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Evidence-Based Systematic Review of Literature on Algebra Instruction and Interventions for Students With Learning Disabilities

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It is imperative teachers use evidence-based practices to instruct all learners. Yet, there are limited reviews focused on educational practices to support secondary students with learning disabilities in algebra. This evidence-based systematic review focused on research published in peer review journals between 1999 and 2019. Eighteen studies across 17 articles were reviewed and analyzed, of which 14 met the Council of Exceptional Children standards of high quality. Researchers identified eight mathematical instructional approaches to teach algebra related content to secondary students with learning disabilities. The main result was that no instructional approach met the necessary criteria to be considered evidence-based for this particular demographic and mathematical content. However, five mathematical practices (i.e., CRA, manipulatives, enhanced anchor instruction, schema based instruction, and peer assisted learning strategy) were found to be potentially evidence-based.

Keywords: **algebra, evidence-based practice, students with disabilities, learning disabilities**

Introduction

Algebra is considered by many to be the mathematical gatekeeper, and mastering algebra skills gives students a passport to educational opportunities and an expansive job market (Ralston et al., 2018). Although often conceptualized as a standalone course, algebra is a strand of mathematics requiring a set of skills used across topics (Ralston et al., 2018; Stephens et al., 2015). Basic algebraic reasoning includes such problems as 3+2 = ___, with more complex algebra studied at the secondary level involving multiple steps and imaginary numbers [e.g., 4(3m – 7) = 2(6 + 9m)]. Algebra may include the manipulation of numbers and symbols to solve for an unknown, identifying and analyzing patterns, examining relationships, making generalizations, and interpreting change (National Council of Teachers of Mathematics [NCTM], 2000; Stephens et al., 2015).

According to the NCTM Standards (2000) and the Common Core State Standards for Mathematics (CCSSM, 2010), algebraic reasoning should be incorporated into all grade levels. Foundations of algebra are introduced upon entering school and students begin by developing fluency with numbers, exploring structure in operations, and describing relationships (Kieran, 2014; Stephens et al., 2015). Students build on these skills every year and should learn to express algebraic relationships symbolically using appropriate mathematical language by middle school. This

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includes solving basic expressions and equations, analyzing patterns between independent and dependent variables, and solving both real-life and mathematical problems using numerical and algebraic knowledge (CCSSM, 2010). Once students enter high school, they are challenged to create and reason with equations, inequalities, and systems of equations at an even more advanced level (Kieran, 2014).

There are several unique challenges associated with learning algebra. To begin, algebra requires a considerable amount of abstract thinking and in order to further advance their mathematical understanding, students must learn to navigate the gap from concrete to abstract reasoning (Stephens et al., 2015; Witzel, 2016). Further, language plays an integral part in gaining proficiency in mathematics, and the novelty associated with algebra creates additional challenges (Witzel, 2016). Specifically, assigning appropriate meaning to symbols is difficult for some students. For this reason, it is important to generate opportunities for students to practice using algebraic language as they converse about strategies, concepts, and mathematical procedures (Star et al., 2015). Finally, many students struggle to recognize and understand the structural characteristics of algebra (Star et al., 2015). For example, often students believe a variable can only stand for one number, instead of recognizing it could represent a large set of values. Each challenge creates barriers as students work to develop their algebraic thinking and strategies. While these challenges can be difficult for all students, they are especially demanding for students with learning disabilities (Star et al., 2015).

Algebra and Students with Learning Disabilities

When analyzing questions involving algebra (i.e., understanding of patterns, using variables, algebraic representation, and functions) on the National Assessment of Educational Progress (NAEP, 2019), students with disabilities scored an average of 40 points lower as compared to their same-aged peers without disabilities (NAEP, 2019). The average for eighth-grade students with disabilities was below the score for basic on the NAEP, while the average for students without disabilities was above basic but below proficient. Previous researchers also suggested students with learning disabilities can face challenges in algebra due to difficulties with working memory and organization (Scanlon, 2013), representing the algebraic problem (Maccini & Ruhl, 2000), as well as recall of basic facts or computational processes (Maccini & Hughes, 2000). In order to close the gap between students with learning disabilities and those without, it is imperative teachers use effective teaching strategies to give students with learning disabilities access to and support with the general education curriculum, such as algebra (CCSSM, 2010; Stevens et al., 2018). One way to determine effective—or evidence-based practices—for teaching algebra is through systematic reviews of the literature or evidence-based practices syntheses (Cook et al., 2014; Witzel, 2016).

Within the last decade, researchers conducted three systematic reviews focused on effective mathematical practices to teach algebra-related content to students with disabilities (Hughes et al., 2014; Hwang et al., 2019; Watt et al., 2016). Hughes and colleagues (2014) limited their analysis to quasi-experimental and experimental designs, and included more than peer-reviewed articles (e.g., dissertations). They analyzed 12 manuscripts including 13 different studies spanning from 1983-2013.

