Promoting Personally Relevant Access to the General Mathematics Curriculum for Students With Intellectual Disability

Jennifer Elizabeth Cook
jcook28@vols.utk.edu

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To the Graduate Council:

I am submitting herewith a dissertation written by Jennifer Elizabeth Cook entitled "Promoting Personally Relevant Access to the General Mathematics Curriculum for Students With Intellectual Disability." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Education.

Tara C. Moore, Major Professor

We have read this dissertation and recommend its acceptance:

David F. Cihak, Marion B. Coleman-Lopatic, Christopher H. Skinner

Accepted for the Council:

Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)
Promoting Personally Relevant Access to the General Mathematics Curriculum for Students With Intellectual Disability

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

Jennifer Elizabeth Cook
August 2020
Dedication

To my husband Justin, thank you for taking care of everything to allow me to focus on this one thing. Your unconditional love, unwavering support, and tireless commitment to me and to our boys has made this dream of mine a reality. You are and always will be our rock.

To my mom who has always had my back, has believed in me from the beginning, and will always be my biggest cheerleader. Thank you.

To my dad who taught me to always root for the underdog and that everyone needs someone who believes in them. Thank you.

To my lifelong friends, Mandy, Vanessa, and Allison. Not many people are blessed with friendships as strong or as long as ours. We have been through it all together. Thank you for always standing by my side. Because of you, life is fun.

To my Morristown friends, thank you for taking care of my boys in my absence, for keeping me and them on track, and for always giving even when I did not have much to give in return.

To my doc student friends, this has been a wild ride and I am thankful we were in it together. To those ahead of me, thank you for your advice and support. To those after me, I am here for you, too. You will always have my support. We are in this together.

And finally, to my boys Kaelan and Drew. I know the sacrifices you have made over the past three years. I hope you know that you were, are, and always will be my world. You make me proud every single day. Thank you for not giving up on me. I know Dad has taught you so much about life. I hope I have taught you the unequivocal power of education; the beauty of diversity; and the wonder of sharing this life with individuals with disabilities.
Acknowledgements

Thank you to Dr. Tammy Bowlin who recognized my passion and encouraged me to apply to UT– I am forever grateful to you for getting this ball rolling. To the CEHHS faculty at UT, thank you for your guidance throughout this journey and for bringing back some of the ideology that had slipped away from me over time. Dr. Cihak, thank you for seeing the potential in me and providing me the opportunity to fulfill my dreams. You have shown us all that higher education is important and challenging work, but is also a great deal of fun. Dr. Skinner, you were my first professor at UT and I am fortunate to have been able to learn from one of the best in the field of behavior science. Thank you for believing in me from the beginning to the end. Dr. Coleman, thank you for your guidance throughout this dissertation and for recognizing the value of personally relevant instruction for students with disabilities. Through your example, I know that even in higher education, our students are our priority and relationships matter most. Dr. Moore, thank you for giving me with the opportunity to work with and learn from you and TBSP. You ignited in me a passion for positive behavior supports for students with disabilities and I hope to continue this line of work moving forward. Thank you for the endless hours you invested in me to support, encourage, and ensure my success. Without you, I would not be here today at the end of this arduous academic journey and at the beginning of a career in higher education. Go Vols! Finally, to the special education faculty at ETSU, thank you for giving me the chance to join you in the amazing work you are doing with our teacher candidates. Drs. Mims, Chambers, Rowe, Marks, and Hitt, I am grateful for your support when I transitioned to higher education. Thank you for your mentorship, leadership, and friendship. Most importantly, thank you for believing in me. I look forward to the years ahead at ETSU and to collaborating with all of you who are passionate about our work with students with disabilities. Go Bucs!
Abstract

Providing access to the general curriculum for students with intellectual disability (ID) has been a topic of debate in the field of low-incidence disabilities (e.g., Ayers et al., 2011; Trela & Jimenez, 2013). Researchers (e.g., Spooner et al., 2006; Trela & Jimenez, 2013) generally agree that students with ID should have access to the general academic curriculum, but some (e.g., Ayers et al., 2011) are concerned that adhering to a standards-based academic curriculum may not lead to independence. Trela and Jimenez (2013) proposed the term personally relevant to describe curriculum modifications for students with ID. Personally relevant modifications provide individualized support and a focus on academic curriculum that is meaningful for each student. Finally, a 2006 literature review of academic interventions for students with ID (Spooner et al.) found more evidence for reading interventions than for math interventions. The purpose of this dissertation was to identify effective strategies and interventions to support personally relevant access to the general mathematics curriculum for students with ID. Study one of this dissertation was a systematic review of math fact literature for students with ID. Basic math fact acquisition and fluency is imperative for independent living (Codd ing et al., 2011) and students with ID should be provided opportunity to acquire basic math facts to automaticity. The purpose of the review was to identify empirical studies on math fact interventions for students with ID, summarize the evidence base, and use those findings to offer recommendations to the field of ID for future research and application. Study two investigated the use of a technology-aided instruction (TAI) and augmented reality (AR) intervention for basic math fact acquisition in elementary students with ID. Three students participated in a multiple baseline design single-case study. An AR application was used to teach basic addition and multiplication facts. Results indicated the AR intervention improved math fact acquisition for all three students. Findings
were discussed in the context of TAI and Universal Design for Learning (UDL) to provide personally relevant access to the general math curriculum for students with ID.
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Chapter One
Promoting Personally Relevant Access to the General Mathematics Curriculum for Students With Intellectual Disability

Significance of the Problem

Much has changed in the field of special education since the original federal law (Education for All Handicapped Children Act (EHA), P.L. 94-142, 1975) legally mandated a public education for students with disabilities. Prior to EHA, many children with Intellectual Disability (ID), frequently defined as students exhibiting substantial limitations in intellectual functioning and adaptive behavior (Schalock et al., 2019), were excluded from public education. As more and more students with ID began attending public schools for the first time, schools and teachers had to shift their focus of instruction from a traditional academic curriculum for all to one that was designed to meet the individual and unique needs of students with ID. Historically, Spooner and Browder (2015) note an increasing trend towards inclusion with three major advances in the focus of instruction for students with ID shifting from developmental to functional and academic. Furthermore, the No Child Left Behind Act (NCLB; No Child Left Behind Act, 2001) established and the Every Student Succeeds Act (ESSA; Every Student Succeeds Act, 2015) further promoted a standards-based reform for all students.

With the passing of ESSA, states were required to develop a system of academic-standards, assessment, and accountability measures for all students including those with the most severe cognitive disabilities (ESSA, 2015). However, regarding students with disabilities, the language of ESSA seemed to conflict with the language of the Individuals with Disabilities Education Act (IDEA, 2004). Specifically, ESSA required states to set consistent and challenging academic standards for all students, while IDEA focused on an individualized education for students with disabilities. Both laws, however, included similar language requiring
that students with disabilities must be afforded access to the general curriculum. Access to the
general curriculum included high expectations and rigorous academic standards. The question
remained, how do we provide students with significant disabilities access to the general
education, including academic standards, while also providing an individualized education? This
question provided the focus of this dissertation.

**Purpose and Organization of This Dissertation**

The purpose of this dissertation was to identify effective strategies and interventions for
academic skills acquisition that support students with ID in accessing the general curriculum.
This dissertation is organized into four chapters. Chapter 1 includes a review of literature to
outline the problem beginning with historical context and culminating in the development of a
theoretical framework for *personally relevant* access to and progress in the general curriculum
for students with ID. Chapters 2 and 3 are designed as two stand-alone studies related to general
curriculum access for students with ID. Chapter 2 is a systematic review of research on math fact
interventions for students with ID. Chapter 3 extends the findings of that review through a
single-case design study investigating the use of an augmented reality application for math fact
acquisition for students with ID. Finally, Chapter 4 includes a discussion, limitations, and
implications for practice and future research. The purpose for each of the two studies in this two-
study dissertation are outlined in the following paragraphs.

**Study 1**

The purpose of this study is to systematically map the research on math fact interventions
for students with ID in Kindergarten through 12th grade classrooms. Specifically, this review will
identify empirical literature addressing math fact interventions for students with ID, identify gaps
in the knowledge base, and use the findings to offer recommendations to the field of ID for
focusing future research and classroom application. Therefore, this review will: (1) summarize characteristics of existing research base; (2) evaluate methodological quality of existing research studies; and (3) summarize outcomes at the case level of methodologically sound studies.

**Study 2**

The purpose of this study is to determine if an AR technology application is an effective tool to teach basic math facts to elementary students with ID. More precisely, research questions addressed in this study include: (a) Is an AR-based intervention effective for student math fact acquisition? (b) if acquired, can the skill be generalized? and (c) what is the social validity of using AR for math fact acquisition?

**Historical Context**

In the 1970s, an increasing number of students with moderate and severe ID began regularly attending public schools. These programs typically used a behavior analytic approach to instruction inspired by principles of operant behavior and the work of B. F. Skinner (Spooner & Browder, 2015). During this time, students with ID were acclimated into the culture of public schools via instruction that was largely developmental in nature and typical of an early childhood curriculum (Spooner & Browder, 2015) focusing on school readiness skills like toileting, peer interaction, and basic communication. While these programs and interventions were largely successful in that students acquired basic developmental skills, overall instruction frequently lacked goals for future outcomes for students with ID and lacked focus on age-appropriate instruction (Jackson et al., 2008; Spooner & Browder, 2015). Furthermore, though students with ID were included in public schools, they often participated in instruction in self-contained classrooms segregated from their peers. What followed was the widespread adoption of an ecological framework for instruction largely championed by Lou Brown and colleagues (1979).
The ecological framework emerged out of general concern that the developmental curriculum had not led to improved quality of life outcomes for students with ID (Hunt et al., 2012). Brown proposed a curriculum that prioritized functional skills instruction. Functional skills “refer to the variety of skills that are frequently demanded in natural domestic, vocational, and community environments… which influence a student’s ability to perform as independently and as productively as possible in home, school, and community” (Brown et al., 1979, p. 83). The focus of instruction shifted from basic, developmental skills taught in a separate classroom setting, to age appropriate and useful skills taught in natural settings such as vocational and community locations. Again, through instruction using behavior analytic-based strategies, students learned skills in the least restrictive or natural environment; skills included street crossing, navigating the school environment, and attending sporting events with peers, for example. This focus on fostering functional skills development while preparing students for adulthood was a shift in the right direction. While a functional curriculum continued to be a critical component in instruction for students with ID, access to the general curriculum (defined here as grade level standards-based instruction in academic content) afforded peers without disabilities was not yet a priority.

The No Child Left Behind Act (NCLB, 2001) mandated accountability in schools in the areas of language arts, mathematics, and science instruction for all students, including students with disabilities, and introduced standards-based school reform. Additionally, the Individuals with Disabilities Education as reauthorized in 2004, required students with disabilities to have access to the state standards with accountability measures based on alternate achievement of these standards. With that shift in legislation, the field of special education saw a shift in advocacy, research, and practice to include academic instruction and interventions for students
with ID (Hunt et al., 2012). While this move was primarily met with support (e.g., Spooner & Browder, 2015; Wehmeyer, 2006), it did not come without debate (e.g., Ayres et al., 2011; Turnbull et al., 2003).

**Opposing Views**

A review of the literature focusing on access to the general curriculum for students with ID revealed some dispute among researchers and practitioners. While there has been general agreement that students with ID should have access to the general academic curriculum (e.g. Smith, 2006; Spooner & Browder, 2015), debate has arisen in the context of prioritization of learning and instruction and the concept of an either/or choice between standards-based curriculum and a functional curriculum (Ayres et al., 2011). “Standards-based curriculum has an outcome of grade-level achievement that may or may not lead to more independent functioning. Functional curriculum has outcomes of improving a student’s independent functioning in their current and future environments” (Ayers et al., 2011, p. 11). Ayers and colleagues (2011) conceded that the two approaches are not and should not be mutually exclusive, but individual needs must be considered, recognized, and prioritized in instruction. Meaningful instruction for students with ID must be developed by meeting the requirements of a standards-based curriculum while continuing to focus on functional quality of life outcomes (Ayres et al., 2011). However, other researchers have argued for a fundamental shift in educational expectations towards the inclusive nature of the general curriculum (Wehmeyer, 2006) and have noted that students with ID often meet our expectations when we raise the bar (Spooner & Browder, 2015). Finally, Hunt et al. (2012) offered a solution to the either/or debate. The authors proposed the union of an ecological framework focusing on quality of life outcomes and a standards-based academic curriculum (Hunt et al., 2012). This approach allows for access to the general
curriculum while holding true to the concept of individualization as outlined in IDEA. More importantly, it has switched the focus away from if students with ID should access the general curriculum to how to support these students in making meaningful progress in the general curriculum (Trela & Jimenez, 2013)

**Theoretical Framework: Personally Relevant Access to the General Curriculum**

Access to the general curriculum is imperative for students with ID. The general curriculum offers a wider variety of curricular options, increases student expectations, allows students to obtain well rounded skills, and offers opportunities for peer interaction and social development in an integrated setting (Olson et al., 2016). Without access to the general curriculum, students with disabilities risk marginalization and isolation (Wehmeyer et al., 2004). Wehmeyer (2006) has argued that we must move beyond access and towards progress in the general curriculum for students with ID, stating, “access does not ensure progress, any more than presence in the general classroom ensures inclusion” (p. 323). Ensuring progress in the general curriculum means setting academic goals that extend beyond school and lead to positive outcomes in transition to adult living and employment (Hunt et al., 2012). However, ensuring progress in the general curriculum and maintaining academic rigor while providing instruction that is functional or meaningful for to students with ID has proven challenging (Trela & Jimenez, 2013).

Building on the work of Hunt et al. (2012), Trela and Jimenez (2013) recommended use of the term *personally relevant* to replace the word *functional* to describe curriculum modifications for students with ID. Whereas the functional curriculum implies a *different and separate* curriculum for students with ID, the term personally relevant promotes inclusive practice through *differentiated* instruction and a *common* curriculum (Trela & Jimenez, 2013).
Personally relevant modifications provide a student with ID access to the general curriculum by maintaining high expectations of academic learning while providing necessary supports that are individualized to match the strengths, needs, and interests of the student (Trela & Jimenez, 2013). This process ensures a daily balance between grade-level academic standards and meaningful individualized student goals (Trela & Jimenez, 2013). In sum, personally relevant access to the general curriculum is individualized, not standardized; differentiated, not different; inclusive, not separate; and intentional, not ambiguous. With personally relevant modifications to the general curriculum, students with ID can be full and active members of their school community through sharing a common curriculum. Furthermore, the authors have noted a growing body of evidence that has demonstrated students with ID can make meaningful progress in the general curriculum and by and large, the strategies used included a measure of personal-relevance via connection to students’ lives (e.g., following class routines, drawing similarities between literary character’s preferences and one’s own preferences; Trela & Jimenez, 2013). This research has demonstrated positive effects on learning academic-standards in reading/language arts (Douglas et al., 2011; Hudson et al., 2013), mathematics (Browder et al., 2008), and science (McMahon et al., 2016). Finally, personally relevant access to the general curriculum with a focus on self-determination (e.g., Lee et al., 2008), inclusive practices, and alignment of academic instruction to state-standards can lead to progress in the general curriculum for students with ID.

Self-Determination

Promoting self-determination in students with ID is considered best practice (Wehmeyer et al., 2004) and has been substantiated in the literature (Spooner et al., 2006). Furthermore, self-determined individuals exhibit a variety of behaviors such as choice-making, goal-setting, and
self-instruction. Wehmeyer (2007) defined several elements of self-determined behavior (see Table 1.1, all tables and figures are located in the appendices) and has proposed a definition of self-determination for students with ID in that, “self-determined behavior refers to volitional acts that enable one to act as the primary causal agent in one’s life and to maintain or improve one’s quality of life” (Wehmeyer, 2007, p. 117). Finally, Field and colleagues (as cited in Wehmeyer et al., 2004) described self-determined individuals as having autonomy, a solid understanding of individual strengths and limitations, and a sense of capability leading to greater success and independence in adulthood.

Self-determination theory stemmed from the field of psychology (Deci & Ryan, 1985, as cited in Wehmeyer, 2007) and was later applied to the area of special education. For example, with the enactment of The Individuals with Disabilities Education Act (IDEA, 1990), federal law required that students with disabilities be directly involved in their own transition planning (Wehmeyer, 2007). While initially a focus only in the secondary years, instruction aimed at promoting self-determination is now seen as important for students of all ages (e.g., Papay et al., 2015; Rowe et al., 2015; Wehmeyer et al., 2004) with a growing consensus that instruction should begin in early childhood (Erwin & Brown, 2000; Palmer & Wehmeyer, 2000). Self-determination can be viewed as both a means to and result of access to the general curriculum (Garrels & Palmer, 2019). Furthermore, strong positive correlations have been found between self-determination and academic achievement in students with cognitive disabilities (Gaumer-Erickson et al., 2015; Zheng et al., 2014). When students with disabilities receive explicit instruction in self-determination skills such as student-directed learning (self-instruction), goal-setting and self-monitoring, and choice-making, they have enhanced motivation to perform tasks and achieve goals (Wehmeyer et al., 2004).
**Student-Directed Learning**

Student-directed learning is the process in which students identify learning goals, help plan a course of action for achieving those goals and work independently towards reaching those goals. Students with ID who are supported in self-directed learning have improved academic outcomes (Wehmeyer et al., 2004). The Council for Exceptional Children (CEC) has outlined crucial elements of self-determination and student-directed learning in their performance-based standards for teacher preparation, including encouraging self-advocacy and independence in students with ID (Council for Exceptional Children, 2003). Increasing independence and self-determination in students with ID can lead to enhanced post-school outcomes. Furthermore, students with higher self-determination are more likely to live outside the family home, open a bank account, and be gainfully employed as adults (Wehmeyer et al., 2004).

