enhance differentiation. Certain programs also offer many customization options (e.g. operation choice, speed of problems presented, number of problems presented, etc.) for teachers to utilize to set the program specifically for individual students' success. Customization is positive feature for both teachers and parents by offering flexibility for the program to be individualized to students' practice needs. Many of the programs are affordable, but require some additional source of technology to run (i.e. iPad, Computer, tablet, Internet, etc.). Data tracking is available in many programs for both the student and teacher. This is extremely helpful at a time when teachers are expected to use data driven instruction and report progress on student goals. It is feasible that many teachers (general education and special education) can effectively implement a digital-based math intervention into their classroom if existing technology is available.

Limitations of the Studies Reviewed

There are at least two limitations of the reviewed studies, which caused limitations in this review. First,

inconsistencies in ways by which various elements of the research were presented caused limitations. The mastery criteria were different for many of the studies. Growth in fluency was also reported in different ways, making it difficult to compare which specific elements contributed to student success or which participants benefitted the most from the interventions. Second, six of the studies lacked clarity of how much instruction students were receiving before beginning the interventions. Research has established that students must have an understanding of the fact conceptually and be accurate with it before they are able to practice it for fluency (Rhymer, Skinner, Henington, D'Reaux, & Sims, 1998). None of the interventions worked with students until they had an entire operation mastered, which would assist in bridging the gap in proficiency. The studies also primarily focused on elementary aged students. NMAP (2008) has shown that students through the eighth grade are still showing fluency problems, which impede with their Algebra knowledge and understanding. Most of the studies focused on an individual operation without considering the cumulative practice needed in previously mastered operations in order to maintain fluency.

Future Research

Future research should continue to evaluate the effects of digital-based interventions on students with mathematics difficulties and students with disabilities. Research should focus on the effects on specific populations of students including more specific disability categories and middle school students, as fluency continues to be an area of need for students through eighth grade. As

additional technology becomes available, there are many other programs or critical features (e.g. mastery criteria, assessments used for placement, presentation of problems, etc.) that could be evaluated in order to determine their effects on fluency. The various elements of programs (e.g. response choices, wait time, correction procedures, etc.) could also be drawn out and isolated to determine which elements help promote the most growth in fluency. Further research should consider established criteria for best practices in fluency interventions and evaluate programs that meet those practices. Another consideration would be to compare the results of a digital-based program and a similar paper-based program to determine which establishes higher rates of growth.

Conclusion

This literature review set out to answer the following questions: What are the effects of digital-based interventions on the math fact fluency of students with math difficulties? How are the digital programs structured in regard to computer or tablet and frequency and duration? How are the students practicing within the programs (i.e. using operations, response choices, wait time, and correction procedures)? The review established that students with mathematics difficulties are showing positive rates of growth in math fact fluency when using a digital-based intervention. The digital programs are structured differently with various presentations, timings, and error correction procedures. The students are practicing the four basic operations on digital-based programs during sessions with pre-determined timings.

As discussed in the introduction, there is limited research in the use of digital-based mathematics fluency interventions. Due to the fact that much of the research is supported solely by research foundation papers, not many interventions evaluated through research meet the scientific community's high standard of empirical research (Kroeger, Brown, & O'Brien, 2012). Several things can be learned from review of the previous research; helping future research to become stronger. Although research in this area documents positive effects, more specifics on the elements of the digital-based programs and specific disabilities that are most successful in regards to the intervention would be useful. In a digital age, technology is a tool in which there is much opportunity for student growth and achievement.

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*Indicates a study met the inclusion criteria for this review.

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