Participants included students with disabilities, with three studies involving elementary students and 10 studies focused on secondary students. Researchers identified six intervention categories: (a) cognitive/model-based instruction, (b) co-teaching, (c) concrete-representational-abstract (CRA) framework, (d) graphic organizer, (e) single-sex interventions, and,(d) technology. All intervention categories had a positive effect on algebra achievement, except single-sex interventions. However, only two categories—cognitive/model-based instruction and the CRA framework—had enough information to calculate a weighted effect size. Both practices indicated moderate effects on students' algebra achievement and included systematic and explicit instruction as part of the intervention.

Watt et al. (2016) included only students with identified learning disabilities and expanded on the previous review by Hughes et al. (2014) by including single-case design along with quasi-experimental and experimental design. Although their search for articles meeting criteria spanned 1980-2014, the publication dates of studies that met the inclusion criteria were limited to 2000-2014. In all, they reviewed 15 studies, including five single-case and 10 group design. Watt et al. suggested large effects from the interventions, but often an intervention package was used making individual interventions difficult to disentangle. They identified five interventions that constituted the majority of research regarding algebra and students with learning disabilities. Some interventions were consistent with the findings by Hughes et al. (2014), such as the CRA framework, cognitive strategy or modeling-based instruction, and graphic organizers. In addition, Watt et al. also suggested researchers have examined enhanced anchor instruction and tutoring to support the learning of algebra by students with learning disabilities. All of the studies included in the review by Watt et al. used explicit instruction as part of the intervention, and all but three used some type of visual representation.

Hwang et al. (2019) also focused on students with learning disabilities—with attention to secondary students—but examined problem solving and cognitive processes relative to algebra. Hwang et al. (2019) identified 11 studies focused on middle school students with learning disabilities involving algebra. Across the 11 studies, four cognitive processes emerged: the CRA, the virtual-abstract (VA), the integrated CRA (CRA-I), and solely abstract. Across all the studies, Hwang et al. (2019) concluded the interventions were effective and that researchers explicit instruction was used throughout the studies.

Purpose of the Study

Due to the importance of using evidence-based practices (EBP) to teach mathematics to students with learning disabilities, there has been an increase in systematic reviews exploring instruction used to support students with disabilities in general—and learning disabilities in particular—in the area of mathematics (e.g., Bouck et al., 2018; Hughes et al., 2014; Hwang et al., 2019; Marita & Hord, 2017; Watt et al., 2016). However, two reviews exist in the last ten years that focus explicitly on effective algebraic instruction for students with learning disabilities (Hwang et al., 2019; Watt et al., 2016). Yet, neither examined the quality of the studies in comparison to quality indicators and standards relative to determining evidence-based practices. The aim of this evidence-based synthesis was to identify and critically ana-

lyze the practices for teaching secondary school appropriate algebraic concepts to secondary students with learning disabilities. By applying the quality indicators and practice standards set by the Council for Exceptional Children (CEC, 2014; Cook et al., 2014) to the current research base, the authors sought to identify EBP in teaching algebra to secondary students with learning disabilities. The research questions included: (a) What educational practices have been used to teach algebra to secondary students with learning disabilities? (b) According to CEC standards, which of these educational practices used to teach algebra to secondary students with learning disabilities are evidence-based?

Method

Literature Search

This evidence-based synthesis focused on research regarding algebraic instruction and students with learning disabilities. To begin, the authors conducted a keyword search of existing databases. Specifically, the authors searched three databases: ProQuest, EBSCOhost, and Google Scholar. Search terms were chosen to identify studies focused on practices used to teach algebraic content to students with learning disabilities. The author used a combination of different search terms in an effort to obtain all available research in this area: (algebra OR linear equations OR equations OR systems of equations OR expressions OR multi-step equations) AND (high-incidence disabilit* OR mild disabilit* OR learning disabilit*) AND (teach OR learn OR support OR intervention OR instruction). The authors also conducted similar searches in the following journals: *Exceptional Children, Journal of Special Education, Remedial and Special Education.* Finally, the authors conducted ancestral searches of accepted articles as well as reviewed the included articles of systematic reviews focused on secondary students and mathematics (e.g., Marita & Hord, 2017; Watt et al., 2016) published within the time period.

The search was restricted to articles published in English in a peer-reviewed journal between 1999 and 2019. The authors limited articles to the last twenty years to ensure practices being evaluated were still relevant to current educational standards (Sahlberg, 2016). Two hundred and four articles were initially identified through searches; an additional 10 articles were screened through the ancestral search. Each was screened for adherence to inclusion criteria: (a) one dependent variable relative to algebra learning or skill acquisition described under the Expressions and Equations (Grades 6–8) or Algebra (Grades 9–12) domains of the CCSS; (b) target population as students with learning disabilities (LD); (c) conducted with students enrolled in sixth through 12th grade; (d) involved a single case design (SCD) or a group comparison design; (e) results could be disaggregated for students with disabilities, (f) the instruction delivered in English; and (g) the impact could be connected to an algebra instruction. Researchers excluded studies if they did not meet the inclusion criteria. For example, articles were included if (a) students were in grades PK-5 or out of school; (b) the target mathematics was not algebra; (c) the results were not disaggregated for students with disabilities or the impact of an algebraic instruction; (d) the group design involved a pretest/posttest, meaning there two groups were not compared; and (e) the study was a secondary analysis of a previously included study.