**Goal-Setting and Self-Monitoring**

Goal-setting and self-monitoring are commonly implemented and validated instructional strategies in special education which can expand access to the general curriculum for students with ID (Lee et al., 2009). Goal-setting is the practice of students’ independently establishing their own learning targets and self-monitoring is the active engagement of the student in self-observing and recording progress towards that learning target (Lee et al., 2009). Students with disabilities who have been taught to set goals and self-monitor progress have demonstrated increased fluency in single-digit math calculation (Figarola et al., 2008), improved composition skills (Graham et al., 1992), and better reading comprehension (Johnson et al., 1997; Jitandra et al., 2000). Overall, a combination of goal-setting and self-monitoring can enhance access to the general curriculum and lead to improved engagement in academic activities for students with ID (Lee et al., 2009).
Choice-Making

Choice-making is generally defined as a right or opportunity in which an individual is free to select or decide what he or she wants (Sparks & Cote, 2012). All individuals should be given the right to exert choice over daily decisions—large or small (Browder & Spooner, 2011). However, students with significant cognitive disabilities often need explicit instruction to make choices (Sparks & Cote, 2012). Choice making is central to self-determination and self-determined individuals make choices, live with the results, and are free to make additional choices in the future (Argan et al., 2010). Students gain a sense of self-control when they are provided with choices and those choices are honored by others (Wehmeyer, 2005).

In a 2009 review of literature, Von Mizner and Williams summarized the effects of student choices on academic performance. The researchers found when given choices related to goals, assignments, instructional supports, and/or rewards, students with significant cognitive or behavioral disabilities had improved academic outcomes (von Mizner & Williams, 2009). Research has shown that students who choose their school activities are more engaged in that activity and more likely to achieve goals related to that activity (Wehmeyer et al., 2004). Furthermore, students with disabilities are less likely to exhibit undesirable behaviors when they are provided choices (Seybert et al., 1996).

In summary, providing students with opportunity for self-directed learning, goal-setting, self-monitoring, and choice making can promote self-determination. Furthermore, self-determination can lead to personally-relevant access to the general curriculum in an inclusive setting.
Inclusive Practices

Inclusion is the integration of students with disabilities and peers who do not have disabilities in one general education setting. Ideally, all students with disabilities will be full members of their neighborhood school community with opportunities to learn alongside their peers (Browder, 2011). While federal policy has mandated students with disabilities be educated alongside their peers without disabilities “to the maximum extent possible” (IDEA, 2004), this practice must be individualized and viewed as more than just an environmental placement. Wehmeyer (2006) noted a shift from the idea of inclusion as a place to inclusion as part of the curriculum. Additionally, inclusive practices have evolved over three generations from the early 1970s to the present day and fall in line with the curricular shifts as noted by Spooner and Browder (2015; Wehmeyer, 2006). The first generation was largely additive with students with disabilities and supports being added into the general education classroom. The second generation worked towards improvement in services within the general education classroom. The third and current generation of inclusive practices shifts the focus from where to what students with disabilities should learn. With a shift towards access and progress in the general curriculum, students with ID need carefully designed instruction and supports. Common themes in the literature point to the following supports as effective in supporting students with ID and access to the general curriculum: UDL (Spooner et al, 2006; Wehmeyer, 2006), peer-support (Carter & Kennedy, 2006; Downing, 2006), and collaborative teaming (Browder, 2011; Dymond et al., 2006; Smith, 2006).

Universal Design for Learning

UDL was inspired by the idea of universal design in architecture where structures are designed purposely to be accessible to all people. It evolved through research in cognitive
neuroscience that integrate in designing accessible learning environments and opportunities for all students (CAST, 2018). It is a proactive approach to lesson design and instruction providing flexible means of engagement, representation, and action and expression (Hall et al., 2012). “The principles of UDL enable us to recognize that variance across individuals is the norm, not the exception… curriculum should be adaptable to individual differences rather than the other way around” (Hall et al., 2012, p. 3). UDL, like architectural design following the Americans with Disabilities Act (ADA), removes many common barriers to access to the general curriculum for students with disabilities. Unlike general education or special education which separate individuals based on status of disability, UDL provides a vision for one unifying curriculum for all students.

Within the UDL framework, curricular goals, assessments, materials, and methods are designed with flexibility to provide access to the general curriculum for all learners (Hall et al., 2012). In lesson planning, clearly defined goals are well articulated without posing barriers or defining methods, modes, or materials. Instructional methods and materials are flexible, varied, and allow for a balance of access, challenge, and support for all students (Hall et al., 2012). Assessments are tailored towards individual learning styles and modes of expression, with frequent assessments used to monitor student progress towards learning goals and evaluate the effectiveness of instructional strategies. Universally-designed lessons frequently incorporate the use of technology in lesson design and delivery, as well as student expression and assessment.

The use of technology to provide means of access and expression in learning is advantageous for all learners but is especially beneficial for students with disabilities. Universally-designed lessons utilize the power and flexibility of technology to deliver instructional practices directly within core instruction where students can access the curriculum
and materials on an individualized level (Hall et al., 2012). Today, classroom instruction, independent practice, and assessment are easily deliverable via handheld devices like tablets, mobile phones, and e-readers. Furthermore, tablet and mobile devices are prevalent in today’s classrooms and their use is socially acceptable, entertaining, and user-friendly (Kim et al., 2017). The use of technology provides access to the general curriculum for students with disabilities in math through virtual manipulatives (Bouck et al., 2014; Root et al., 2017), reading using e-texts (Alison et al., 2017), and science through augmented reality (McMahon et al., 2016). The use of UDL and technology for students with significant disabilities not only promotes access to the general curriculum but can provide students with 21st century skills needed for successful employment and independent adult living. Furthermore, UDL and technology use can promote peer engagement because technology (e.g., video games, smart devices) is a common source of entertainment for people of all ages.

**Peer support**

Engagement in interactive grade-level learning activities can be both the means to and end results of inclusive education for students with disabilities. Peer support has been shown to be an effective and practical intervention for supporting students with ID in accessing the general curriculum and developing peer relationships (Carter & Kennedy, 2006). Academic support is critical for students with significant disabilities because, as Wehmeyer and colleagues (2003) noted, physical presence in a general education classroom does not guarantee active academic engagement. However, students with disabilities have reported feeling embarrassed by working with paraprofessionals and found it difficult to make friends with paraprofessionals’ supporting their learning (Broer et al., 2005). Peer supports allow students with disabilities to fully participate in academic instruction with their peers without the looming presence of a teacher or
paraprofessional. Furthermore, properly trained and appropriately matched peers who support students with disabilities have been shown to help maintain or enhance academic engagement (Carter & Kennedy, 2006). Studies supporting the use of peer supports are numerous and encouraging.

In a randomized controlled experimental design study of 51 students with severe disabilities, Carter and colleagues (2016) found that, when compared to receiving adult attention alone, students with peer support experienced increased: peer interactions, academic engagement, progress on individual social goals, social participation, and new friendships. Students with severe disabilities learned to self-monitor classroom survival skills (e.g., in class when bell rings, ask questions, answer questions) with the help of peer supports with strong changes in performance over baseline levels for all five students participating in the study (Gilberts et al., 2001). Additional studies have shown improvements through peer interventions in reading fluency and comprehension for students with autism (Kamps et al., 1994) and on spelling accuracy (McDonnell et al., 2001) and social studies (Mastropieri & Scruggs, 2001) in students with cognitive disabilities. While more work needs to be done in the area of peer interventions for academic gains for students with ID, the research is promising. Additionally, there is certainly strong evidence in increased social gains, which is a goal of inclusive education.

**Collaborative Teaming**

Collaboration between stakeholders is imperative to the successful inclusion and education of students with disabilities and has been defined as a partnership between two or more educators, who equally share student responsibility, accountability, and resources (Da Fonte & Barton-Arwood, 2017; Lingo et al., 2011). A collaborative team functions by members
working together to brainstorm ideas to meet a student’s needs across environments and in natural settings (Browder, 2011). In doing so, each member of the team is working on shared goals for the student therefore assuring faster acquisition of skills and generalization across settings (Browder, 2011). Collaboration between general education teachers who are content area experts, special education teachers who are adept at adapting and modifying curriculum, and various support team members (speech and language therapist, occupational therapists, etc.) can be accomplished through effective communication and joint planning (Jones, 2012).

**Effective Communication.** Da Fonte and Barton-Arwood (2017) discussed the importance of partnership in communication between special education and general education teachers supporting shared students. Developing long-term, working relationships is important to the collaboration process and effective communication is integral to a working relationship between co-professionals. Conflict avoidance and resolution are mentioned in the literature as both concerns and important personality traits (Da Fonte & Barton-Arwood, 2017). A respect for and understanding of inclusion with a student-centered focus of communication is essential, and while face-to-face communication is important, written correspondence can also be helpful. Jones (2012) developed “the special education students at a glance approach” for written communication that includes beginning and end of year forms and an inclusion running record as means for special education teacher and general education teacher communication and collaboration. Finally, a mutual respect for the strengths each partner brings to the inclusive practice is seen as a means of breaking down the barriers to inclusion (Da Fonte & Barton-Arwood, 2017; Jones, 2012).

**Joint Planning.** For students to access the general curriculum, with a strong focus on academics, joint planning time is needed for the collaborative team. During joint planning, the
general education teacher(s) focuses on the important content area concepts that all students must master, and the special education teacher(s) focuses on adapting that curriculum to make it both accessible and meaningful for students with disabilities. Giving teachers a “concrete format for planning can expedite their ability to develop ideas for inclusive instruction” (Browder et al., 2006, p. 313). A UDL planning template is one such tool to accomplish this goal. With a universally-designed lesson plan, the general education teacher will focus on “what” material should be presented and the special education teacher can focus on “how” the material will be presented. In this way, the team works together to present the academic content linked to grade-level standards in a manner that is meaningful to students with ID.

**Aligning Instruction with Grade-Level Academic Standards**

For students with ID to have access to the general curriculum, they need to be provided instruction in grade level academic content that directly links to their state’s core content standards (Browder et al., 2006). These standards are outcomes for learning and are created to improve life activities (Browder et al., 2006). While these standards were created for all students, questions have been raised regarding their applicability and meaningfulness to students with ID and have not been regularly applied to this population of student until mandated by federal policies (e.g., Every Student Succeeds Act [ESSA], 2015; IDEA, 2004; NCLB, 2001). Since that time, researchers have worked to determine the extent to which academic content is both available and relevant to students with intellectual disability (Browder et al., 2006). While we do not yet fully realize the consequences of current policies, we do know that students with ID benefit from the increased expectations. The challenge is in properly aligning instruction and academic standards.
Alignment (Courtade & Browder, 2016) is the process of matching standards, goals, instruction, and assessment for students with disabilities (Courtade & Browder, 2016). Courtade and Browder (2016) site three reasons why alignment is important: preparation for state alternate assessment, meaningful academic instruction, and progress in academic content. In other words, aligning academic instruction to grade-level standards is a method for personally-relevant access to the general curriculum for students with ID. Browder and colleagues (2006) suggest seven steps for aligning instruction to academic content standards:

1. Identify the academic domains for planning
2. Identify the state standards for student’s grade level
3. Plan with general educators to focus on typical materials, activities, & contexts
4. Plan alternate achievement targets at student’s symbolic level
5. Review content and performance centrality
6. Enhance the skills by applying long-standing values
7. Identify pivotal skills for the IEP and balance with other priorities.

To achieve these criteria would ideally involve the work of the collaborative team. First, familiarity with the grade-level academic content areas is primarily the responsibility of the general education teacher(s) and should be included in the UDL lesson plan. Second, the special education teacher works with the general education teacher to define the achievement level or expectations for the student with ID which will include increased expectations as the student moves across grade levels. Next, planning for instruction for the expected level of participation should begin with grade level materials that are adapted, modified, or augmented to fit the symbolic level of communication for the student. Finally, determining which pivotal skills will be targeted for instruction is necessary before developing meaningful IEP goals (Browder et al.,
With these targeted action steps and UDL lesson planning, providing personally relevant access to the general curriculum for students with ID can be less challenging. However, there is much work to be done to make the process more accessible for teachers and students and should include identifying evidence based practices (EBPs) for supporting personally relevant access to the general curriculum for students with ID, especially in the development of basic reading and math skills that are needed for independent living and future employment.

Development of basic reading and math skills can lead to increased independence and quality of life outcomes for students with ID. Recent comprehensive reviews of teaching academic content to students with ID have focused on literacy (Browder et al., 2006) and math (Browder et al., 2008; Spooner et al., 2018). Overall, research on academic instruction for students with ID is limited and more research is available for teaching literacy than math. Given that the development of basic math skills is a major goal of the general curriculum and basic math skills are needed for independent living, teaching math skills to students with ID should be part of a personally relevant curriculum. Math is a spiral curriculum meaning that students need to learn the basics to be able to focus on higher order and functional math skills. For example, automatic recall of basic math-facts helps students understand concepts of money and time and is needed to perform higher-level math such as basic algebra (Coddin et al., 2009). Quick retrieval of basic math facts is crucial for future employment and independent living (Coddin et al., 2009, 2011; Hayter et al., 2007) and, therefore, is part of a personally relevant curriculum for students with ID.

**Summary**

Students with ID can succeed in and should have access to the general curriculum. There is an inherent right of people with ID to supports that afford access in a way that is personally
relevant while promoting self-determination and the highest quality of life (Shogren et al., 2006; Trela & Jimenez, 2013). Furthermore, promoting personally relevant access to the general curriculum for students with ID can lead to outcomes of increased independence, community engagement, and successful transition to integrated adult living and employment. The challenge for practitioners and researchers is to identify and develop evidence-based practices for academic skills acquisition that are not only effective, but also contribute to improved outcomes in school and in transition to independent living and integrative employment opportunities.
Chapter Two
Systematic Review of Math Fact Interventions for Students With Intellectual Disabilities

A major goal of the general curriculum is the development of basic math skills, especially those skills needed in everyday life. The National Mathematics Advisory Panel (NMAP, 2008) recognized the importance of automatic recall of basic math facts (e.g., addition, subtraction, multiplication, and division) not only for participation and achievement in higher level math concepts (e.g., algebra), but as crucial for future employment. When students can retrieve math facts quickly, working memory can be devoted to completing more complex mathematical equations (Carr et al., 2011). Finally, basic math fact acquisition is necessary for independent living (Codding et al., 2009; Hayter, 2007) and for understanding and applying concepts of money and time (Codding et al., 2009).

Math-Fact Instruction

In 1978, Haring and Eaton (as referenced in Burns et al., 2010) described a hierarchy of math learning with four distinct phases in skill development: acquisition, fluency, generalization, and application. Relative to math facts, acquisition refers to a student’s ability to accurately recall basic math facts, while fluency refers to a combination of speed and accuracy in performing calculations (Shapiro, 2010). Once students can solve math facts fluently, they can more easily apply those skills to novel math procedures (Burns et al., 2010). Furthermore, an understanding of students’ present levels of functioning is necessary to inform intervention decisions.

Acquisition

Students working at the math-fact acquisition level need explicit instruction (Burns et al., 2010; Fuchs et al., 2008) to develop a basic understanding of math-fact calculation and multiple opportunities to respond (i.e., practice) for automatic recall of facts (Gersten et al., 2009).
Explicit instruction for automatic recall of math facts should include modeling, guided practice, prompting, error correction, frequent feedback, prompt fading procedures, and cumulative review (Burns et al., 2010; Fuchs et al., 2008; Gersten et al., 2009). Furthermore, several simple math interventions have been shown to have a positive effect on the acquisition of basic-math facts including flash cards, cue cards, count-by strategies, and earning free-time (Codding et al., 2009). Finally, Codding et al. (2009) found several moderate intensity interventions to improve math-fact accuracy including Taped-Problems, Cover-Copy-Compare (CCC), and Self-Instruction.

**Fluency**

Students working at the fluency level need repeated practice with modeling to increase their rate of accurate responding (Codding et al., 2011). The Institute of Education Sciences (IES; Gersten et al., 2009) recommends 10-minutes of math fact practice every day to assist fluency building in students with math difficulties. Additionally, a meta-analytic component-analysis of math fluency interventions by Codding et al. (2011) found multi-component (i.e., 3 or more components) interventions to be more effective than interventions with less than three components (Codding et al., 2011). Student-directed interventions (e.g. CCC) were found to be the most effective intervention agent. Lower-intensity interventions of 29 sessions or less were found to be more effective than higher-intensity interventions of 30 or more intervention sessions. These findings have several implications for practice in the classroom. Findings suggest students in need of fluency intervention may need a more comprehensive intervention package with several intervention components built in (e.g., modeling, practice, and error correction like CCC); students benefit from directing their own learning which also leads to reallocation of
teacher resources (e.g., teachers able to focus on other students during that time). Finally, math-fluency interventions can be both effective and time-efficient.

**Intervention Intensity and Acceptability**

Codding et al. (2011) described intervention intensity as the total number of intervention sessions. Intervention intensity is an important consideration when designing or implementing interventions to remedy skill deficits in students with disabilities for several reasons. Skinner (2008) described skills deficits or learning problems as typically being “not a failure to learn, but a failure to learn specific skills or behaviors as rapidly as expected” (p. 310). Remediating skills deficits involves either procedures for enhancing learning rates or allotting more time to treating the target behavior (Skinner, 2008). Time in a school day spent remediating skills is time spent away from other activities. For students receiving special education services, this time may mean missing instruction in other areas (e.g., social studies), missing time at recess, and receiving specialized instruction in a separate classroom. Any time away means time segregated from peers. Finally, teachers and schools prefer interventions that are not only effective and time-efficient, but also resource efficient (Codding et al., 2011; Poncy et al., 2015). Interventions that are resource efficient and easily implemented are more likely to be used consistently and with integrity (Codding et al., 2011).

While knowledge of effective and efficient intervention strategies for math-fact acquisition and fluency is important, much of this work has been focused on students without disabilities or students with high-incidence disabilities (e.g., learning disabilities or emotional or behavioral disorders; Burns et al., 2009; Codding et al., 2011). By comparison, academic math interventions for students with low-incidence disabilities such as ID have historically received significantly less attention from both practitioners and researchers (Browder et al., 2008).
**Math Interventions and Students with ID**

Students with disabilities, especially those with ID, require high-quality academic interventions that will lead to improved quality of life outcomes (Browder, 2011). Research on academic interventions for students with ID is sparse and not yet well understood. In a review of evidence for academic interventions for students with ID, Spooner et al. (2012) found mostly evidence for functional skills interventions and, in academic interventions, found more studies focusing on reading than mathematics. In 2008, Browder et al. conducted a meta-analysis of mathematics interventions for students with significant cognitive disabilities. In all, they found a total of 68 experimental studies on teaching mathematics to students with ID over a 30-year period (Browder et al., 2008). An update to the Browder meta-analysis was conducted by Spooner et al. (2018) and included an additional 36 studies focusing on teaching math skills to students with moderate to severe ID/DD.

**Overview of Findings**

Combined, the previous math reviews for students with ID (Browder et al., 2008; Spooner et al., 2018) included a total of 104 studies focusing on academic math interventions for students with ID. These 104 studies spanned a period of 40 years (1975-2015)- an average of 2.6 studies per year. However, when comparing the numbers between studies, the data shows an increase in the number of studies focusing on math interventions for students with ID from the time of the Browder review in 2008 to the Spooner review in 2018. For example, between 1975 and 2005 (time span of Browder review) math studies focusing on students with ID were conducted at a rate of 2.1 studies per year. From 2005 to 2016 (11 years), studies were conducted at a rate of 3.3 per year. However small, the increase in math studies focusing on students with
ID is at least trending in a positive direction, suggesting that researchers and practitioners see the importance of academic math skills instruction for students with ID.

**Browder et al., 2008**

The 2008 review by Browder and colleagues included a total of 63 studies and 493 students with ID. The studies covered a range of mathematics skills, including primarily Numbers and Operations (54.4%) or Measurement skills (53.7%). Of the studies covering Numbers and Operations, 12 studies (19% of total studies) included math calculation. None of the studies specifically targeted math facts. Without consideration of methodological quality of studies, Browder and colleagues found an overall large effect size for teaching math skills to students with ID. When assessed for methodological quality of single-case research designs (SCRD; Horner, 2005), 19 SCRD studies met all quality indicators (QIs) of research methodology, and 30 met “most” QIs, with 28 out of those 30 studies lacking procedural fidelity. The 19 studies meeting all QIs were reviewed for outcomes across studies. Overall, this review found the use of “systematic instruction with explicit prompting and feedback for a defined response (or set of responses) taught across days” (p. 414), multiple opportunities to respond, and practice within in vivo settings (applications of math skills in authentic settings) to be an evidence-based practice (EBP) for teaching academic math skills to students with ID.

**Spooner et al., 2018**

The 2018 review by Spooner and colleagues was conducted as an extension to the Browder et al. (2008) meta-analysis and included a total of 36 new studies with 147 participants. Student participants were identified as having moderate or severe developmental disabilities (DD). For their review, moderate or severe DD was defined by the authors as students with:
“autism, developmental disability, or moderate, severe, or profound ID, or participating in alternate assessment if disability not specified…. With ASD further specified to target those with moderate or severe ID, those taking alternate assessments aligned with AA-AAS, or participant description included extensive level of support need.” (p. 7)

The 36 studies covered a range of math skills, including primarily Number and Operations (64%), Algebra (31%), Measurement (19%), Geometry (14%), and Data and Analysis (6%). One study targeted math-fact memorization. Of the 36 included studies, 25 studies were deemed to be of “high” or “adequate” methodological quality according to the National Technical Center on Transition Evidence Based Practices Quality Indicators (NTACT, 2015) and were then used for evidence to establish evidence-based practices (EBPs). The review provided additional evidence in the use of systematic instruction for academic math skills acquisition for students with moderate to severe disabilities and identified four additional new EBPs including technology-aided instruction (TAI), use of manipulatives, explicit instruction, and use of graphic organizers. Additionally, the authors noted a decrease in instruction in community settings when compared to the Browder et al. (2008) review, but no increase in studies conducted in inclusive/general education settings. Finally, the authors noted an increase in teaching mathematics skills aligned with grade level academic standards and an increase in small and whole group instruction over the ten years since the Browder review.

To date, Browder et al. (2008) and Spooner et al. (2018) have provided the only identified reviews of published research for mathematics interventions for students with significant cognitive disabilities. These two reviews were comprehensive in focus, including an analysis of all main components of mathematics instruction as identified by the National Council
of Teachers of Mathematics (NCTM, 2002 as cited in Browder et al, 2008). There have been no published reviews to summarize research on mathematics interventions for students with ID to specifically improve math fact fluency or acquisition. However, three review teams have published findings summarizing research on math fact acquisition and/or fluency for students without ID that may give insight into effective intervention strategies targeting math-fact acquisition or fluency that may be extended and applied to interventions for students with ID. The first (Burns et al., 2010) was a meta-analysis of acquisition and fluency interventions for instructional versus frustration level skills with students in grades 2-6 and included both students with and students without disabilities. The second was a review of simple and moderate interventions for addressing math computation difficulties (Codding et al., 2009). The third was a meta-analysis of math fluency interventions focused on all students (with and without disabilities) in grades 1-6 (Codding et al., 2011). Together, these reviews led to several findings and implications for math-fact instruction for students with math difficulties which also may be relevant for math fact instruction for students with ID. Given the wide focus of the math reviews for students with ID (Browder et al., 2008; Spooner et al., 2018) and the fact that, to date, no review has been conducted on math fact interventions for students with ID, a review is warranted. Findings from the Browder et al. (2008) and Spooner et al. (2018) meta-analyses and Codding et al. (2011) meta-analysis will be used to guide the current review.

**Purpose**

The purpose of this review is to systematically map the research on math fact interventions for students with ID in Kindergarten through 12th grade classrooms. Specifically, this review will identify empirical literature addressing math fact interventions for students with ID, identify gaps in the knowledge base, and use the findings to offer recommendations to the
field of ID for focusing future research and classroom application. Therefore, this review will:
(1) evaluate methodological quality of existing studies; (2) summarize characteristics of the 
existing research base; and (3) summarize intervention effects at the case level for studies found 
to be methodologically sound.

Method

Three professionals in the field of special education made up the review team. The 
primary reviewer was a PhD candidate in special education. The second reviewer was a special 
education teacher with a PhD in special education and a focus on interventions for students with 
ID. The third reviewer was a post-graduate with a PhD in special education with a focus on math 
interventions for students with disabilities. All reviewers had experience conducting systematic 
reviews and had completed advanced coursework related to single-case and group design 
research. To ensure consistency in coding variables of interest, the primary reviewer provided 
the second and third reviewers with a list of variables, definitions for each variable, and 
instructions for using Microsoft Excel spreadsheets for coding.

Article Identification and Initial Screening Procedures

The primary review team member searched ERIC, Education Source, and PsycINFO in 
July 2019 to identify math fact studies for students with ID. The following search terms were 
entered into all databases with each string of search terms separated by the word “AND”. 
Intervention terms included: “math facts” or “math fluency” or “addition facts” or 
“multiplication facts” or “subtraction facts” or “division facts” AND “students with disabilities” 
or “special education” or “special needs.” The primary reviewer used quotation marks around 
each search term and did not restrict publication date. This search produced 158 articles, which 
were scanned by title and abstract by the primary reviewer to determine whether the article
should be read in its entirety for further evaluation inclusion for this review. After removal of articles that did not include a single case research design (SCRD) or group research design study, a total of 61 articles remained. These articles were scanned in their entirety by the primary reviewer for final eligibility determination.

**Inclusion Criteria**

Studies eligible for the review had to meet the following criteria: (a) the study included a basic math fact acquisition or fluency outcome (i.e., goal to accurately recall single-digit facts from memory or increase rate of accurate responding; no word problems or multi-step computation) as dependent variable (DV), (b) the study used a group comparison or SCRD (CEC, 2014) that allowed for comparison of an intervention to no treatment conditions (i.e., no alternating/parallel treatment design studies comparing the effectiveness of one intervention to another unless that study also included a continuous no treatment condition), (c) student participants were in Kindergarten through 12th grade and were identified as students with ID (or earlier terms such as mental retardation or developmentally handicapped; i.e., indications of intellectual function that is significantly below average; students with developmental disability or autism spectrum disorder would be included if they were also classified as a student with ID), and (d) the study was written in English and published in a peer-reviewed journal.

The primary reviewer used a binary coding system of met (i.e., met all inclusion criteria) or not met (i.e., did not meet one or more of the inclusion criteria) to determine final eligibility for systematic review. After applying the inclusion criteria, 53 of the 61 studies were excluded (i.e. “not met”), which yielded a total of eight studies (i.e., “met” all inclusion criteria) for full review. These studies are marked with an asterisk in the reference section of this review and included only SCRD studies (i.e., no group design studies). Next, each case (i.e., participating
student or groups) in each study was reviewed by the primary reviewer using a binary coding system of met inclusion criteria (i.e., single student or group of students identified with ID) or not met inclusion criteria (single student or group of students are not identified as student(s) with ID) to determine final eligibility for review at the individual case level. In these eight studies, a total of 15 cases (2 groups of students in 1 study and 13 single participants) met inclusion criteria. In four of the studies, (Figarola et al., 2008; Irish, 2002; Mattingly & Bott, 1990; Miller et al., 1995), one or more students were not included in the review due to not meeting full inclusion criteria (i.e., was not identified as a student with ID). See Figure 2.1 for a Prisma Flow Diagram of search procedures.

Next, the second review team member independently read each of the \( n = 8 \) studies coded as meeting the inclusion criteria by the primary reviewer to assess for interrater agreement for inclusion in the review. Interrater agreement was calculated across studies by adding the total number of agreements (“met” or “not met” inclusion criteria) and dividing by the total number of agreements and disagreements. Interrater agreement for inclusion of studies was 100%. Finally, the second reviewer repeated this process to assess interrater agreement for eligibility for each case in the mutually agreed upon included studies. For each case, interrater agreement was calculated by adding the total number of agreements (i.e., “met” or “not met”) and dividing by total number of agreements plus disagreements then multiplying by 100. Interrater agreement was 93.3% for cases across studies. Disagreement occurred for just one participant in one study (Mattingly & Bott, 1990). The discrepancy in agreement for that case was reconciled by clarifying the definition of *educable mentally handicapped* as an outdated special education term for ID (Mid-South Regional Resource Center; 1997) and both reviewers came to a consensus on inclusion.
Study Coding Procedures and Interrater Agreement

Methodological Quality of Studies

The eight studies were then reviewed to evaluate methodological quality for SCRD studies as described by The Council for Exceptional Children Standards for Evidence-Based Practices in Special Education (CEC Standards; CEC, 2014). The CEC Standards were created as a method to evaluate methodological quality of research design in special education. The standards include eight quality indicators (QI) with 22 evaluative components pertaining to SCRD. Since this review only includes SCRD studies, the author will only refer to CEC Standards for SCRD. According to the CEC, individual studies are coded by assigning an absolute value of “met” or “not met” for each of the eight QIs meaning all components within each QI must be present to code that QI as “met.” For example, QI 6.0 includes a total of six separate components to evaluate a study’s internal validity. Therefore, all six components must be present for QI 6.0 to be coded as “met” in order to meet the absolute coding criteria for that QI.

As an alternative to the absolute criteria of coding, Lane and colleagues (2014) developed a weighted system of coding using the CEC Standards that allows for “partial credit” to be assigned to each QI if some of the components are present (e.g., three out of six components were met for QI 6.0, therefore QI 6.0 was 50% met). “A weighted coding method allows each QI component met to contribute an equal proportion of ‘total credit’ or recognition for being addressed within each QI” (Royer et al., 2017, p. 3). A weighted coding system is a more liberal approach to the absolute coding system and may be useful for evaluating a literature base that spans a period of time prior to the introduction of the CEC Standards because with an absolute coding system, we risk excluding studies of merit that predate a consensus on the critical features
that define SCRD (Horner et al., 2005; Royer et al., 2017). Given the timespan of the studies identified (1990-2011), the review team agreed on the use of a weighted coding system for this review.

Methodological quality of the eight included studies were evaluated and coded using *The Group Comparison and Single-Case Research Design Quality Indicator Matrix Using Council for Exceptional Children 2014 Standards* (Lane et al., 2014). This free MS-Excel tool (retrieved from http://www.ci3t.org/pratice) was created by Lane and colleagues (2014) to assist researchers in rating methodological quality (absolute and weighted) described by *The Council for Exceptional Children Standards for Evidence-Based Practices in Special Education* (CEC Standards; CEC, 2014) and includes coded spreadsheets to assist with data collection across studies. This matrix allows for coding by two or more reviewers with programmed calculation of IRR across studies and QI components. The matrix also calculates and provides an option for use of the weighted coding system in which studies meeting 80% weighted coding criteria (80% of QI components; 6.4 out of 8.0 QIs; Lane et al., 2009) would be rated as methodologically sound and eligible for further evaluation of outcomes by case and study if the study also used a valid SCRD. According to the CEC Standards, a valid SCRD is one that “systematically address(es) common threats to internal validity and reasonably demonstrate(s) experimental control” (CEC, 2014, p. 2) and provides a minimum of three demonstrations of effect across three points in time.

To code for methodological quality, two members of the review team independently reviewed each of the eight eligible studies and, using the MS-Excel matrix, independently coded each of the 22 components of the eight QIs for SCRD and assigned a rating of met, not met, or not applicable (i.e., 0 = not met, 1 = met, NA = not applicable). A component was only assigned a rating of NA if (a) the QI was only applicable to a group design study or (b) rating for that
component was contingent upon the rating of another component (e.g., for QI 5.3 when QI 5.1 and 5.2 are not met; Royer et al., 2017). Next, the two team members merged their ratings into a single sheet in the QI Coding Tab of the matrix. In this way, the matrix would automatically populate and assign a value of “true” or “false” for interrater agreement (IRA) for each QI component. Mean interrater agreement for quality indicator coding was 92.5% across QI components (range 62.5% to 100%) and 92.6% across studies (range 77.3% to 100%). Next, the two review team members met to discuss coding discrepancies (i.e. “false” values for IRA for each component). Given the wide range of levels of agreement across QI components, the primary reviewer consulted additional resources for coding clarification (i.e., Common et al., 2020; Cook et al., 2015; Gast & Ledford, 2014; Horner et al., 2005; Lane et al., 2009; and Tankersley et al., 2008) and created a table describing criteria for coding for each QI component. This table was then used to assist the reviewers in reaching consensus and agreement on final coding. When consensus was reached as to final coding (i.e., determination of whether or not each component was met), the primary reviewer entered that code in the “Final Coding” column. This method allowed the original coding for each rater to remain intact to report on initial levels of agreement across studies and QIs. Furthermore, the final codes were used to determine overall methodological quality for each study. See Figure 2.3 for a summary of CEC quality indicators.

**Methodological Quality Criteria**

1.0. **Context and Setting.** Quality Indicator 1.0 included one component. To meet QI 1.1. *describes context or setting*, the authors had to describe at least one feature of the setting or context (e.g., region, type of school; Lane et al., 2014).

2.0. **Participants.** Quality indicator 2.0 included two components. To meet QI 2.1 *describes participant demographics*, the authors had to describe at least one relevant participant
demographic (e.g., age, gender). To meet QI 2.2 describes disability or risk status, the authors had to describe student disability and method of determination of disability (Lane et al., 2014). Since the focus of this review included only participants with ID, the description had to use either measures of IQ and Adaptive Behaviors, descriptive information of participant(s) indicating significant limitations both in intellectual functioning and in adaptive behavior (Schalock et al., 2019), or statement that student was receiving special education services under IDEA as a student with ID or earlier term (e.g., mental retardation).

3.0. Intervention Agent. Quality indicator 3.0 included two components. To meet QI 3.1 describes intervention agent’s role, the authors had to describe the role of the primary interventionist (e.g., teacher, researcher, student). To meet QI 3.2 describes training, the authors had to describe how the interventionist was trained and how the researcher checked for understanding or is met by virtue of self-design/self-trained if interventionist is author/researcher (Lane et al., 2014).

4.0. Description of Practice. Quality indicator 4.0 included two components. To meet QI 4.1 describes intervention procedures, the authors had to include either a detailed description or checklist for the procedures. To meet QI 4.2 describes materials, the authors must have included a list or description of all relevant intervention materials or cite an accessible source providing that information (Lane et al., 2014).

5.0. Implementation Fidelity. Quality indicator 5.0 included three components. To meet QI 5.1 assess and report fidelity, the authors had to use and report direct, reliable measures of fidelity, including percentage of adherence. Special consideration was given to studies using a technology application or computer program as the primary intervention. There is an implied level of fidelity if the application or program is in operating order, collects and analyzes student
data, and if the researcher reported frequent fidelity checks. To meet QI 5.2 *assess and report dosage and exposure*, the authors had to report implementation related to dosage or exposure to intervention such as length of time per session or number of sessions (available on graphs). To meet QI 5.3 *assess and report throughout the intervention*, the authors had to state that any fidelity measure had occurred across different points of the intervention (Lane et al., 2014).