Further, articles were excluded if they addressed related, foundational, or precursor content to learning algebra (e.g., fractions, proportional reasoning), but not linear or advanced algebraic concepts explicitly. The screening was done by examining the title and abstract and—if needed–the entire article for eligibility or exclusion.

After applying the screening procedures, 18 studies (17 articles; one article included two studies) met all inclusion criteria. Once the studies were identified, the researchers recorded the study characteristics. Study characteristics included: (a) study descriptions (e.g., title, author, and date of publication), (b) sample (e.g., number of participants, age or grade), (c) participants' identified disability or inclusion criteria, (d) the mathematical content, (e) the instruction used to teach the algebraic concept, (f) the measure used to evaluate the effectiveness of the instruction (design), and (g) the results of the study.

Coding for Quality

In quantitative research, methodological rigor refers to the precision of a study in terms of design, data collection, analysis, and distribution of results (Cook & Cook, 2013; Cook et al., 2014). To establish methodological rigor in the 18 studies that met inclusion criteria, the author used specific quality indicators identified and categorized by the CEC (Cook et al., 2014). The categories included: (1) context and setting; (2) participants; (3) instructional agent; (4) description of practice; (5) implementation fidelity; (6) internal validity; (7) outcome data/dependent variable; (8) data analysis. Each category included anywhere from one to nine specific quality indicators based on the type of study (i.e., SCD or group). A majority of the quality indicators were the same for both SCD and group design, however some variation existed. For instance, internal validity was assessed using different quality indicators for each design, and group design also had an additional quality indicator related to outcomes and data analysis. Thus, 22 quality indicators applied to SCD studies and 24 quality indicators to group studies (Cook et al., 2014). Using these standards, a study is methodologically sound only if it meets all of the quality indicators for the specified research design (Cook et al., 2014).

When assessing the study for quality using the indicators proposed by the CEC, the reviewers first determined whether the authors provided sufficient information when describing the setting. This includes describing the general location like the geographic location and community characteristics such as socioeconomic status, as well as more specifics about the space being used for the instruction. For a school this may include whether it is public or private, the type of program and/or physical layout of the classroom (Cook et al., 2014). Next, the reviewers assessed whether authors included adequate information to describe the participants. This includes relevant demographic information such as specific disability diagnosis and/or whether the student is at-risk in a particular area (Cook et al., 2014). In a quality study, authors describe the method used to determine status (e.g., national or state assessments, teacher nomination, curriculum-based measurement probes).

The reviewers then assessed the presence of the instruction agent, description of practice, and fidelity of implementation. A quality study reports on critical characteristics of the person or people implementing the instruction including pertinent demographics, their background as relevant to the study, and proof they are

appropriately qualified to implement the instruction (Cook et al., 2014). In addition, each study should provide sufficient information regarding the critical features of the instruction in a way that it could be replicated by those reading the description. This includes detailed instructional procedures, instruction agents' actions, and detailed explanation of the materials (Cook et al., 2014). If this information is not included, the study should indicate how the information can be accessed (e.g., cite original source). The study should use direct reliable measures to evaluate and document procedures for implementation, including frequency and intensity, regularly throughout each component of the instruction and for each participant.

Reviewers then checked that authors established internal validity. This is demonstrated when the researcher manipulates the variable in a consistent manner, and participants have very limited or no access to the instruction. For single-case research, researchers should also describe the baseline, and for group studies details of the control and comparison conditions need to be explained (Cook et al., 2014). In group studies, assignment to group must be clearly established and described using one of the following methods: (a) randomly; (b) nonrandomly, but comparison and interventions groups are matched (c) nonrandomly, but using techniques to measure and control statistical differences; or (d) nonrandomly, but using a practical cutoff (Cook et al., 2014). Quality group studies should also demonstrate low attrition both across groups (i.e., <30% in a 1-year study) and between groups (i.e., ≤10%) or controlled for by adjusting for those who do not complete the study. In single-case research, the design selected should control for common threats to internal validity (e.g., history, maturation, testing), document three demonstrations of experimental effect at three different points in time, and include a minimum of three data points during baseline indicating unfavorable results in the absence of an instruction (Cook et al., 2014).

Quality studies demonstrate adequate psychometrics as they appropriately apply measures to determine the effect of the instruction on study outcomes. In quality research, the outcomes are socially important and the study establishes reliability (e.g., internal reliability, interobserver reliability, test-retest reliability, parallel-form reliability; Cook et al., 2014). In addition, authors clearly define the study and adequately describe the measurements of the dependent variable, the time and frequency of data collection are considered appropriate, and all effects of the instruction are reported and not just those with positive results (Cook et al., 2014). For group methods, the study should also provide sufficient evidence of validity (e.g., content, construct, criterion, social validity).

Finally, in a quality study, authors use appropriate data analysis and report effect size. For group studies this includes using techniques capable of analyzing change in performance of two or more groups and either reporting effect size or providing the necessary information to calculate effect size (Cook et al., 2014). For single-case research, a graph or graphs that clearly represent all data collected is necessary in order to determine the effect of the instruction using standard visual analysis procedures (Cook et al., 2014).

Determination of Evidence-Based Practice

To determine whether identified instructional approaches met criteria to be considered evidence-based, the author assessed the status of each category of practice. Based on the CEC standards, instructional approaches are classified as (a) evidence-based; (b) potentially evidence-based; (c) mixed effects; (d) insufficient evidence; or (e) negative effects (Cook et al., 2014). For each category, there is set criteria that must be met and in order to classify practices in special education research, methodologically sound studies need to report positive, neutral/mixed, or negative effects. Dependent on the research design, number of participants, and ratio of positive to neutral outcomes, an educational practice may be considered evidence-based with as few as two methodologically sound studies (Cook et al., 2014).

A practice is considered evidence-based if it meets specific criteria established by the CEC. When reviewing group designs, a practice must be supported by at least two methodologically sound studies including random assignment, positive results, and at least 60 participants across studies. If non-random assignment is used, there needs to be at least four studies and 120 participants across studies. When reviewing SCD research designs, a practice must be supported by at least five methodologically sound studies with positive effects and at least 20 participants across studies (Cook et al., 2014). If various research designs are used to evaluate a practice, it is evidence-based if it meets at least 50% of the criteria for two or more of the study designs. In addition, there must be at least a 3:1 ratio of studies conducted with positive results to studies yielding neutral or mixed results. If any of the studies result in negative effects on students, the practice will not be considered evidence-based (Cook et al., 2014).

A practice may be considered potentially evidence-based if there are positive results, but too few high-quality studies. When reviewing group designs, a practice must be supported by at least one methodologically sound group design with random assignment and positive effects. If nonrandom assignment is used, the practice must be supported by a minimum of two or three methodologically sound group studies. When reviewing SCD research, the practice must be supported by two to four methodologically sound SCD research with positive effects (Cook et al., 2014). If various research designs are used to evaluate a practice, it is considered potentially evidence-based if it meets at least 50% of criteria for each of the study designs. In addition, there must be at least a 2:1 ratio of studies conducted yielding positive results to studies yielding neutral or mixed results. Further, if even one study yields negative results, the practice will not be considered potentially evidence-based (Cook et al., 2014).

Interobserver Agreement

Agreement for inclusion of articles in the study and coding of study characteristics were through the consensus of the first author and a doctoral student. Twenty-five of the original 67 studies (i.e., 37.3%) were coded based on the set criteria by the two reviewers. Interobserver agreement (IOA) was determined by dividing the number of agreements by the number of agreements plus disagreement. The IOA was calculated as 97%. When a disagreement occurred, the researchers reviewed criteria and discussed until 100% agreement was reached for both inclusion and study

characteristics. Due to the acceptable IOA, the first author independently coded the remaining studies to determine inclusion for the review.

All studies that met inclusion criteria were coded independently by the first and third author for the application of quality indicators (i.e., 100%). The researcher chose to have all of the studies coded by two people because failure to meet all standards eliminated the study from being categorized as methodologically sound research. When the coders believed there was not a meaningful threat to validity and that the design issue was addressed adequately, a study was considered to have satisfied a quality indicator (Cook et al., 2014). Each coder recorded a Y when the quality indicator was met, and a N when the quality indicator was not met. A disagreement was highlighted red to indicate a need for further discussion. The researcher divided the number of agreements by the total number of indicators and then multiplied the quotient by 100 to determine interrater reliability. The IOA for quality indicators was 98.1%. Once the coders discussed the indicators of disagreement they came to agreement on 100% of the indicators and sixteen studies were classified as methodologically sound.

Results

Eighteen studies (17 articles) met the criteria to be a part of this systematic review spanning from 1999-2019. One study was published in the 1990s, 13 in the 2000s, and six in the 2010s. All studies focused on algebra-related concepts such as word problems including algebraic processes, operations with integers, and solving linear equations. All studies had neutral or positive results, and statistical results indicated moderate to large effects.

Participant Characteristics

Participants were in sixth through twelfth grade. The number of participants across all studies reported was 449. However, a portion represented peers without disabilities. Of the students with disabilities, participants were identified as having various high-incidence disabilities including learning disabilities, disabilities in mathematics, emotional or behavioral disabilities, ADHD, and mild intellectual disability. However, the majority of students with disabilities included in the research were students with learning disabilities. Specifically, 253 students across the studies were identified, as reported in the included articles, as having a learning disability (56.4%).