### 6.0. Internal Validity.

Quality indicator 6.0 included six components. To meet QI 6.1 *controls and manipulates the IV*, the authors had to meet QI 5.1 and researcher had to control and manipulate the independent variable. To meet QI 6.2 *describes baseline condition*, the authors only needed to describe the no treatment condition. To meet QI 6.3 *no or extremely limited access to intervention*, the authors had to explicitly state or demonstrate via measurement on time-series graphs that participants did not have exposure to the intervention during the no intervention condition. To meet QI 6.5 *three demonstrations of effect*, researchers must have used a valid SCRD allowing for three demonstrations of effect at three different points in time (e.g., MBL across participants or behaviors/sets of math facts). To meet QI 6.6 *minimum of three data points in baseline*, the no intervention condition must have included at least three data points. To meet 6.7 *controls for threats to internal validity*, QI 5.1 and 6.5 must have been met, meaning researchers needed to employ a valid SCRD with procedural integrity (Lane et al., 2014).

### 7.0. Outcome Measures/Dependent Variables.

Quality indicator 7.0 included five components. To meet QI 7.1 *socially important*, the authors had to discuss the social significance of the study’s goals, social appropriateness of intervention, and/or social importance of the dependent variable OR measure and report social validity information from a social validity survey, interview, or other measure. To meet QI 7.2 *define and describe dependent measures,*
authors had to define the DV and describe a valid process for administering assessment measures. Authors did not have to include a valid graph to meet QI 7.2. To meet *QI 7.3 reports the effects*, the authors had to report effects of the intervention across all dependent variables related to the systematic review. Additionally, all data relevant to the review had to be included in graphed form for visual analysis. To meet *QI 7.4 measured repeatedly*, QI 7.3 must be met and each phase that is part of a demonstration of experimental effect must include a minimum of 3 data points- key words to QI 7.4 are “part of” demonstration of experimental effect. To meet *QI 7.5 adequate interobserver agreement*, IOA had to be measured and reported across participants and dependent measures AND aggregated IOA was at least 80% with no range of IOA falling below 60% (Lane et al., 2014).

**8.0. Data Analysis.** Quality indicator 8.0 included one component. To meet *QI 8.2 graphs clearly represent outcome data*, graphs had to include data for all participants in the study and for all dependent variables relevant to the review. 6.5 did not need to be met for 8.2 to be considered met (Lane et al., 2014).

*Characteristics of Research Base*

After following the steps outlined above, the primary reviewer then read and coded the methodologically-sound studies for descriptive features using an Excel spreadsheet created by the primary reviewer to facilitate consistency throughout the review. The following information was coded across studies and included variables described in previous math reviews (Browder et al., 2008; Coddington et al. 2011; Spooner et al., 2018): participant age, grade level and identified level of ID, dependent variable, intervention setting and agent, intervention components, and intervention intensity. Purposefully, measures of treatment integrity, interobserver agreement
(IOA) of dependent measures, or social validity were not included here because they would be assessed using the CEC quality indicators later in the review process.

Participant level of ID was defined by the author’s description of participants identified as a student with either mild, moderate, severe, or profound (or an indicator in between; e.g., mild-moderate) ID. Dependent variables were coded as targeting either math fact acquisition or fluency. Acquisition was defined as a measure of accurate responding such as number correct or percent accuracy. Fluency was defined as rate of accurate responding such as digits correct per minute (DCPM) or problems correct per minute. The intervention setting was defined as the specific location where the intervention took place and intervention agent was defined as the person or persons responsible for implementing the intervention (e.g., teacher, student, researcher). Intervention components were coded in two ways. First, did the math-fact studies include any behavior-analytic intervention components or EBPs found in previous reviews (Browder et al., 2008; Burns et al., 2010; Codding et al., 2009, 2011; Spooner et al., 2018)? EBPs included systematic instruction, OTR, and TAI. Behavior-analytic intervention components included: prompting, modeling, feedback, time delay, praise, error correction, guided practice, self-monitoring, and goal-setting. Second, intervention components were coded as the total number of unique intervention components within an intervention. Codding et al. (2011) found that multi-component interventions (i.e., more than three components) were highly effective for students with frustration level math fluency skills. Intervention intensity was defined as the total number of sessions in the intervention phase (Codding et al., 2011). Guided by Codding et al. (2011) findings that interventions of less than 30 sessions were found to be more effective and efficient than interventions of 30 or more studies, intervention sessions were also coded as “less than 30 sessions” or “30 or more sessions.”
Visual Analysis and Intervention Effects

Finally, the primary reviewer used visual analysis to evaluate intervention effects by case for any valid SCRD study meeting the criteria to be classified as methodologically sound (i.e., meeting at least 80% of QIs). Visual analysis of level, trend, overlap, and variability was used to draw conclusions regarding experimental control and analysis of intervention effects (Ledford et al., 2019). Following visual analysis, intervention effects for each case were coded as *positive* (therapeutic change in the intended direction), *neutral* (no functional relation found), or *negative* (change was nontherapeutic) for each case. A second reviewer repeated this process for all methodologically-sound studies. Reviewers then compared their independent ratings to evaluate agreement across cases. Interrater agreement was calculated for overall agreement across all cases by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100. Interrater agreement was 89% for intervention effects by case. Discrepancies in coding intervention effects for each case were reconciled until both reviewers came to a consensus on the final coding. Outcomes at the study level were not part of this review because the purpose of this review was to summarize the existing research base for math-fact instruction for students with ID and did not include determining evidence-based practices.

Results

A total of eight SCRD studies were reviewed in their entirety by the primary reviewer (see Table 2.1 for characteristics of eight eligible studies). These studies included a total of 15 eligible cases. Results were reported at the student level for seven of the studies and 13 participants and at the group level for one study and two groups of participants.
Methodological Quality of Studies

After applying the coding criteria to each of the eight studies, four studies (Figarola et al., 2008; Irish, 2002; Mattingly & Bott, 1990; and McCallum & Schmitt, 2011) met the absolute criteria for methodological quality as outlined by the CEC (2014). One additional study (Miller et al., 1995) met methodological quality using the 80% weighted criteria. The remaining three studies either did not meet the 80% criteria (Hayter et al., 2007; Rao & Mallow, 2009) or met criteria, but were not a valid SCRD study (i.e., MBL design across two participants; Zisimopoulous, 2010). For detailed results of QI components met across studies see Figure 2.2.

Characteristics of Methodologically-Sound Studies

The five methodologically-sound studies included a total of nine eligible cases. Seven of these cases were single participants and two were groups of participants. Students ranged in age from 8-13 years of age with the average age of participants being 10.9 years of age. Student participants were in grades K-5 \( (n = 6) \) and grades 6-8 \( (n = 1) \). All participants were described as students with mild ID. In the group study (Miller et al., 1995), student participants were described as 11 elementary-school students with mild ID. In all five studies, the intervention setting was identified as a special education classroom. The primary intervention agent was a special education teacher in two studies. In three studies, the student was the primary intervention agent (i.e., student-directed) with a special education teacher supervising the student-directed intervention.

Two studies included a dependent measure of single-digit math fact acquisition and three included a dependent measure of math fact fluency. Relative to the findings of Browder et al. (2008) and Spooner et al. (2018), all five studies included EBPs for teaching math to students with ID in intervention conditions, including systematic instruction strategies \( (n = 2) \), OTR \( (n = \)
Furthermore, all five studies included multiple behavior-analytic intervention components as found in the five previous math reviews (Browder et al., 2008; Burns et al., 2010; Coddington et al., 2009, 2011; Spooner et al., 2018), including: prompting, modeling, feedback, time delay, praise, error correction, guided practice, self-monitoring, and goal-setting. See Figure 2.3 for a summary of EBPs and behavior-analytic intervention components for each methodologically-sound study. The number of behavior-analytic intervention components were coded across studies. The average number of intervention components within an intervention package was 4.6 (range 3 to 7).

Intervention intensity was coded for four studies reporting total number of sessions. One study (Irish, 2002) only reported the number of weeks for intervention intensity, without indication of number of sessions per week, and was excluded from coding for this variable. Two studies (McCallum & Schmitt, 2011; Miller et al., 1995) had 29 or fewer sessions and two (Figarola et al., 2008; Mattingly & Bott, 1990) studies had 30 or more sessions. While intervention intensity varied across participants and cases in some studies, the number of sessions across participants/cases never fell into two different categories of coding (i.e., up to 30 sessions and 30 sessions or more). Therefore, intervention intensity was consistently coded at the study level across all four methodologically-sound studies reporting number of intervention sessions.

**Visual Analysis and Intervention Effects**

Visual analysis was used to evaluate the intervention effects for each of the nine eligible cases across five methodologically-sound studies. Following visual analysis, the intervention effect for each case was coded as either positive, neutral, or negative. Intervention effects were coded as *positive* for eight cases and *neutral* for one case.
Figarola et al., 2008

Figarola et al. (2008) used an ABAB withdrawal design to examine the effects of self-graphing on the rate of single-digit addition fluency for three elementary school participants, including one participant with ID. Visual analysis of time-series data reveals a functional relation between self-graphing and goal-setting and rate of responding to single-digit math facts. Data in both intervention phases were consistent in level, trend, and variability. Data in the first no intervention series was stable with overall low to moderate levels of responding. Upon introduction of the first intervention phase, Shannon’s responding to math facts (digits correct per minute; DCPM) improved with an overall accelerating trend in the data. Furthermore, Shannon’s rate of DCPM met or exceeded the aim line for 100% of sessions during the first intervention phase. Upon return to the no intervention condition, the data showed an overall deterioration in level of performance with a decreasing trend in DCPM. Furthermore, Shannon’s fluency rate decreased to at or below the aim line during 5/9 sessions. With the second introduction of the intervention, Shannon’s rate of responding to math facts improved immediately with an overall increasing level and accelerating trend in data. Shannon’s fluency rate met or exceeded the aim line in 13/15 sessions in this phase. Furthermore, Shannon’s fluency rate met or exceeded the aim line for a total of 28/30 (93%) of sessions across both intervention conditions and only 4/9 (44%) sessions in the no intervention condition.

Irish, 2002

Irish (2002) used a multiple baseline across participants design study to examine the effectiveness of a TAI on multiplication fact acquisition for three elementary school students with ID. Visual analysis of the time series data revealed a functional relation between the TAI
Intervention and multiplication fact acquisition in two out of three students (students three and five). There was no evidence of a functional relation for student two.

Data for student three indicated stable and low to moderate level of responding in the no intervention condition. Upon introduction of the intervention condition, data for student three showed an overall accelerating trend over the no intervention condition and improving level of responding. Data for student five indicated steady low levels of responding during the no intervention condition. Upon introduction to the intervention condition, data showed a marked increase in level of responding over the no intervention condition and accelerating trend in data within the intervention condition. Data for student two was unstable for both the no intervention and intervention conditions with very little to no improvement in level of responding from the no intervention condition to the intervention condition.

Mattingly & Bott, 1990

Mattingly and Bott (1990) used a multiple-probe design across behaviors (six unique sets of multiplication facts) to examine the effectiveness of a constant-time delay (CTD) procedure on multiplication fact acquisition including two elementary school students with ID. Visual analysis of time-series data reveals a functional relation between CTD and acquisition of single-digit multiplication facts for both students. Student two had zero-level of correct responding during all six baseline phases. Upon each introduction of the time-delay procedure, she showed an abrupt accelerating trend in correct responding. Throughout the duration of the study, acquired math sets were randomly intermixed and probed. For each intermix session, student two showed an occasional “dip” or decelerating trend in responding to the intermixed math facts. She quickly returned to 100% correct level responding to intermixed probes and maintained 100%
correct responding for the final five intermix sessions. Finally, Student two maintained 100% accuracy during a final maintenance probe for 5/6 of the sets.

Like student two, student four had a zero-level of correct responding during all six baseline phases. Additionally, student four demonstrated a large and abrupt improvement in correct responding with the introduction of the time-delay procedure across all six phase changes from no intervention to intervention conditions. Furthermore, he maintained 100% accurate responding during all intermix phases apart from one instance of deteriorating level of responding during one intermix session near the conclusion of the study. He maintained high levels of accurate and sustained responding for the first 3/6 maintenance probes, with decreasing levels of performance during the final three maintenance probes.

*McCallum & Schmitt, 2011*

McCallum and Schmitt (2011) used a multiple-probes-across-tasks to evaluate the effectiveness of a taped problems intervention on division fact fluency performance with one middle school participant with ID. Visual analysis of time-series data revealed increasing trends in initial sessions during all three baseline phases. However, a slight decrease in level was noted on session five for problem set A. Baseline data for set B shows a large increase from session one to session two and a small increase noted on days three through six. Baseline data for set C also shows an increasing trend from days one through three but a flattening in trend from days three to six. However, data showed overall acceleration in response trends across all three intervention phases. Furthermore, there was 0% overlap in data between baseline, intervention, and maintenance phases for all three problem sets.
**Miller et al., 1995**

Miller et al. (1995) used an ABABC design study to compare the effectiveness of (a) ten-minute work sessions with next day feedback; (B) seven one-minute time trials with next-day feedback; and (C) two one-minute time trials each followed by immediate feedback and self-correction on addition and subtraction fact fluency for two groups of elementary students with ID. For this review, only the initial ABAB series was evaluated for effects since the C phase did not allow for comparison to the no intervention condition. Visual analysis of time-series data showed similar results for both groups of students. The five-day students and three-day students showed consistency in level and trend of responding in both A phases, but data in A₂ phases for both groups showed some variability in responding likely influenced by aggregated data for outcomes by group of students versus individual student outcomes. Similar patterns were noted in B phases. However, data showed improving level and accelerating trends when comparing adjacent intervention phases to no intervention phases across conditions and groups of students. Furthermore, there was little overlap (i.e. less than 20%) in data appoints across adjacent phases.

**Discussion**

Browder et al. (2008) and Spooner et al. (2018) conducted meta-analyses for teaching academic math skills to students with moderate and severe ID and/or DD. Additionally, three reviews of math-fact interventions (i.e., Burns et al., 2010; Codding et al., 2009; Codding et al., 2011) have outlined effective strategies for teaching math facts to students with and without disabilities. Following their work, the purpose of this review was to summarize the existing research base focusing on math fact interventions for students with ID. Before discussing the findings from these studies, it is important to recognize the limitations of this review.
**Limitations**

First, relative to the review process, by only including three of the more popular search engines, there is a chance that some published studies may have been missed. Second, this review only included studies published in peer-reviewed journals. By not including non-published studies, dissertations, or theses, some studies of merit may have been excluded. Third, this review did not include interrater agreement on search procedures which also may have resulted in missed studies. Fourth, this review did not include interrater agreement on study characteristics. Agreement on study characteristics would have strengthened the findings. Finally, there are limitations to the findings from this review.

Relative to findings, overall, the research on math-fact interventions for students with ID is sparse. While the initial article search procedures did not restrict publication date, the articles located in the initial search spanned a period from 1972 to July 2019. Therefore, this search identified only eight studies with only fourteen cases (student- and group-level cases) specifically targeting math fact acquisition or fluency in students with ID over a 47-year time frame, indicating studies on math-fact interventions for students with ID have been published at a rate of 0.17 per year. However, studies meeting inclusion criteria for this review spanned from 1990-2011. Put another way, the included studies began around the time of the initial enactment of IDEA (IDEA, 1990). From 1990-2011, studies were published at a rate of 0.38 per year. Finally, given the emphasis on academic interventions and access to the general curriculum for students with ID as mandated first by NCLB (2001) and again with the reauthorization of IDEA in 2004, one would expect an increase in the number of studies focusing on academic content instruction, including math-facts, for students with ID. Including one study published in 2002 (likely written before NCLB; Irish, 2002), a total of 6 studies were published from January 2002
to the last identified published study in 2011. These numbers indicated a rate increase to .67 per year between 2002-2011. However, since 2011, no published studies were identified targeting math fact acquisition or fluency for students with ID. Therefore, the fact remains clear that students with ID are grossly underrepresented in research on math fact interventions.

**Methodological Quality and Intervention Effects**

Of the eight studies included in the initial review, only four studies (Figarola et al., 2008; Irish, 2002; Mattingly & Bott, 1990; McCallum & Schmitt, 2011) met all CEC standards for methodological quality of SCRD. One additional study (Miller et al., 1995) met the 80% weighted criteria of methodological quality as outlined in the method section. This resulted in a total of nine cases in five methodologically-sound studies. Visual analysis of intervention effects at the case level indicated positive effects for eight cases and neutral effects for one case. Positive effects were seen in elementary and middle school settings. Characteristics of the five methodologically-sound studies are discussed below.

**Characteristics of Methodologically-Sound Studies**

While the focus of participants in the two math meta-analyses (Browder et al., 2008; Spooner et al., 2018) included only students with moderate, severe, or profound ID/DD, the focus of the current review was participants with any level of ID–mild to profound. Across all five methodologically-sound studies, the participants in this review were described as students with mild ID. Four of the studies included participants in elementary school and one study included a participant in middle school. The setting for all studies was a special education classroom, which is consistent with previous findings (Browder et al., 2008; Spooner et al., 2018) that students with ID continue to receive academic instruction outside of an inclusive, general education setting. When looking at this body of research, what stands out most in this review is
the consistent application of multi-component interventions using behavior-analytic strategies (e.g., prompting, systematic instruction, feedback) for math-fact interventions across studies.

Findings from this review are consistent with previous findings (Browder et al., 2008; Burns et al., 2010; Coddington et al., 2009, 2011; Spooner et al., 2018) supporting the use of behavior-analytic intervention components to teach math skills or math facts to students with and without disabilities. Additionally, the two previous meta-analyses (Browder et al., 2008; Spooner et al., 2018) provided support for a total of seven EBPs for teaching math to students with ID: systematic instruction, in-vivo practice, OTR, Explicit Instruction, TAI, use of manipulatives, and graphic organizers. Three of these EBPs (i.e., in-vivo practice, manipulatives, and graphic organizers) are not relevant to this review. In-vivo practice typically applies to generalization and application of math skills whereas this review focused on acquisition and fluency of basic-math facts. The use of manipulatives and graphic organizers, while frequently used to teach students with disabilities to solve math equations (e.g., Bouck & Park, 2018; Spooner et al., 2018) were not considered relevant to this review because the focus of this review was accurate and/or fluent responding to math-facts from memory (i.e., not the use of strategies or processes to find an answer). Additionally, there was no evidence of the use of Explicit Instruction in teaching math facts to students with ID. However, findings from this review were consistent with findings from previous reviews (Browder et al., 2008; Coddington et al., 2011; Spooner et al., 2018) on effective strategies for teaching math skills to students with disabilities and suggest the potential effectiveness of the use of multiple behavior-analytic intervention components embedded within systematic instruction, OTR, and TAI intervention packages for improved outcomes in math-fact acquisition and fluency for students with ID.
**Systematic Instruction**

Systematic instruction is not a single intervention component but an intervention package with a well-defined response taught to mastery using multiple behavior-analytic strategies (Browder et al., 2008). Examples of behavior-analytic strategies typically incorporated in systematic instruction include prompting, modeling, constant time-delay, praise for correct responding, and error correction (Browder et al., 2008). Relevant to the current review, there is some evidence to suggest that systematic instruction strategies are also effective in teaching-math facts to students with ID. In 1990, Mattingly and Bott (1990) used a constant time delay procedure to teach two middle school students to recall 30 multiplication facts. Irish (2002) also used a systematic instruction package with TAI to teach multiplication fact acquisition. Finally, McCallum and Schmitt (2011) used a taped problems intervention which incorporated principles of systematic instruction, including constant-time delay, feedback, error correction, and positive reinforcement.

**Opportunities to Respond**

Providing students with multiple opportunities to respond (OTR) has been described as an evidence-based practice for improving math performance in students with and without disabilities (Browder et al., 2008; Codding et al., 2011). However, simply increasing the total number of responses required of students (e.g., rote practice) is insufficient in improving student performance (Burns et al., 2010; Codding et al., 2011). Research has demonstrated interventions with OTR and modeling, guided practice, feedback, and error correction (e.g., CCC, incremental rehearsal) have been effective for increasing accurate responding for students working at the acquisition level (Burns et al., 2010; Skinner et al., 1997). For students who are accurate but slow responders, interventions using OTR with modeling, feedback, and error correction (e.g.,
taped problems, explicit timing) have been shown to be effective in increasing rate of accurate responding, leading to improved math fact fluency and response maintenance (Burns et al., 2010; Codding et al., 2011). This review also found some evidence to suggest the use of OTR may support math fact acquisition and fluency for students with ID. All five methodologically-sound studies incorporated the use of OTR in targeting either acquisition (Irish, 2002; Mattingly & Bott, 1990) or fluency (Figarola et al., 2008; McCallum & Schmitt, 2011; Miller et al., 1995) of math facts. Mattingly and Bott (1990) targeted math fact acquisition using OTR with modeling, guided practice, feedback, and error correction. Irish (2002) targeted multiplication fact acquisition using OTR with prompting, feedback, and weekly review with error correction. Additionally, one study (McCallum & Schmitt, 2011) targeting fluency used OTR with feedback and error correction. Figarola et al. (2008) used OTR with feedback, self-monitoring, and goal-setting to increase addition act fluency. Miller et al. (1995) targeted fluency using OTR with feedback and praise. Taken together, results of this review support and extend the findings of previous reviews (Browder et al., 2008; Burns et al., 2010; Codding et al., 2011) that OTR with modeling, guided practice, feedback, and error correction can be an effective strategy for math fact acquisition for students with ID. Furthermore, fluency interventions using OTR with feedback with or without error correction may be effective for students with ID. One noticeable difference between interventions for acquisition versus fluency is guided practice (i.e., teacher guidance) may not be necessary for students working at the fluency level, indicating independent practice or student-directed interventions may also be effective for fluency-level interventions for students with ID.
**Technology-Aided Instruction**

Spooner and colleagues (2018) found TAI to be an EBP for math instruction for students with moderate to severe ID/DD. The current review found the use of TAI in three studies targeting math fact fluency (Figarola et al., 2008; Irish, 2002; McCallum & Schmitt, 2011) for students with ID. Figarola et al. (2008) used a computer and Microsoft Excel for goal-setting and self-monitoring (i.e., self-graphing and monitoring performance via an aim line) to improve the addition fluency of one student with mild ID. Irish (2002) used a computer software program (Memory Math) to teach multiplication facts to three students with ID. Finally, McCallum used a compact disk recording and audio player in a taped problems intervention to improve the division fact fluency skills of one student with mild ID. All three TAI interventions also incorporated the use of OTR and other behavior-analytic intervention components. These findings are consistent with the findings of Spooner et al. (2018) in the use of TAI for math instruction for ID. Furthermore, findings from this review also showed an increase in student-directed TAI since 2002 (Figure 2.2). Of importance is that TAI and the use of technology in general can lead to independent learning and improved quality of life outcomes for students with ID.

**Intervention Intensity and Efficiency**

Intervention intensity is an important consideration when evaluating intervention effectiveness. Interventions that are effective and efficient (i.e., easy to implement, inexpensive, and produce rapid learning gains) are more favorable to schools, teachers, and students (Poncy et al., 2015). Codding et al. (2011) found studies of less than 30 sessions produce larger intervention effects than studies of 30 sessions or longer. In this review, three (Figarola et al., 2008; McCallum & Schmitt, 2011; Miller et al., 1995) out of five methodologically-sound
studies (including a total of four cases) incorporated interventions that were effective at improving math-fact skills in fewer than 30 sessions. Taken together, information on intervention intensity from the included studies shows that math facts for students with ID can be effective in a relatively short period of time.

Effective interventions that are resource and time efficient are preferred by schools and teachers (Codding et al., 2011; Poncy et al., 2015). All five methodologically-sound studies included interventions that could be viewed as resource efficient. For example, three of the four studies were student-directed (Figarola et al., 2008; Irish, 2002; McCallum & Schmitt, 2011). Studies that are student-directed are resource efficient because they free the teacher to work with other students and provide the student with opportunity for taking responsibility for their own learning. Furthermore, all five interventions incorporated common teacher practices such as praise, feedback, opportunity to respond (practice), and error correction. Taken together, these five studies incorporated interventions that were time and resource efficient and effective indicating these interventions may be favorable to teachers and schools.

**Needs for Future Research**

Findings from this review point to a clear need for future research on math-fact interventions for students with ID. First, this review identified zero studies published since 2011 that targeted math fact acquisition and fluency for students with ID. Given the importance of basic math fact fluency for access to the general curriculum and improved quality of life outcomes, findings from this review are concerning. Furthermore, search results identified only five methodologically sound studies with nine cases meeting review criteria. These studies included four studies at the elementary level, only one study at the middle school level, and no studies at the high school level. Research is limited, but suggests the use of TAI, systematic
instructional strategies, and OTR has been effective for some students with mild ID.

Furthermore, research suggests the use of behavior-analytical procedures such as simultaneous prompting, CTD, and OTR with guided practice and/or modeling, feedback, and error correction. These practices are time-efficient and easily implemented in classrooms. More research is needed to investigate the use of other effective and efficient math-fact interventions (e.g., CCC) with students with ID. Additionally, more research is needed to expand math-fact research on all types of math facts (e.g., addition, subtraction, multiplication, division) and should include students across grade levels (elementary to high school) and students with moderate and severe ID. Finally, systematic lines of research are needed to examine which intervention components in intervention packages (e.g., systematic instruction) are most effective and if any components could be successfully eliminated—thus decreasing intervention intensity, increasing intervention efficiency, and potentially increasing intervention use, integrity, and acceptability in practice.

**Implications for Practice**

The most important implication for teachers and practitioners from this review is research has shown students with ID can learn to recall math facts accurately and fluently from memory. Students with ID need multiple and continued opportunities to accurately practice this basic math skill beginning in elementary school so that these skills can be applied towards grade-level math content in elementary, middle, and high school. Since math is a spiral curriculum, students need a solid understanding of basic math facts to develop other math related life skills such as time and money. Quick recall of math facts is important to the development of higher-level math skills (e.g., algebra) because it frees up working memory needed to focus on task completion. Finally, basic math fact fluency leads to improved quality of life outcomes by increasing independence and opportunity for future employment.
Summary

To date, research for math fact interventions for students with ID is sparse and zero studies have been published since 2011. A total of eight studies were identified for this review and only five studies met liberal criteria for methodological criteria. However, the five identified methodologically-sound studies were generally effective at increasing accurate and fluent responding to math facts for students with ID. Furthermore, these five studies included interventions that were time and resource efficient. Though very limited in scope and in need of more research, the results of this review are promising in that students with ID can memorize basic math fact.
Chapter Three
The Effectiveness of an Augmented Reality Application for Math Fact Acquisition in Students With Intellectual Disabilities

Since 2002, federal legislation (e.g., NCLB, 2001; IDEA, 2004; ESSA, 2015) has emphasized standards-based reform and accountability measures for all students, including those with significant cognitive disabilities. Academic standards provide a framework of expectations for student learning from year to year (Rao & Meo, 2016). While standards-based education is not new, the inclusion of students with intellectual disabilities as it pertains to standards-based learning and achievement is relatively in its infancy. Since NCLB (2001) and the reauthorization of IDEA (2004), researchers in the field of special education have contributed to a slow but steady increase in studies aimed at improving academic interventions and supports for personally-relevant access to the general curriculum for students with ID (Browder et al., 2006, 2008; Spooner et al., 2018; Trela & Jimenez, 2013). While research is steadily increasing, there continues to be a need for more research focusing on foundational mathematics instruction for students with ID (Spooner et al., 2018).

Math Instruction for Students with ID

Educational researchers, including the National Council of Teachers of Mathematics and the National Mathematics Advisory Panel (NCTM, 2000; NMAP, 2008) have reported the importance of strong foundational skills in mathematics for all students. However, according to the National Assessment of Educational Progress (NAEP), students with disabilities continue to lag behind their peers without disabilities in math achievement and only 16% of fourth-grade students and 9% of eight grade students with disabilities have achieved math proficiency standards (NAEP, 2017). Furthermore, basic mathematical knowledge is critical for future employability (Coddings et al., 2009; Matthews, 2007). Since math is a spiral curriculum, the
acquisition of one skill is required for application to other math skills. For example, acquisition of basic math facts is applied to the skill of counting money or solving equations. Therefore, more research is needed on how to best approach math skill progression for students with ID (Spooner et al., 2018). Recent research has pointed to the use of technology for academic instruction for students with ID. For example, the Center for Applied Special Technology (CAST, 2018) has recommended incorporating the use of technology in academic instruction via universal design for learning (UDL). Furthermore, technology-aided instruction (TAI) was found to be an evidence-based practice (EBP) for teaching math to students with ID (Spooner et al., 2018).

**UDL and TAI**

Universal design for learning (UDL) was officially defined with the 2004 reauthorization of the Individuals with Disabilities Education Act (IDEA). UDL has gained momentum among researchers, educators, and policy makers over the past decade and incorporates proactive design and delivery of lessons that address the myriad needs of a diverse student body. Teaching and learning can be optimized using the UDL framework through lesson design that provides students with multiple means of engagement, representation, action, and expression (CAST, 2018) and commonly includes aspects of technology. Advancements in technology have led to enhancements in universally designed lessons by reducing instructional barriers, individualizing levels of student support, and promoting access to the general curriculum in inclusive environments (CAST, 2018). These efforts can improve student outcomes in all content areas while maintaining high standards for all learners, including those with the most significant cognitive disabilities.
The use of technology in core academic instruction for students with ID has been supported by recent research (Knight et al., 2013; Root et al., 2017). Carnahan et al. (2012) advocated for technology use to support reading for students with ID and ASD while Israel et al. (2013) recommended the use of technology for science, technology, engineering, and mathematics (STEM) learning for students with disabilities. TAI has been used to facilitate vocabulary acquisition for students with ASD and ID (Bosseler & Massaro, 2003) and results have demonstrated high levels of student engagement and motivation (Travers et al., 2011). Additionally, Wehmeyer et al. (2006) found technology use can lead to positive changes in vocational and employment outcomes for students with ID. Finally, Spooner et al. (2018) found TAI to be an evidence-based practice for teaching math skills to students with ID.

The use of TAI provides opportunity for self-paced learning and content mastery for all students but is particularly useful in instruction for students with disabilities. Instructional technology is an essential feature of UDL and must be considered in lesson planning and in designing classroom environments suitable for all learners. Today, classroom instruction and independent practice are easily deliverable via handheld devices like tablets, mobile phones, and e-Readers. Furthermore, tablet and mobile devices are prevalent in today’s classrooms and their use is socially acceptable, entertaining, and user-friendly (Hughes, 2013; Kim et al., 2017). Research in special education has demonstrated that the use of mobile technology is expanding from software and computer applications for academic and life skills instruction, to the use of virtual and augmented reality experiences for acquisition of both adaptive skills and academic skills (Cihak et al., 2010).
Augmented Reality

Augmented reality (AR), is a multimedia tool accessible through mobile devices and can be accessed through a coordinating application. AR applications combine real-world objects and virtual media to create an interactive approach to learning (Craig, 2013). Recent introduction of AR in the classroom has presented new opportunities for students in the areas of math application, foreign language instruction, engineering, medicine, museum exploration, science, navigation, storybooks, and enhancing the characteristic scopes of visual schedules and chain task completion for individuals with autism (Billinghurst & Dunser, 2012; Bujak et al., 2013; Cihak et al., 2016; McMahon et al., 2016; Santos et al., 2016; Squire & Klopfer, 2007; Yoon, 2012). Augmented Reality is also resonating in the world of social media (Facebook), retail shopping, and advertising. It provides a seamless connection between digital and physical worlds, enhancing student learning and knowledge retention (Billinghurst & Dunser, 2012). AR provides interactive lessons by pairing visual and virtual discovery with a traditional physical learning experience; this intuitive teaching tool has many potential benefits for learning, especially for students with disabilities, due to the ability to transform abstract information into concrete representation (Bujak et al., 2013).

The use of AR compliments the application of UDL in meeting diverse learning styles in the contemporary classroom. Through TAI, the UDL framework promotes multiple means of engagement, representation, action, and expression for all learners (Cast, 2018; McMahon, 2014; Rose & Meyer, 2002). The use of AR as a tool for UDL adds creativity to the design and delivery of classroom instruction, which can meet the unique learning needs of all students in the classroom. One of the greatest benefits of AR is the ability of this technology to bolster a learning experience by pairing a common object or image with complementary visual and
auditory information, providing access to the content for a wider range of students (Cihak et al., 2016).

The purpose of this study was to determine if AR is an effective method to teach basic math facts to elementary students with intellectual disability. More precisely, research questions addressed in this study included: (a) Is an AR-based intervention effective for student math fact acquisition? (b) if acquired, can the skill be generalized? and (c) what is the social validity of using augmented reality for math fact acquisition?

Method

Participants

Participants in the study included three male elementary school students (Dave, Jason, and Michael) who qualified for special education services under the eligibility category of intellectual disability; they ranged in age from 9 to 11 years (see Table 3.1 for participant demographics). Participants were selected based on the following criteria: (a) identified as a student with an ID, (b) Individualized Education Program (IEP) goals for single-digit math fact acquisition (IEP goals were developed based on present levels of performance as measured by curriculum-based measures, IEP team input, and student choice/preference), (c) participation in alternate assessment, and (d) agreement to participation in the study. All three boys received reading, math, and pre-vocational instruction in a self-contained special education classroom, spending 50% of their day within the special education setting. The boys received modified content instruction in science, social studies, and all special areas in their general education classrooms. All students’ cognitive levels fell within the mild to moderate intellectual disability range: students’ Wechsler Intelligence Scale for Children (WISC-V; Wechsler, 2014) standard scores (SS) ranged from 55 to 69 ($M = 100; SD = 15$). On the Vineland Adaptive Behavior Scale-
all three students’ adaptive functioning fell within the moderate intellectual disability range.

Dave

The first participant, Dave, was an 11 years old male in the fifth grade. He was diagnosed with ADHD and met special education eligibility criteria as a student with ID, other health impairment (OHI), and language impairment; he received instruction in all academic areas with modified content based on alternate learning standards. Dave’s WISC-V standard score was 59 and VABS-II was 65. Dave also had difficulties with short-term memory and ability to recall information. At the time of the study, he had scored below the first percentile in math compared to his fifth grade peers on curriculum based measures (CBM) benchmarks. Dave’s mathematics instruction included adding and subtracting within groups of ten using manipulatives, writing and identifying simple fractions, and telling time to the quarter-hour using an analog clock. Dave successfully solved single digit addition and subtraction problems using manipulatives and representational drawings but had difficulties with automatic recall of simple math facts. When working in small groups with a teacher present, Dave would sit upright in his chair, answer teacher questions, and complete his work with no additional teacher prompting. He was very friendly with students and adults and actively participated in group discussion.