Study Designs

Of the 18 studies, 12 involved single-case research methodology and 6 used group design methodology (see Table 1 for characteristics and information of included studies). Within the SCD studies, one used alternating treatment design, eight used a multiple probe design, and three used a multiple baseline design. The group design methodology included two experimental designs and six quasi-experimental designs. For the quasi-experimental designs, participants were generally assigned to either a treatment or control group based on their class at school.

Table 1. ***Study characteristics***

Study	Participants	Disability	Content	Practice	Design	Results
Bottge et al. (2002)	n= 100 6-12th grade	LD, EBD, CD, SL	pre-algebra	EAI	quasi-experimental	SWD benefited from EAI and retained a majority of what they learned over time.
Bottge, Rueda, Laroque et al. (2007)	n = 42 8 SWD 7th grade	LD, EBD	pre-algebra	EAI	quasi-experimental	Participants in EAI outperformed TPI group on contextual posttest and transfer. No difference in computation and word problems. All SWD in EAI group had higher scores on the word problems, but 75% had lower computation.
Bottge, Rueda, Serlin et al. (2007)	n = 128 13 SWD 7th grade	12 LD (1 ADD)	pre-algebra	EAI	quasi-experimental	Students (inclusive of LD) benefited from EAI, including students with LD making comparable progress to students without LD
Bouck et al. (2019)	n = 4 middle school	ID, LD, ADHD	linear algebra equations	VA	SCD: multiple probe across behaviors replicated across participants	All four participants acquired the algebra skills, but were unable to maintain skills when instruction was not provided directly before completing the probe.
Calhoon & Fuchs (2003)	n = 92 9th-12th grade	LD, EBD, ID	operations & algebraic thinking, measurement, & geometry	PALS	quasi-experimental	PALS + CBM group outperformed the control group on computation scores. Both groups increased comparably on concepts/applications.

Table 1. ***Study characteristics (continued)***

Ives (2007a&b)	n = 14 (GO) n =16 (CG)	LD	solving systems of linear equations	graphic organizer	experimental	Participants who used graphic organizers outperformed those who did not when solving systems of linear equations. In Study 1, participants maintained learning over a couple of weeks. In Study 2, students had more success actually solving the problems.
Jitendra et al. (2002)	n = 4 8th grade	LD	word problems	SBI	SCD: multiple probe across participant	All participants improved word problem–solving performance and maintained performance over the duration of the intervention. All participants demonstrated high scores during generalization.
Jitendra et al. (1999)	n = 4 6th-7th grade	LD	word problems	SBI	SCD: multiple baseline across participants replicated across behaviors	All participants improved from baseline to intervention in using correct operations. Participants generalized strategy. 2 participants maintained, 1 slightly decreased, 1 drastically decreased.
Maccini & Hughes (2000)	n = 6 ages 14-18	LD	problem solving with integers	CRA	SCD: multiple probe across participant	Problem-solving skills dramatically improved following instruction at the concrete, semi concrete, and abstract levels. Participants' strategy use increased and they were able to generalize skills to novel situations.

Table 1. *Study characteristics (continued)*

Maccini & Ruhl (2000)	n = 3 8th grade	LD	subtraction of integers	CRA	SCD: multiple probe across participant	All participants demonstrated an improvement in strategy use, accuracy on problem representation, and average accuracy on problem solution from baseline to concrete instruction. Participants were able to maintain skills over time, and were able to generalize to near tasks, but have lower transfer skills for far generalization.
Satsangi et al. (2016)	n = 3 11th-12th grade	MLD	linear algebraic equations	manipulatives (virtual & concrete)	SCD: alternating treatment	All participants solved more algebraic questions correctly with both types of manipulatives. 2 students learned the material quickest with concrete, and one student learned quickest with virtual. All 3 students had fewer prompts and completed problems quicker using virtual manipulatives suggesting greater independence.
Satsangi et al. (2018a)	n = 3 9th grade	MLD	multistep algebraic equations	manipulatives (virtual)	SCD: multiple baseline across participant	Using virtual manipulatives all participants scored above their baseline scores during intervention, maintenance, and generalization. All participants said they benefited and enjoyed using the virtual manipulatives.
Satsangi et al. (2018b)	n = 3 9th grade	MLD	multistep algebraic equations	manipulatives (virtual)	SCD: multiple baseline across participants	All participants improved from baseline. Accuracy scores ranged from 70-100% during intervention and maintenance. Independence scores ranged from 78-100% during intervention and maintenance.