Jason

The second participant, Jason, was an 11 year old male in the fifth grade with ID and a history of Neonatal Abstinence Syndrome (NAS). He, like the other two participants, received instruction in all academic areas with modified content based on alternate learning standards. Jason’s WISC-V standard score was 69 and VABS-II was 68. At the time of the study, Jason’s math calculation skills were in the first percentile for a student entering fifth grade according to
his most recent CBM benchmark. Jason’s instructional level for math was at a beginning third grade level according to CBMs. His math instruction focused on identifying and writing fractions, telling time to the one-minute interval, adding and subtracting within three- and four-digit numbers with regrouping, and rounding decimal numbers to the nearest whole number. Jason had yet to use multiplication to solve arrays or memorize multiplication facts. When completing academic tasks, he could remain on task, participate in discussion and activities, and complete independent work with a teacher seated nearby, but had difficulties remaining on task for independent work when the teacher was working with other students. Jason was generally eager to participate in small group activities and to help other students when needed.

**Michael**

The third participant, Michael, was a 9 year old male in the third grade. Michael was diagnosed with ADHD and met eligibility criteria for intellectual disability and language impairment; he also received instruction in all academic areas with modified content based on alternate learning standards. Michael’s *WISC-V* standard score was 55 and *VABS-II* was 60. Michael had difficulties following teacher directions. He also had difficulty paying attention to tasks, was easily distracted by external stimuli, and exhibited impulsivity in decision-making and other classroom behaviors. Michael’s most recent CBM benchmark scores placed him below the first percentile for math when compared to his typical third-grade peers. Specifically, his math numbers and operations scores fell below the beginning first grade level. Michael’s math instruction consisted of telling time to the half-hour, identifying U.S. coins, adding and subtracting within ten using manipulatives, and identifying numbers from 50-100. Michael was unable to solve simple addition facts without visual or tangible representation. When completing academic tasks in small groups, Michael was both easily distracted by others and distracting to
When working one on one with his special education teacher, he was typically eager to please, but performed best with activities that allowed flexibility in seating and movement, novel uses of technology, game play, or competition.

**Setting**

The study was conducted in a small, rural southeastern school-district in a PK-5 elementary school with 400 students. The school had a 69% free and reduced lunch rate and 11% of students were identified as students with disabilities. Most of the students in the school (93%) were identified as white. All 3 participants attended a special education classroom for at least 50% of their day to receive 1:1 or small group instruction based on IEP goals to address academic and pre-vocational skills deficits. They received all academic instruction in reading, language arts, and math in the special education setting. Four other students with multiple disabilities were present in the classroom during intervention phases but were engaged in other activities with paraprofessionals at the time. Research activities took place in the school setting during the participants’ time in the special-education classroom. Most often, the study activities (i.e., baseline assessments, probing, and AR instruction) occurred just outside of the classroom at a desk at the end of hallway; this provided the students with fewer distractions and a quieter environment that was more conducive to the intervention package. The learning environment was consistent during baseline and intervention phases. During the generalization phase, the researchers administered paper-and-pencil math fact probes at a table within the special education classroom.

**Intervention Materials**

The math fact intervention incorporated flashcards, a common instructional material, with digital media created using a free mobile augmented reality application HP Reveal (HP, 2014).
HP Reveal uses the camera on a mobile device to identify a unique object or marker that triggers a user-created digital media overlay. For this study, the markers were black and white graphic images printed on laminated math fact flashcards. The video overlay is linked to the marker through the AR application; once a marker (i.e. flashcard with black and white graphic images; See Figure 3.1) is scanned by the application, the corresponding video is triggered and appears on the iPad screen. Thus, the AR learning experience is launched.

**Flashcards**

For the intervention, each student had a physical set of either addition (Dave, Michael) or multiplication (Jason) flashcards; a flashcard set contained five flashcards. The flashcards were created using a standard 3 by 5-inch index card template, then printed and laminated. For the content, each flashcard included a single addition or multiplication fact (e.g., a single-digit number added to or multiplied by another single-digit number) printed in the same format without the solution (e.g., 3 + 2= __; 4 × 2=__). Flashcards were created in sets of five for each student beginning with the number two for addition (e.g., 2 + 2, 3 + 2) and the number two for multiplication (e.g., 2 × 2, 3 × 2). Printed on each flashcard was a unique set of black and white graphic image (e.g., a marker). The set of black and white images on each flashcard triggered the AR video content for that math fact using the HP-Reveal app. Purposefully, the solution for each math fact did not correspond with the number of markers on the flashcard (i.e., the flashcard containing the math fact “1 + 2” = would not contain a set of 3 graphic images). Flashcards were created by the researcher. Figure 3.1 provides an example of the flashcards with AR markers and Figure 3.2 provides the set of math facts targeted for each student.
**AR content**

HP-Reveal was available for student use on an iPad Mini in the special education classroom. Holding the iPad mini over a flashcard marker would automatically trigger a very brief video overlay to appear. For the intervention, the elements included in each video overlay were (a) a static visual prompt of the flashcard with the math fact and the solution (which was not printed on the physical flashcards), (b) a constant time delay (CTD) of 5 seconds, and (c) audio of a read aloud of the math fact with the solution (i.e., “Four plus two equals six”). The classroom teacher created the videos for the AR content.

**Variables and Data Collection**

The independent variable in this study was the use of the AR app to acquire basic math facts (e.g., single-digit addition and multiplication). The math facts (addition or multiplication) were specific sets of facts included in each student’s IEP goals that had not yet been acquired by that student (i.e., student had low or zero-rates of responding in curriculum-based measures). The dependent variable was defined as the percentage of correct oral responding within 5-seconds to single-digit math facts presented via flash cards for 10 trials (i.e., each of the five math facts probed twice). Mastery criterion for assessments was set at 80% or greater over three consecutive sessions. Mastery criterion was chosen by the classroom teacher to correspond with student IEP goals.

**Research Design**

A multiple baseline design across participants (Kazdin, 2011) was used to examine the relationship between the augmented reality-based math fact intervention and single-digit math fact acquisition in three elementary students with ID. All students began baseline phase simultaneously; then the AR-based intervention was introduced to one participant at a time. Dave
began the AR-based intervention first; after Dave reached the 80% criterion for acquisition on one data point, Michael subsequently began the AR-based intervention. Once Michael achieved the mastery criterion of 80% correct responding over three days, the AR-based intervention was introduced to the third participant, Jason. Through systematic introduction of the AR-based intervention at three distinct points in time, a functional relationship between the math fact intervention (the independent variable) and the percentage of correct oral responding to single-digit math fact probes (the dependent variable) could be demonstrated (Kazdin, 2011).

**Procedures**

**Assessment**

For every phase of the experiment, each session started with assessment. To begin, the teacher gained student attention by delivering a verbal prompt familiar to the students and frequently used in class (e.g., “Let’s see where you’re at” and “Show me what you got”). Then, sitting with the teacher one-on-one, each student was probed on his individual set of five math facts (Figure 3.1) with each math fact repeating two times in random order for a total of ten trials. If the participant indicated the correct solution for the math fact within five-seconds, it was recorded as a correct response (+) on the data sheet. If the participant was unable to provide the correct solution within five seconds, it was recorded as incorrect (-) on the data sheet. Only neutral feedback was provided for student responses (e.g., “Ok” and “Uh-huh”) during all assessment probes. After the student completed the session, the total number of correct responses was divided by 10 (the total number of opportunities to respond) to calculate the percentage of correct responses which was graphed for visual analysis.
**Baseline**

The baseline phase consisted of oral-probing of students’ basic (single-digit) addition or multiplication math facts by following the assessment procedures described above. Baseline conditions continued for a minimum of five sessions, data was stable in all tiers, and mastery criterion was met (Ledford & Gast, 2018). During the baseline phases, all students continued with typical math instruction on math concepts (i.e., geometry, measurement, and data) unrelated to the DV while explicitly withholding instruction on math facts or math calculation.

**AR Training**

Prior to introducing the AR-based math fact intervention, students were trained to operate the HP-Reveal app so they could independently trigger the AR content (math fact flashcard, oral read aloud of math fact and solution). Students were given the opportunity to examine a sample flashcard. Then, students were taught that the black and white symbols (i.e., markers) on the card positioned around the math fact were there to help the HP-Reveal application “read” the flashcard and provide the right video. This teaching was intended to eliminate students being distracted by the markers. Students were instructed that the number of symbols did not relate to the math fact in any way. While all students were very familiar with the iPad, training on the AR application was still provided to each student independently using a one on one model-lead-test procedure (Adams & Englemann, 1996). First the classroom teacher modeled placing the iPad on a stand and positioning a flashcard over a yellow sticky note which marked the approximate placement necessary for the flashcard to trigger the AR content. Next, the student was guided through the steps (i.e., place the iPad in the stand; place the flashcard in the appropriate spot on the sticky note; view the AR-content) using least-to-most prompting procedures. The least-to-most prompting procedure included: (1) teacher gave verbal directive, “now you try it”, (2)
waited 3-seconds for student response, (3) praised for correct response within 3-seconds, (4) if student responded incorrectly or did not respond, teacher gave the verbal directive again followed by the least intrusive response prompt (gestural/point prompt, verbal prompt), (5) repeated prompting procedure until all steps were performed by the student independently. No student needed additional prompting to place the iPad on the stand and no student needed prompting beyond a point prompt to place the flashcard appropriately. Furthermore, students all independently viewed the flashcard through the iPad after placement of the flashcard on the sticky note. All three students were successfully independent in using the technology after two trials. By the start of intervention phase, students no longer needed the yellow sticky note to visually prompt flashcard placement allowing them to focus independently and intently on the content displayed by the iPad and the math fact on the flashcard.

**Augmented Reality**

During the AR intervention phase, students began each intervention session with an oral probe of math-facts as outlined above. Following probing, each student was given a set of 5 flashcards placed on the table to the left of the iPad. The student was instructed to look at the math fact on the flashcard and try to provide the answer aloud. Students were encouraged to maintain a quick pace and try to “beat the video.” As the student attempted the solution, he would place the flashcard under the iPad camera to verify the answer. After the student listened to the math fact being read-aloud with the solution (through the paired video/voice recording in the app), he would then place the flashcard in a stack to the right of the iPad. The student would repeat this procedure for each of the five flashcards for a total of three rounds. Incorporated within the AR intervention were (a) numerous opportunities to respond, (b) natural
reinforcement for correct responding, (c) time delay, and (d) immediate feedback on accuracy of responding.

**Generalization**

Generalization probes were conducted immediately following each intervention phase. Generalization consisted of administration of paper-and-pencil probes for each set of math facts for each student.

**Maintenance**

Follow-up probes were conducted 6 weeks after the end of the intervention phase. The length of time between generalization and maintenance probes was impacted by school-based holiday activities and winter break. At this point, only one student, Dave, remained in the school setting. During maintenance phase, the teacher used identical procedures from the baseline phase to check the student’s math fact acquisition with the same study materials.

**Interobserver Agreement (IOA) and Procedural Integrity**

The research team consisted of three people. The primary researcher was the special education teacher and the second researcher was a graduate research assistant. Both the primary researcher and research assistant were PhD students and had completed advanced coursework in SCRD. The third member of the team was a paraprofessional from the special education classroom who had been trained in data collection procedures. Prior to the start of the study, the classroom teacher trained the two observers on intervention procedures and assessment and data collection procedures.

Assessment and data collection procedures included: (1) wait for teacher to show student the flashcard and read the fact aloud, (2) once the teacher says the word equals, the student had five seconds to provide the correct answer, (3) if student provides the correct answer within five
seconds, record a (+) on the data sheet, (4) if student does not respond within five seconds or responds incorrectly, record a (-) on the data sheet, (5) record all data on a clipboard facing away from the student to avoid him observing your response. The classroom teacher then used role play to simulate the assessment procedures whereby one member of the review team played the role of a student and provided answers in response to the classroom teacher presenting each flashcard (deliberately providing both correct, incorrect, and no response during five second time delay) and the classroom teacher and second member of research team independently recorded data and calculated percent accuracy. This procedure was then completed with the second and third members of the research team switching roles. The classroom teacher and second team member then compared answers and accuracy data for each role play scenario to ensure consistency and calculate agreement for assessment and data collection procedures. Interobserver agreement for the mock trials was 100% across the two sessions.

During the study, the classroom teacher and a second observer collected data for interobserver agreement (IOA) and procedural integrity for baseline phases and each subsequent phase across all participants. IOA data was collected during a minimum of 25% of baseline sessions and during each subsequent phase. Both observers independently recorded each student response as correct (+) or incorrect (-) on a data sheet. Next, the two team members used point by point comparison of their data to calculate agreement. IOA was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100. Once agreement was verified, the classroom teacher recorded percent accuracy data for that session. Data for each session and each participant was entered into an Excel spreadsheet at the end of each week and graphed for visual analysis.
The research assistant was trained on the intervention procedures prior to the start of the study. Following similar procedures for training on assessment and data collection, the classroom teacher used role play to demonstrate the intervention procedures and provided the research assistant with a checklist for procedures (Figure 3.3). The checklist was provided at the beginning of each subsequent session to ensure consistency of procedures during the study including, presentation of flash cards, following the provided script, adhering to number of trials, quiz administration, CTD procedures, and recording accuracy of student responses on a data sheet. First the classroom teacher modeled the procedures. Next, the classroom teacher used the procedural checklist to guide the research assistant step-by-step through the intervention procedures. Finally, the research assistant used the procedural checklist to independently perform each step of the intervention as the classroom teacher observed. Training lasted for one session until the research assistant was able to independently demonstrate all intervention procedures.

At the introduction of the baseline phase (i.e., first three baseline sessions across participants) and start of the intervention phase (i.e., first three sessions of intervention for student one), the classroom teacher followed the checklist 100% of the time (i.e., checking off each step upon completion) to assure compliance with assessment (baseline and intervention phases) and intervention (intervention phase) procedures. The research assistant was present and collected IOA data on treatment integrity for sessions across phases and participants when all three participants were available at the same time of day (i.e., mornings on sessions 1, 2, 3, 6, 7, 8). The second member of the review team observed the classroom teacher and collected data on adherence to the checklist for these sessions. Following that initial phase of frequent integrity checks, the second member of the review team only collected IOA data one time for the intervention phase for the second and third participants and one additional time for the first
participant (i.e., session 18). IOA of procedural integrity was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100. The number of sessions with procedural fidelity data collected by two members of the research team was impacted by scheduling difficulties. However, procedural integrity measures were collected for a total of 23%, 33%, and 29% of sessions respectively for students 1, 2, and 3, but differing for each student in the number of sessions by phase (i.e., baseline or intervention) rather than remaining consistent across phases and students. On days when the research assistant was unavailable, treatment integrity measures were conducted by self-assessment by the classroom teacher using the checklist for a minimum of 20% (i.e. at least one time each week) of the remaining sessions across participants.

Social Validity

Social validity information was collected following the conclusion of the intervention. The special education teacher and paraprofessional each completed a paper-and-pencil social validity survey regarding the acceptability of the AR-based math fact acquisition intervention. The questionnaire, adapted from the Teacher Acceptability Rating Form (Reimers & Wacker, 1988), contained 5-item Likert-type scale responses to 15 social validity questions. While the response choices differed from question to question, the scale consistently included a one to five rating range with one indicating the least amount of social acceptability and five indicating the greatest amount of social acceptability. The scale was designed in this manner to prevent the need for reverse coding during analysis. The survey also included a blank space for “comments.”

Students also participated in a social validity survey following the intervention. This survey was conducted through an informal interview format using questions from a student social validity interview (adapted from McMahon et al., 2016). Each participant responded to a
verbal prompt regarding their opinion on the use of the AR app to learn their math facts. Students were asked to indicate their response through a thumbs-up (yes), thumbs-sideways (OK/kind of), or thumbs-down (no) response to each question; each response option was visually represented with a corresponding icon to indicate an up, down, or sideways thumb response from students. Students commonly used this response format in their special education classroom; therefore, no additional training was needed for student responses. During the interview, the special education teacher read the social validity questions aloud to each student and circled his response on a survey response form.

Results

The average correct response to basic math fact probes for each student is presented in Figure 3.4. Student baseline scores demonstrated very low initial knowledge of basic math facts; the baseline average correct response was 13.7% with scores ranging from 0% to 40% correct responses over 10 trials. Once the AR-based math fact intervention was implemented, student’s independent performance immediately increased for all 3 participants with 80% average correct responses and 100% nonoverlapping data (PND; Scruggs & Mastropieri, 1998). PND was used as a measure of intervention effectiveness (Scruggs & Mastropieri, 1998). PND was calculated by comparing data points between adjacent baseline and intervention phases for each participant and adding the number of data points that were different across phases then dividing that number by the total number of data points in both phases. When data points in the intervention phase have little to no overlap with data points from baseline phase, a strong argument can be made that the intervention was effective (Sruggs & Mastropieri, 1998). Furthermore, Scruggs and Mastropieri (1998) developed guidelines for using PND to describe intervention effectiveness: very effective (PND of 90% or greater); effective (PND 70%-89%); and questionable (PND less
than 70%). Therefore, this AR intervention could be described as very effective across student participants.

**Participant Outcomes**

**Dave**

Dave’s baseline average correct response was very low with 8% (range 0% - 10%) accuracy for addition math facts. During the AR-based intervention, his performance immediately improved in the first session. Dave required a significant number of sessions with the AR-based intervention (i.e., 17 sessions total) to reach mastery criteria compared to the other participants. His intervention average correct response was 72% (range 50% - 100%) with 100% nonoverlapping data. Dave showed generalization of the skills by paper-and-pencil math fact probing with an average of 97% (range 90% - 100%) accuracy across three separate probes. Follow up probing 6 weeks later indicated that Dave maintained math fact acquisition with an average of 93% (range 90% - 100%) across three probes despite no further intervention using the same math facts.

**Jason**

Jason’s baseline average correct response was 20% (range 10% - 30%) for multiplication math facts. During intervention, he required only four sessions to reach mastery as his performance immediately improved in the first session and increased above the mastery criteria level for the second and subsequent sessions. Jason’s intervention average correct response was 85% (range 50% - 100%) with 100% nonoverlapping data. He was able to demonstrate generalizability of this skill using paper-and-pencil probe completion with an average of 90% (range 80% - 100%) accuracy over four sets of ten math problems. Jason moved to a neighboring
school upon completion of the intervention phase, therefore, no information is available regarding maintenance.

**Michael**

Michael’s baseline average correct response was also very low at 13% (range 0% - 40%) for addition math facts. Like Jason, Michael required four sessions during intervention to reach mastery; his performance improved immediately upon introduction of the intervention and improved to at or above the mastery criteria level for the following three sessions. Michael achieved an intervention average correct response of 83% (range 60% - 100%) with 100% nonoverlapping data. Michael was able to generalize this skill by completing paper and pencil math fact probes with an average of 97% (range 90% - 100%) accuracy across three days of probing. Michael moved to another school district prior to implementation of the maintenance phase, therefore, no information is available regarding maintenance.

**Interobserver Agreement (IOA) and Procedural Integrity**

IOA data on accuracy data collection for student response was collected during a minimum of 25% of baseline and each subsequent phase. IOA for each student was 100%. IOA on procedural integrity for sessions observed by the second member (PhD student) of the research team ($n = 7$) sessions for each participant with a minimum of 1 data point for each phase across participants was 100% across participants and sessions. Procedural integrity was consistently met at 100% across participants due to the special education teacher’s adherence to following the checklist and script. Procedural integrity data via self-assessment remained at 100% across participants.
Social Validity

Results of the student social validity interview indicated that all three students liked using AR to study math facts and wanted to use AR to learn new things. Averages for student responses, based on three-point Likert-type items, are summarized in Table 3.2.

Results of social validity surveys for both respondents (classroom teacher and paraprofessional) indicated favorable responses to all social-validity survey items. The classroom teacher provided a qualitative type response in the space provided at the end of the survey, indicating, “students loved (the) intervention/AR!” Additionally, the classroom teacher provided an unsolicited comment to the first question (How willing are you to implement this intervention in the future?) by writing, “(the) only drawback is time to create flashcards + videos.” The survey question responses are summarized in Table 3.3.

Discussion

Key Findings

The purpose of this study was to investigate the effectiveness of an AR-based math fact intervention in increasing accuracy of oral responding to math fact probes in elementary aged students with ID. Following the introduction of the intervention condition, all students demonstrated an abrupt improvement in correct oral responding to math facts with an accelerating trend over baseline conditions; a functional relationship was established. Furthermore, students were able to generalize this knowledge to paper and pencil probes with novel staff. Additionally, Dave demonstrated maintenance and further generalization of this skill through oral probes with novel staff six-weeks after intervention. Finally, the percentage of nonoverlapping data (PND) was 100% for all three students, indicating the intervention was highly effective (Scruggs & Mastropieri, 1998).
These findings are consistent with previous findings on the use of an AR-intervention to enhance academic and vocational skill acquisition in students with ID (e.g., Cihak et al., 2016; McMahon et al., 2016; Smith et al., 2017). The use of technology to teach academic skills to students with ID has previously been supported in research (Bosseler & Massaro, 2003; Carnahan et al., 2012; Israel et al., 2013; Travers et al., 2011). Additionally, results from the current study extend the use of mobile devices for academic and life skill acquisition in students with ID (Kim et al., 2017; Smith et al., 2013).

Results from the study expand the use of mobile devices for learning by incorporating AR technologies. Blending hands-on materials with digital information (Craig, 2013) provided a unique learning platform for these young students with ID. The use of AR and tablet devices create a mobile learning opportunity allowing students the freedom to acquire new skills independently and in an environment of their choosing, thus allowing for meaningful student engagement and access to challenging academic content (Ogata & Yano, 2004). This study broadened findings for using AR to provide students with increased opportunity for independent learning (Lin et al., 2015).

This study also adds to the growing body of literature on the use of AR for STEM education. STEM knowledge and technology use are critical to future employability in our increasingly technological society. However, adults with ID are consistently underemployed in STEM related fields (AccessSTEM, 2017; Mathews, 2017). To improve employment related outcomes for students with ID, access to STEM learning is needed. McMahon et al. (2016) have found the use of AR to be effective in teaching science vocabulary to postsecondary students with ID and ASD. Additional studies on the use of AR for STEM learning have shown the use of AR for virtual manipulation of 3-dimensional objects to be effective for solving mathematical
equations and puzzle completion for students with ID (Bouck at al., 2013; Lin et al, 2015; Root et al., 2017).

**Limitations and Future Research**

Findings from this study demonstrated a functional relation between the AR intervention and the dependent variable. However, limitations must be considered when interpreting this study. First, maintenance data was collected for only one student because two students moved prior to maintenance probing. Conducting maintenance probes earlier in the study may have prevented this missing data and could have provided additional evidence of skill maintenance over time. Next, the study only consisted of three participants all of whom were male, of similar age, and all were students with mild ID. Therefore, the results must be interpreted within the context of the study.

Using AR as an instructional tool in special education needs additional research. Potential next steps include: (a) studies examining the use of AR among all disability categories and age groups; (b) studies examining the use of AR to teach additional academic skills such as reading comprehension; (c) studies that explicitly compare/contrast marker-based AR with other forms of research-based practices in group design settings; and (d) studies examining the use of AR for student-directed learning.
Chapter Four
Discussion of Promoting Personally Relevant Access to the General Mathematics Curriculum for Students With ID

The purpose of this dissertation was to identify effective strategies and interventions to support personally relevant access to the general mathematics curriculum for students with ID. Chapter one started with a literature review to outline the problem and provide historical context. It culminated in the development of a theoretical framework for supporting personally relevant access to the general curriculum for students with ID and identified the need for more research specific to math fact instruction for this population.

Personally Relevant Access to the General Curriculum

Driven by federal legislation (i.e., NCLB, 2001; IDEA, 2004; ESSA, 2015) beginning in 2001, research and practice in the field of special education has shifted away from an emphasis on a functional curriculum for students with ID towards access to the general curriculum (Spooner et al., 2006). While there was general agreement among researchers in the field (e.g., Smith, 2006; Spooner & Browder, 2015), there was also a concern that prioritizing standards-based learning may not lead to improved quality of life outcomes for students with ID (Ayers et al., 2011). However, others pointed towards the inclusive nature of the general curriculum (Trela & Jimenez, 2013; Wehmeyer, 2006) and see this change as progress towards a more fully integrated system of education for all. While research has demonstrated that students with ID can make progress towards the general academic curriculum (Browder et al., 2006, 2008; Spooner et al., 2012, 2018), students with ID need individualized support for personally-relevant access and progress in the general curriculum (Trela & Jimenez, 2013).

Personally relevant access to the general curriculum (Figure 1.1) provides support to students with ID to access grade-level content in a manner that is differentiated. It maintains
general academic curriculum expectations while individualizing learning expectations based on student strengths and needs (Trela & Jimenez, 2013). Balancing academic rigor with meaningful instruction for a population of diverse students is challenging, but personally relevant support means building a connection between academic standards and student lives (Trela & Jimenez, 2013). Furthermore, personally relevant access to the general curriculum includes promoting self-determination in students with ID through thoughtful alignment of instruction with grade-level academic standards and supporting full inclusion in school, community, and future employment opportunities.

**Self-Determination**

Personally relevant modifications to the general curriculum include supports directly linked to students’ personal preferences, strengths, and limitations (Trela & Jimenez, 2013) and explicit awareness of one’s own preferences, strengths, and limitations lead to self-determination (Wehmeyer et al., 2004). Self-determination can be seen as both a means to and a product of personally relevant access to the general curriculum. For example, explicit instruction on self-determination skills (e.g., goal-setting, self-monitoring, and problem-solving) prepares students for the rigor of academic standards. Additionally, elements of self-determination such as goal-setting, problem-solving, and decision-making are common to the academic standards in most states (Wehmeyer et al., 2004). As Wehmeyer et al. (2004) noted, “efforts to promote access to the general curriculum are not intended to de-emphasize the importance of functional and outcomes-oriented instructional experiences for youth with disabilities” (p. 417). Rather, personally-relevant access to the general curriculum includes academic instruction but maintains a focus on self-determination and meaningful outcomes for students with disabilities.
Aligning Instruction With Grade-Level Academic Standards

Personally relevant access to the general curriculum must include intentionally aligning instruction with grade-level academic standards to improve quality of life outcomes for students with ID (Browder et al., 2006; Trela & Jimenez, 2013). Ideally, instruction should target pivotal skills needed to access future grade-level content and that can be applied to acquisition of skills required for independent living and future employment. Targeting pivotal skills is an efficient use of instructional time and improves future academic and quality of life outcomes. Research has shown that having a solid foundation in basic reading and math skills reduces instructional burden (i.e. frustration) and leads to increases in task completion, comprehension, time on task, and learning growth (Burns et al., 2010). For example, by targeting basic math fact automaticity early in elementary school, students are better prepared and more likely to engage in higher level math skills (i.e., solving algebraic equations) in future instruction. Furthermore, these skills can be applied to concepts of time, money, and budgeting which enable independent living. Finally, targeting pivotal academic skills and self-determination empower students with ID to be fully integrated members of their current and future school, home, social, and vocational communities.

Inclusive Practices

As previously mentioned in this dissertation, inclusion is integrating individuals with disabilities and individuals without disabilities in one common or general curriculum. By shifting the focus from where to what students with ID should learn, teachers can begin to plan how all students will learn. The UDL framework provides a proactive method of lesson planning and instruction that provides flexible means of engagement, representation, action, and expression (Hall et al., 2012). Universally designed lessons frequently incorporate the use of technology to eliminate common barriers (e.g., difficulties with accessing printed materials) to learning for
students with ID. Advancements in technology and affordability have contributed to the wide availability of computers and handheld devices in many of today’s classrooms. While technology can lead to increased access to the general curriculum, understanding and using technology can contribute to improved life outcomes and employability. Relative to access to the general curriculum, technology changes the way content is presented to students and technology provides multiple means of engagement for students. For example, rather than listening to a lecture, reading a text, or performing paper-and-pencil computations, students can actively engage with instructional content through videos, virtual field trips, or video games. Furthermore, TAI allows for student-directed learning, self-pacing, and self-monitoring all of which lead to increased student independence and reallocation of valuable teacher resources (e.g., focus on instruction to other groups of students). TAI is one strategy for individualized instruction and skill development for students with ID. Furthermore, TAI is an EBP for teaching math skills to students with ASD and ID (Spooner et al., 2018).

Math Fact Interventions for Students With ID

Findings from the review of literature in chapter one led to the development of a theoretical framework for personally relevant access to the general curriculum. This framework was used to guide the two independent studies in this dissertation. The development of foundational math skills like automatic recall of basic math facts is part of a personally relevant curriculum for students with ID. Quick recall of basic math facts is needed to perform higher-level math skills and is crucial to understanding concepts of daily living such as time, meal preparation, and household budgeting. Furthermore, quick retrieval of basic math facts is crucial for future employment (Codding et al., 2009, 2011; Hayter et al., 2007). Therefore, studies one and two focused on math fact interventions for students with ID.
Study One

Study one was a systematic review of math fact literature for students with ID. The review began with an examination of previous literature reviews focusing on broad math skills interventions for students with ID (Browder et al., 2008; Spooner et al., 2018) and math fact interventions for students with mathematics difficulties (Burns et al., 2010; Codding et al., 2009, 2011). The former two reviews (Browder et al., 2008; Spooner et al., 2018) provided insight into effective intervention strategies targeting general math outcomes for students with ID. The latter three reviews (Burns et al., 2010; Codding et al., 2009, 2011) summarized research on effective intervention strategies targeting math fact acquisition and/or fluency for students with math difficulties. Reading these reviews gave insight into what works for students without disabilities and students with low-incidence disabilities that may be extended and applied to interventions for students with ID.

The review of math fact interventions for students with ID included eight SCRD studies, five of which were methodologically-sound. While the research was scant, there was some data from the five methodologically-sound studies that showed students with ID can acquire and fluently respond to basic math facts. Findings from the review were consistent with findings from previous reviews (Browder et al., 2008; Spooner et al., 2018) supporting the use of behavior-analytic intervention components within systematic instruction, OTR, and TAI interventions to teach math skills to students with ID. Additionally, findings were consistent with findings (Burns et al., 2010) supporting the use of OTR with specific behavior-analytic intervention components (modeling, guided practice, and frequent feedback with error correction) for increasing accurate responding to math facts for students working at the acquisition level. Relative to math fluency, the findings were also consistent with findings from
Burns et al. (2010) and Codding et al. (2011) supporting the use of OTR with specific behavior-analytic components (modeling, feedback, and error correction) to increase rates of accurate responding to math facts. Finally, results from this review suggested that math-fact interventions for students with ID can be time and resource efficient and effective which could lead to the likelihood of teacher acceptability and implementation. Despite some positive findings, this review pointed to several limitations and needs for future research.

**Limitations of the Research Base**

Findings from this review were limited by the paucity of published research targeting math fact interventions for students with ID. Without restricting publication dates in the search procedures, only eight published studies were identified. Furthermore, of those eight, only four were methodologically sound according to the CEC criteria for methodological quality and one more study met the 80% weighted criteria suggested by Lane and colleagues (2014). These limitations point to a clear need for future research on math-fact interventions for students with ID.

Previous systematic lines of research (i.e., Browder et al., 2008; Spooner et al., 2018) have demonstrated the use of behavior-analytic intervention components within systematic instruction, OTR, and TAI intervention packages to be effective math interventions for students with mild, moderate, and severe ID. The use of systematic instruction strategies with OTR has been replicated across 38 studies and 125 participants spanning all grade levels (Browder et al., 2008; Spooner et al., 2018). The use of TAI has been replicated across nine studies and 35 participants spanning all grade levels (Spooner et al., 2018). Furthermore, behavior-analytic strategies such as simultaneous prompting, CTD, guided practice, modeling, feedback, and error correction have been effective for teaching math skills to students with ID (Browder et al., 2008;
Spooner et al., 2018) and math fact acquisition and fluency for students with math difficulties (Burns et al., 2010; Codding et al., 2009, 2011). These strategies have been effective across all ages and grade levels.

Results from the systematic review presented in this dissertation support the effectiveness of systematic instruction, OTR, and TAI intervention packages incorporating behavior-analytic strategies (prompting, modeling, feedback, time delay, praise, error correction, guided practice, self-modeling, and/or goal-setting) for teaching math fact acquisition and fluency in particular for students with mild ID. However, this research is limited. The five methodologically-sound studies included in this review included only a total of seven individual and two small groups of participants with mild ID. All participants were at the elementary and middle school level. No methodologically-sound studies included participants at the high school level or participants with moderate or severe ID.

**Future Research**

Future research can begin by exploring the use of systematic instruction, OTR, TAI, and other behavior-analytic procedures to teach math-facts to students with ID across grade levels and should include students with moderate to severe disabilities. Recall of basic math facts is needed to access the general curriculum from elementary through high school. Therefore, more research is needed on effective interventions for teaching math fact acquisition and fluency skills to students beginning in elementary school so that these skills can be applied to future mathematical learning and provide personally relevant access to the general curriculum. More research is also needed on the use of TAI interventions for math fact instruction for students with ID. Since TAI interventions are most often student-directed, TAI can be a tool for personally
relevant access to the general curriculum by increasing student independence and decreasing the need for teacher support.

**Implications for Practice**

As discussed throughout this dissertation, quick recall of math facts is important for future mathematics learning and for increased independence and future employability. This review suggests that students with ID can learn to recall math facts accurately and fluently. Since math is a spiral curriculum, students with ID need frequent opportunities for practicing foundational math skills such as math-facts using effective research-based strategies beginning in elementary school. Acquiring these skills can lead to continued access to the general curriculum in middle school and high school when these opportunities become increasingly challenging (i.e., due to an increasingly demanding and challenging math curriculum and high school graduation requirements).

**Study Two**

Building on the findings from the systematic review, study two was a multiple-baseline across participants SCRD examining the effects of TAI with AR on math fact acquisition for three elementary aged students with ID. The TAI intervention package using AR incorporated some of the instructional components found to be effective in the systematic review including: (a) TAI, (b) OTR, (c) CTD, (d) modeling, and (e) feedback. Furthermore, the intervention was designed to be student-directed, resource efficient (iPad, iPad stand, AR app, flash cards), and time efficient (average time per day was approximately five minutes). More importantly, the intervention was effective in increasing correct oral responding to math facts for all three students. Furthermore, social validity data collected via survey from the students indicated that all three students enjoyed the AR intervention and wanted to use the intervention again to learn
new things. Social validity survey responses from the special education teacher and paraprofessional indicated high levels of treatment acceptability.

These findings were consistent with previous findings on the use of TAI instruction for math interventions for students with ID (Spooner et al., 2018) and the use of instructional components such as CTD, OTR, modeling, and feedback for math fact acquisition interventions (Burns et al., 2010; Codding et al., 2009). The findings were also consistent with previous findings supporting the use of AR to enhance academic and vocational skill acquisition in students with ID (e.g., Cihak et al., 2016; McMahon et al., 2016; Smith et al., 2017). Results from the study also expand the use of mobile devices for learning by incorporating the use of AR. The study broadened the use of TAI and AR to provide students with opportunity for self-directed learning (Lin et al., 2015). Furthermore it expands the research on math interventions for students with ID (Browder et al., 2008; Spooner et al., 2018) and interventions targeting math fact acquisition for students with math difficulties (Burns et al., 2010; Codding et al., 2009) by applying those intervention strategies to math-fact instruction for students with ID.