Table 1. ***Study characteristics (continued)***

Scheuermann et al. (2009)	n = 14 6th-8th grade	LD	one-variable equations	Explicit Inquiry Routine (EIR)	SCD: multiple probe across participant	All participants made substantial progress, all but 1 student reached mastery criterion (80% accuracy) by the final instructional probe. Participants were able to generalize their skills to new problems written in the same format and maintained performance for up to 11 weeks.
Strickland & Maccini (2012)	n = 3 8^{th}-9^{th} grade	LD	multiplying linear expressions	CRA-I + Graphic Organizer	SCD: multiple probe across participants	All participants substantially increased overall accuracy from baseline to intervention. 2/3 demonstrated mastery level during maintenance, 1 was improved from baseline, but not mastery. Participants transferred info to novel situations but were not able to transfer to higher level mathematics. Participants reported that they found the intervention beneficial and enjoyable.
Strickland & Maccini (2013)	n = 5 high school	LD, MD	quadratic expressions within area word problems	CRA-I + Graphic Organizer	SCD: multiple probe across two groups	Participants' accuracy improved and they maintained their skills over time. Participants reported the intervention was beneficial and they would recommend it to peers.
Van Garderen (2007)	n = 3 8th grade	LD	word problems (algebra skills)	Diagrams	SCD: multiple probe across participants	Students improved ability to generate diagrams and use them to solve 1 and 2-step word problems. Participants generalized their skills to solve different types of word problems.

Note: EAI = enhanced anchored instruction, VA = virtual-abstract; PALS = peer-assisted learning strategies CRA = concrete-representational-abstract, SBI = schema-based instruction

Categories of Mathematical Practice

After analyzing the mathematical practices described in each study, eight instructional categories emerged: (a) concrete-representational-abstract (CRA) framework (b) schema-based instruction, (c) enhanced anchor instruction, (d) manipulatives, (e) peer-assisted learning strategies, (f) virtual-abstract (VA) framework (g) graphic organizers and diagrams; and, (h) explicit inquiry routine. Three studies explored the CRA instructional sequence, three manipulatives outside of an instructional sequence, and one virtual manipulative-based sequence. Two studies investigated schema-based instruction (SBI) and three studies investigated enhanced anchored instruction (EAI). One study explored peer-assisted learning strategies (PALS), one the impact of visual displays like graphic organizers and diagrams, and one study explicit inquiry routine.

Applying Quality Indicators

After applying the criteria established by the CEC, four studies did not meet the requirements to be considered methodologically sound research. Four of the six group design studies had all 24 quality indicators (See Table 2) and 10 of the 12 single-case studies had all 22 quality indicators (see Table 3). Studies not meeting quality indicators included (a) Scheuermann et al. (2009), who did not include adequate implementation fidelity information; (b) Ives (2007), who reported two studies in one publication with both missing several key indicators including adequate procedural information, proof of fidelity of implementation, and adequate internal validity; and (c) Strickland and Maccini (2012), who only included two baseline data points for one of their participants.

Based on the CEC standards and the 14 studies that met all quality indicators for algebraic instruction and students with high-incidence disabilities, no interventions met the criteria to be considered evidence-based. All studies yielded neutral or positive results, but the research base lacked adequate quantity of high-quality studies for each practice. Five mathematical practices can be considered potentially evidence-based including: CRA, manipulatives, EAI, SBI, and PALS (see Table 4).

Three quality studies explored the CRA framework and all yielded positive results. Two studies paired the CRA framework with the problem-solving strategy STAR (search, translate, answer, review; Maccini & Hughes, 2000; Maccini & Ruhl, 2000), and one modified the CRA strategy to include a graphic organizer during the abstract phase (Strickland & Maccini, 2013). When only including studies that explored manipulatives as a stand-alone mathematical tool, and not part of an instructional sequence, three SCD studies with nine participants existed. One study compared concrete and virtual manipulatives and found both to be effective for secondary students with disabilities (Satsangi et al., 2016), and two paired virtual manipulatives with explicit instruction and reported a functional relation (Satsangi et al., 2018a, 2018b).

Table 2. ***Cook et al. (2014) Quality Indicators (QI) Applied to Group Design Algebra Studies Involving Students with Learning Disabilities***

	1.1	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	5.3	6.1	6.2	6.3	6.4	6.8	6.9	7.1	7.2	7.3	7.4	7.5	7.6	8.1	8.3
*Bottge et al. (2002)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Bottge, Rueda, LaRoque, et al. (2007)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Bottge, Rueda, Serlin, et al. (2007)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Calhoon & Fuchs (2009)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ives (2007a)	Y	Y	Y	Y	Y	N	Y	N	N	N	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ives (2007b)	N	Y	Y	N	N	N	Y	N	N	N	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y

Note: Y = yes, quality indicator present & N = no, quality indicator not present. Quality indicators 6.5, 6.6, 6.7, and 8.2 only applied to single case studies and are not included here. See Cook et al. (2014) for the complete list of quality indicator (e.g., 1.1 – 8.2). Note, Ives (2007a and 2007b) were reported both in one article

* means the study met all quality indicates

Table 3. ***Cook et al. (2014) Quality Indicators Applied to SCD Algebra Studies Involving Students with Learning Disabilities***

	1.1	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	5.3	6.1	6.2	6.3	6.5	6.6	6.7	7.1	7.2	7.3	7.4	7.5	8.2
*Bouck et al. (2019)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Jitendra et al. (2002)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Jitendra et al. (1999)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Maccini & Hughes (2000)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Maccini & Ruhl (2000)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Satsangi et al. (2016)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Satsangi et al. (2018a)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*Satsangi et al. (2018b)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Scheuermann et al. (2009)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Strickland & Maccini (2012)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y
*Strickland & Maccini (2013)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
*VanGarderen (2007)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Note: Y = yes, quality indicator present & N = no, quality indicator not present. Quality indicators 6.4, 6.8, 6.9, 7.6, 8.1, and 8.3 only applied to group design studies and are not included here. See Cook et al. (2014) for the complete list of quality indicator (e.g., 1.1 – 8.2).

* means the study met all quality indicators.

Table 4. ***Evidence-Base Categories of Practices***

Practice	Group	Single	Participants	Random	Results	Category
Manipulative-Based Approaches	0	7	27	N/A	Positive	Evidence-based
Enhanced Anchor Instruction	3	0	142	No	Positive/Neutral	Potentially Evidence-Based
Peer-Assisted Learning Strategies	1	0	92	Yes	Positive	Potentially Evidence-Based
Schema Based Instruction	0	2	27/8	N/A	Positive	Potentially Evidence-Based
Graphic Organizers & Diagrams	0	1	3	N/A	Positive	Insufficient Evidence

This review included three group designs that investigated EAI. Two of these studies yielded positive results (Bottge, Reuda, Laroque, et al., 2007; Bottge, Reuda, Serlin, et al., 2007), while the other had neutral results where participants in the EAI outperformed the control group and students with disabilities scored better on word problems using EAI, but their computation skills were lower (Bottge et al, 2002). Two SCD studies with eight participants (Jitendra et al., 1999; Jitendra et al., 2002) investigated SBI and one group design with 92 participants explored PALS (Calhoon & Fuchs, 2003). These three studies yielded positive results categorizing these two practices as potentially evidence-based.

Discussion

This evidence-based synthesis analyzed the literature on teaching algebra to secondary students with learning disabilities. Eighteen studies were reviewed and analyzed, of which 14 met the CEC standards of high quality (Cook et al., 2014). Across the 18 studies, researchers investigated eight different mathematical instructional approaches to teach algebra related content to secondary students with learning disabilities. The main result of the review was that none of these instructional approaches met the necessary criteria to be considered evidence-based for this particular demographic and mathematical content. However, five mathematical practices (i.e., CRA, manipulatives, EAI, SBI, and PALS) were found to be potentially evidence-based. From this systematic review, educators can make informed decisions about the instructional practices they use to teach algebra to students with high-incidence disabilities, and researchers can plan future studies to fill the gaps in literature.

When focusing specifically on instruction to support secondary students with learning disabilities in the area of algebra, no one instructional approach category met the CEC's (2014) standards of evidence-based. The lack of evidence-based practice determinations is likely due to a lack of literature on the topic. Researchers found 18 studies in the past 20 years focused on algebra interventions and instructional practices to support secondary students with learning disabilities. This number is relatively small compared to research pertaining to interventions and instructional practices to support students in reading (Wood et al., 2018) and mathematics interventions and instructional approaches focused on more foundational content (e.g., early numeracy, basic operations; Dennis et al., 2016; Stevens et al., 2018). Further, there was a decrease in the last decade as compared to the previous decade (almost double in the 2000s to that in the 2010s). Combined, these findings demonstrates the need for more high-quality research to be conducted to provide practitioners with evidence-based practices for teaching algebra to secondary students with learning disabilities.

Nearly one-fourth of the studies analyzed in this review failed to meet the standards established by the CEC to be considered methodologically sound (Cook et al., 2014). CEC's standards were published in 2014, resulting in the majority of included studies published before the standards were established. While quality indicators and standards existed previous to this date (e.g., Horner et al., 2005 for single-case and Gersten et al., 2005 for group), nearly half of the included publications published before these earlier quality indicators and standards. In this evidence-based synthesis, we applied indicators and standards ex post facto to studies published prior

to such guidelines. Further, the CEC quality indicators and standards applied here may be more rigorous than other options, because they require studies to meet all quality indicators in order to be considered methodologically sound (Cook et al., 2014; Cook & Cook, 2013). Applying quality indicators with such high standards means only the most credible studies are included when determining whether a practice is evidence-based (Cook et al., 2014; Cook & Cook, 2013). Thus, when a practice meets evidence standards, practitioners can use it with confidence. However, the authors also acknowledge the problem when applying quality indicators—they can only be applied to studies that actually get published. Studies with negative results or insignificant results are likely not published and hence evidence-based syntheses are subject to publication bias (Cook & Therrien, 2017).