Overall, because math-fact acquisition is important for independent living and employment, the study outcomes may be considered socially important by contributing to improved quality of life outcomes. Furthermore, all three participants in the study had previously participated in their own IEP meetings and had indicated a desire to learn their math facts which then became part of their annual IEP goals. Finally, math-fact instruction is an essential part of a personally relevant curriculum for students with ID.

Limitations and Future Directions

Findings from this study demonstrated a functional relation between the AR intervention and the dependent variable. However, limitations must be considered when interpreting the AR
study. First, maintenance data was only collected for one student. Additional maintenance data from the other two students could have provided additional support for skill maintenance over time. Second, the study was limited to three students all of whom were students with mild ID. Therefore, the results must be interpreted within the context of the study.

The use of TAI and AR combined to create a unique learning opportunity for these young students with ID. Furthermore, the students were all meaningfully engaged throughout the intervention and were eager and able to access challenging academic content. Together the findings from this study point to the need for future research around TAI, AR, OTR, CTD, modeling, and feedback as tools for access to the general curriculum for students with ID. Given the innate challenges to learning for this population of students, it makes sense to find a practical intervention that can be applied to multiple academic skills. TAI and AR may provide a common tool for accessing the general curriculum for students with ID. Furthermore, this intervention may lead to increased independence via opportunity for student-directed learning.

Summary

Researchers and practitioners in the field of education must work together to develop a common curriculum that is accessible to all students. Without access to the general curriculum, students with ID risk marginalization and isolation (Wehmeyer et al., 2004). However, with personally relevant modifications and supports, students with ID can not only access but make progress in the general curriculum. Having worked with students with disabilities for 25 years, I am continuously amazed by the progress our students with ID can make when they are held to the high expectations they deserve and are provided with the proper supports and opportunities to learn. When we as special educators agree that merely more than de minimus educational benefit (Endrew v. Douglas County School District; 2016) is far from acceptable and never enough, then
we agree that learning and achievement for our students with ID have no limits. Together with high expectations, the availability of technology, the science of evidence based practices, and the promise of personally relevant access to the general curriculum, the long-standing goal of a fully inclusive and integrated society has never been more obtainable.
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https://doi.org/10.1177/0741932516643592


https://doi.org/10.1080/10508400701413435


Appendices
Appendix A Tables

Table 1.1  
*Elements of Self-Determined Behavior*

<table>
<thead>
<tr>
<th>Self-Determined Behavior Traits</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Choice-making skills</td>
</tr>
<tr>
<td>- Decision-making skills</td>
</tr>
<tr>
<td>- Problem-solving skills</td>
</tr>
<tr>
<td>- Goal-setting and attainment skills</td>
</tr>
<tr>
<td>- Independence, risk-taking, and safety skills</td>
</tr>
<tr>
<td>- Self-observation, evaluation, and reinforcement skills</td>
</tr>
<tr>
<td>- Self-instruction skills</td>
</tr>
<tr>
<td>- Self-advocacy and leadership skills</td>
</tr>
<tr>
<td>o Positive attributions of efficacy and outcome expectancy</td>
</tr>
<tr>
<td>o Self-awareness</td>
</tr>
<tr>
<td>o Self-knowledge</td>
</tr>
</tbody>
</table>

*Note: Adapted from Wehmeyer, 2007, p. 8*
### Table 2.1

*Characteristics of Eligible Studies*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants</strong></td>
<td>1 female- age 11</td>
<td>2 males- ages 15 &amp; 17</td>
<td>2 females- ages 10 &amp; 11, 1 male- age 11</td>
<td>1 female- age 12 1 male- age 11</td>
</tr>
<tr>
<td><strong>Setting</strong></td>
<td>Elementary</td>
<td>High School</td>
<td>Elementary</td>
<td>Elementary</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>ABAB</td>
<td>Multiple Baseline Across Participants</td>
<td>Multiple Baseline Across Participants</td>
<td>Multiple Probe Across Behaviors</td>
</tr>
<tr>
<td><strong>Intervention Description</strong></td>
<td>Self-graphing and goal-setting with technology-aided instruction, contingent praise, and performance feedback</td>
<td>Flash cards with Direct Instruction, opportunities to respond, performance feedback, error correction, and modeling</td>
<td>Mnemonics via technology-aided instruction with performance feedback, opportunities to respond, goal-setting, and scaffolding</td>
<td>Flash cards with constant time delay procedures, error correction, opportunities to respond, and modeling</td>
</tr>
<tr>
<td><strong>Dependent Variable &amp; Measure</strong></td>
<td>Addition fact fluency, digits correct per minute on written probes</td>
<td>Multiplication fact acquisition, percent correct and errors per minute on written probe</td>
<td>Multiplication fact acquisition, percent correct on electronic and written probes</td>
<td>Multiplication fact acquisition, percent correct oral responding within 5 seconds</td>
</tr>
<tr>
<td><strong>Intervention Effects</strong></td>
<td>Positive effects</td>
<td>Positive effects for 2 students; neutral or no effect for 1</td>
<td>Positive effects for 2 students</td>
<td>Positive effects for 2 students</td>
</tr>
</tbody>
</table>

*Note. *Intervention effects based on visual analysis conducted by the review team and only provided for methodologically-sound studies; Blank cells indicate study was not methodologically sound and not included in outcome review.*
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants</strong></td>
<td>1 female- age 13</td>
<td>2 groups Ages 9-12</td>
<td>1 male- age 14</td>
<td>2 males- ages 11 &amp; 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 males 6 females</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Setting</strong></td>
<td>Middle School</td>
<td>Elementary</td>
<td>Elementary</td>
<td>Elementary</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Multiple Probe Across Sets</td>
<td>ABABC</td>
<td>Multiple Probe</td>
<td>Multiple</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Across Sets</td>
<td>Across Sets and</td>
<td>Baseline Across</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Participants</td>
<td>Participants</td>
</tr>
<tr>
<td><strong>Intervention</strong></td>
<td>Taped problems/ technology-</td>
<td>Time trials w/</td>
<td>Flash cards with</td>
<td>Flash cards w/</td>
</tr>
<tr>
<td>Description</td>
<td>aided instruction with</td>
<td>immediate performance</td>
<td>simultaneous</td>
<td>mnemonics and</td>
</tr>
<tr>
<td></td>
<td>constant time delay, error</td>
<td>feedback and</td>
<td>prompting,</td>
<td>prompt fading,</td>
</tr>
<tr>
<td></td>
<td>correction, performance</td>
<td>opportunities to</td>
<td>opportunities to</td>
<td>error correction,</td>
</tr>
<tr>
<td></td>
<td>feedback, and</td>
<td>respond and</td>
<td>respond and</td>
<td>performance</td>
</tr>
<tr>
<td></td>
<td>opportunities to</td>
<td>contingent praise</td>
<td>contingent</td>
<td>feedback,</td>
</tr>
<tr>
<td></td>
<td>respond</td>
<td></td>
<td>praise, and</td>
<td>contingent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>positive</td>
<td>reinforcement</td>
</tr>
<tr>
<td><strong>DV &amp; Measure</strong></td>
<td>Division fact fluency,</td>
<td>Addition and</td>
<td>Multiplication</td>
<td>Multiplication</td>
</tr>
<tr>
<td></td>
<td>digits correct per minute</td>
<td>subtraction fact</td>
<td>fact acquisition,</td>
<td>fact acquisition,</td>
</tr>
<tr>
<td></td>
<td>on written probes</td>
<td>fluency, percent</td>
<td>percent correct</td>
<td>percent correct</td>
</tr>
<tr>
<td></td>
<td></td>
<td>correct per minute</td>
<td>oral responding</td>
<td>oral responding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>on written probes</td>
<td>within 4 s</td>
<td>within 4 s</td>
</tr>
<tr>
<td><strong>Intervention Effects</strong></td>
<td>Positive effect</td>
<td>Positive effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>for all 11 students</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. a Intervention effects based on visual analysis conducted by the review team and only provided for methodologically-sound studies; Blank cells indicate study was not methodologically sound and not included in outcome review.*
Table 3.1

Participant Demographic Information

<table>
<thead>
<tr>
<th>Student</th>
<th>Age</th>
<th>Ethnicity</th>
<th>Grade Level</th>
<th>Disability</th>
<th>I.Q.\textsuperscript{a}</th>
<th>Adaptive Skills\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dave</td>
<td>11</td>
<td>White</td>
<td>5</td>
<td>ID, OHI</td>
<td>59</td>
<td>65</td>
</tr>
<tr>
<td>Jason</td>
<td>11</td>
<td>Black</td>
<td>5</td>
<td>ID</td>
<td>69</td>
<td>68</td>
</tr>
<tr>
<td>Michael</td>
<td>9</td>
<td>White</td>
<td>3</td>
<td>ID, OHI</td>
<td>55</td>
<td>60</td>
</tr>
</tbody>
</table>

\textit{Note.} All names are pseudonyms. ID = intellectual disability. OHI = other health impairment.

\textsuperscript{a}As measured by WISC-V. \textsuperscript{b}As measured by VABS-II.
### Table 3.2

**Average Student Response to Social Validity Interview**

<table>
<thead>
<tr>
<th>Social Validity Likert-Type Questions</th>
<th>Likert Average Across Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>I liked using AR to study math facts.</td>
<td>3.0</td>
</tr>
<tr>
<td>Learning how to use AR helped me learn my math facts.</td>
<td>3.0</td>
</tr>
<tr>
<td>The AR math instruction was easy for me to do by myself.</td>
<td>3.0</td>
</tr>
<tr>
<td>I could see the math fact and the video with the AR app.</td>
<td>3.0</td>
</tr>
<tr>
<td>I learned my math facts faster this way than using paper flashcards.</td>
<td>3.0</td>
</tr>
<tr>
<td>Hearing my teacher’s voice on the video helped me remember my facts better.</td>
<td>2.7</td>
</tr>
<tr>
<td>I want to use AR again to learn new things.</td>
<td>3.0</td>
</tr>
</tbody>
</table>

*Note.* Average Likert-type response based on a 3-point scale with 1 indicating least amount of social acceptability and 3 indicating the greatest amount of social acceptability.
Table 3.3

*Average Response to Treatment Acceptability Rating Form*

<table>
<thead>
<tr>
<th>Treatment Acceptability Items</th>
<th>Likert Average Across Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>How willing are you to implement this intervention in the future?</td>
<td>4.5</td>
</tr>
<tr>
<td>How likely is this intervention to make permanent improvements in this student’s math skills?</td>
<td>5.0</td>
</tr>
<tr>
<td>How disruptive will it be to carry out this intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>Given your student’s academic and behavioral concerns, how acceptable do you find the AR intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>How much do you like the procedures used in the intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>How willing will other staff members be to carry out this intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>To what extent are undesirable side-effects likely to result from this intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>How much discomfort is this student likely to experience during this intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>How willing would you be to change your routines to carry out this intervention?</td>
<td>5.0</td>
</tr>
<tr>
<td>How well will carrying out this intervention fit into the existing routine?</td>
<td>5.0</td>
</tr>
<tr>
<td>How effective will the intervention be in teaching your student math facts?</td>
<td>5.0</td>
</tr>
<tr>
<td>How well does the goal of the intervention fit with the student’s IEP goals?</td>
<td>5.0</td>
</tr>
</tbody>
</table>

*Note.* Average Likert-type response based on a 5-point scale with 1 indicating the least amount of social acceptability and 5 indicating the greatest amount of social acceptability.
Figure 1.1 Personally Relevant Access to the General Curriculum

Note. Adapted from Treala & Jimenez, 2013.
Figure 2.1 Prisma 2009 Flow Diagram

Figure 2.2 Methodological Quality of Studies Across Quality Indicator Components

Note. 1.0 Context and setting- 1.1 Describes context and setting; 2.0 Participants- 2.1 Describes participant demographics, 2.2 Describes disability or risk status; 3.0- Intervention agent- 3.1 Describes intervention agent's role, 3.2 Describes training; 4.0- Description of practice- 4.1 Describes intervention procedures; 4.2 Describes materials; 5.0 Implementation fidelity- 5.1 Assess and report fidelity, 5.2 Assess and report dosage and exposure, 5.3 Assess and report throughout intervention; 6.0 Internal validity- 6.1 Controls and manipulates the IV, 6.2 Describes baseline condition, 6.3 no or extremely limited access to intervention during baseline, 6.5 Three demonstrations of effect, 6.6 Minimum of three data points, 6.7 Controls for threats to internal validity; 7.0 Outcome measure/dependent variable- 7.1 Socially important, 7.2 Define and describe dependent measure, 7.3 Reports the effects, 7.4 Measured repeatedly, 7.5 Adequate interobserver agreement; 8.0 Data analysis- 8.2 Graphs clearly represent outcome data.
### Table 2.3: Intervention Components in Methodologically-Sound Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Systematic Instruction</th>
<th>Opportunities to Respond</th>
<th>Technology-Aided Instruction</th>
<th>Prompting</th>
<th>Modeling</th>
<th>Feedback</th>
<th>Time Delay</th>
<th>Praise</th>
<th>Error Correction</th>
<th>Guided Practice</th>
<th>Self-Monitoring</th>
<th>Goal-Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mattingly &amp; Bott- 1990</td>
<td>●</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Miller et al.- 1995</td>
<td></td>
<td>●</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irish- 2002</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figarola et al.- 2008</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>McCallum &amp; Schmitt- 2011</td>
<td>●</td>
<td>●</td>
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</tbody>
</table>

**Key**

● = Present in Study

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**Figure 2.3 Intervention Components in Methodologically-Sound Studies**

**Note.** aEstablished evidence-based practice for math instruction for students with ID (Browder et al., 2008; Spooner et al., 2018).
Figure 3.1 Examples of Flashcards with AR Markers
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$2 + 2$</td>
<td>$2 \times 2$</td>
<td>$2 + 2$</td>
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<td>$2 + 3$</td>
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<td>$2 + 5$</td>
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<td>$2 + 6$</td>
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</tbody>
</table>

**Figure 3.2 Students’ Math Fact Sets**
AR-Intervention Treatment Plan

Student: _________________________ Date: _______________________

Materials: flashcards, iPad, iPad stand, pencil, data sheet

Directions: Gather all materials and go with student to desk in the hallway. Complete the following steps in order. It is important to follow the steps as written. Place a check mark next to each step after that step is completed.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Start session by “quizzing” student on set of math facts. Begin with delivering a statement to ensure attention statement such as, “Show me what you know!”</td>
</tr>
<tr>
<td>2.</td>
<td>Record data for each probe immediately after trial (+ if student responds correctly within 5 s or – if student does not respond within 5 s or student responds incorrectly.)</td>
</tr>
<tr>
<td>3.</td>
<td>Quiz student on the entire set of 5 flashcards two times in random order.</td>
</tr>
<tr>
<td>4.</td>
<td>Begin AR intervention by telling student it’s time to practice his math facts. Set up iPad on iPad stand on desk in front of student and place flashcards next to student.</td>
</tr>
<tr>
<td>5.</td>
<td>Encourage student to work quickly and try to “beat the video” (i.e. provide the answer out loud before the video provides the answer).</td>
</tr>
<tr>
<td>6.</td>
<td>Remind student to watch and listen to the entire math fact video one time before moving on to the next flashcard. (i.e. “3 plus 2 equals 5”).</td>
</tr>
<tr>
<td>7.</td>
<td>Student should cycle through the set of 5 flashcards three times.</td>
</tr>
<tr>
<td>8.</td>
<td>Observe student throughout session to ensure completion of 3 practice rounds.</td>
</tr>
<tr>
<td>9.</td>
<td>When finished, collect the iPad and flashcards.</td>
</tr>
</tbody>
</table>

Figure 3.3 Intervention Plan and Treatment Integrity Checklist
Figure 3.4 Verbal Recall of Math Facts Across Participants and Phases
Vita

Jennifer Cook was born and raised in Cape Cod, Massachusetts. She earned her Bachelor of Science in Psychology from Bridgewater State College in Bridgewater, Massachusetts in 1995. Upon graduation, Jennifer worked as a teacher for students with severe autism at The May Institute in Braintree, Massachusetts. In 1998, Jennifer earned her Master of Science in Special Education from Wheelock College (now Boston University, Wheelock College of Education) in Boston, Massachusetts. Upon graduation, she moved to Atlanta, Georgia and started her career in special education. Throughout her career, Jennifer has served the field of special education as a parent advisor and developmental evaluator in birth-3 early intervention and as a teacher of students with high- and low-incidence disabilities in both elementary and middle school classrooms. She also completed her residency year at the University of Tennessee, Knoxville (UTK) as a graduate assistant with Dr. Tara Moore and Tennessee Behavior Supports Project.

Currently, Jennifer is a clinical instructor in the special education program at East Tennessee State University (ETSU). In this role, she has taught undergraduate and graduate level courses in special education and led residency seminars for undergraduate and graduate students completing their residency year. She supervised undergraduate and graduate students in the field. As part of her PhD program at UTK, Jennifer has completed the verified course sequence and fulfilled her supervised fieldwork in July 2020 for Board Certified Behavior Analyst certification. Jennifer will take over as the program coordinator for the special education program at ETSU in August 2020. She plans to continue teaching courses and collaborating with her colleagues at ETSU on grant and research projects, contributing to publications, and leading online collaboration projects with behavior support professionals across the state of Tennessee. Jennifer's research interests include single-case research in positive behavioral interventions and
supports and access to the general curriculum for students with low-incidence disabilities and autism spectrum disorder.