Five mathematical practices met the criteria for potentially evidence-based: CRA, manipulatives, EAI, SBI, and PALS. Consistent with previous reviews, the implementation of these instructional approaches yielded positive results for students with disabilities acquiring algebra skills (e.g., Marita & Hord, 2017; Watt et al., 2016). A classification of potentially evidence-based means there were too few studies and/or participants to confirm the effectiveness of the practice (Cook et al., 2014). However, within the case of EAI and SBI, Bottge and colleagues and Jitendra and colleagues examined issues related foundational algebra concepts—including fractions and proportional reasoning—but fewer examining algebra as defined in this review. If the review was expanded to include these fundamental concepts, EAI and SBI would likely be determined EBPs for secondary students with learning disabilities. However, there is a need for more research focused on algebra and students with learning disabilities in order to validate that seemingly effective instructional approaches are backed by multiple sources of high-quality evidence as well as continue to explore the efficacy of new instructional approaches that take into consideration emerging technologies and understanding of algebra in mathematics education. Yet, the results offer secondary educators options for consideration when teaching algebra, given only practice could be considered evidence-based for teaching algebra to secondary students with learning disabilities.

Over one-third of the high-quality studies reviewed involved manipulatives either as a stand-alone tool (e.g., Satsangi et al., 2016) or as part of a framework (e.g., Bouck et al., 2019, Maccini & Ruhl, 2000). If combined, the category of manipulative-based instructional approaches—inclusive of CRA, VA, and manipulatives—would have been an evidence-based practice. Yet, the differences of the instructional approaches within this larger category are great and as such, the authors opted not to combine or aggreate. However, the potential evidence-base determination for the CRA and manipulatives aligns with the recommendation of the National Council of Teachers of Mathematics to use manipulatives for teaching mathematics at all levels (NCTM, 2013). Further, Bouck et al. (2018) found the CRA to be evidence-based for students with learning disabilities generally across mathematics, not disaggregated by domain.

Implications for Practice

The results of this systematic review hold implications for practice. The first is that there are five potentially evidence-based practices to teach algebra to students

with learning disabilities. When implemented with fidelity, researchers demonstrated these practices support student learning in mathematics (Maccini & Hughes, 2000; Satsangi et al, 2018a). While they are not guaranteed to work for every student, these mathematics instructional approaches should be a consideration in algebra instruction decision making for secondary students with learning disabilities (Cook & Cook, 2013). Although secondary students with learning disabilities are making gains in mathematics, gaps still exist between those with disabilities and those without (NAEP, 2019), thus it is imperative teachers use practices that are shown to be effective for students with disabilities (NCTM, 2013).

A final implication for practice is the emergent of the use of virtual manipulatives to support secondary students with learning disabilities in the area of algebra. The four most recent studies included in this review involved virtual manipulatives in some capacity (e.g. Bouck et al., 2019, Satsangi et al., 2018a; Satsangi et al., 2018b; Satsangi et al., 2016), suggesting virtual manipulatives represent an up-to-date and relevant practice. Accessible through Chromebooks, iPads, or computers, virtual manipulatives do not take up extra space in the classroom, allow for individualized scaffolding within the program, and are often less stigmatizing to older students compared to concrete manipulatives (Satsangi & Miller, 2017). Secondary teachers delivering math instruction may want to consider using virtual manipulatives during whole group instruction or for small group interventions targeting specific skill deficits.

Limitations and Future Direction

This evidence-based systematic review is not without its limitations. Although steps were taken to ensure all relevant peer-reviewed research was included, there is a chance the inclusion criteria excluded literature that could add to the results and discussion. Further, only peer-reviewed journal articles published in English were considered, leaving out both dissertations and chapters from books. Future researchers should consider including non-peer-reviewed publications to gather a larger scope of the existing literature. Regardless, the low number of peer-reviewed published studies is a call to action for researchers to expand research on algebra interventions and instructional approaches for students with learning disabilities.

Another limitation was that the instructional approaches examined among studies were sometimes an intervention package (i.e., a combination of instructional components, such as manipulatives plus explicit instruction) making it difficult to credit the effects to a single element (e.g., manipulatives; Watt et al, 2016). In some situations, the intervention or instructional approach was paired with a strategy already established as evidence-based to teach mathematics to secondary students with learning disabilities (e.g., National Center on Intensive Intervention, 2016; Satsangi et al, 2018a). When paring explicit instruction with other practices, like manipulatives, it is difficult to determine whether the use of the manipulatives or the quality instruction was the source of success. Future researchers should include direct comparisons of instructional practices in order to help educators in determining the most effective evidence-based practices for teaching algebra to students with learning disabilities. However, the researchers also acknowledge that intervention packages are more likely to help educators achieve the acquisition, maintenance, and generalization of algebra they seek to achieve for their secondary students with disabilities (Park et al., 2020).

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