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Teaching Mathematical Word Problem Solving to Students with Autism Spectrum Disorder: A Best-Evidence Synthesis

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Abstract: *This systematic review provides a synthesis of intervention research that taught mathematical word problem solving skills to students with autism spectrum disorder between 1975 and April of 2020 by evaluating the body of research in terms of "what works", "for whom" and "under what conditions". The Council for Exceptional Children (CEC, 2014) quality indicators were used to evaluate methodology of the 20 included studies. The 18 studies that met the criteria to be classified as "high quality" were further analyzed in terms of intervention components (i.e., the "what"), how effectiveness was measured (i.e., defining "works"), characteristics of individuals included in the research (i.e., "for whom") and the tasks, settings, and instructors used (i.e., "under what conditions"). While six practices met the CEC criteria for classification "evidence based", including task analysis, system of least prompts, graphic organizers, explicit instruction, schema-based instruction, and technology assisted instruction, these practices were consistently used in combination as "treatment packages". Implications for practice and future research are discussed.*

Unlike reading, school is likely to be the only context where students receive instruction in mathematics (Van de Walle et al., 2010). Engaging in mathematical problem solving tasks within school settings may increase individuals ability to apply acquired mathematics skills in real-world settings (Spooner et al., 2017). Supporting problem solving skills of learners with autism spectrum disorder (ASD) will likely increase vocational, leisure, and daily living opportunities (Bowman et al., 2019). Contextualizing or anchoring mathematics instruction may increase engagement necessary for students to persevere through challenging mathematics tasks (Bowman et al., 2019). Word problems provide a way for students to practice real-world application of mathematical tasks by applying computational strategies in an analytical method (Spooner et al., 2017). Further, state standards in mathematics include word problem solving skills across all grade levels (National Governors Association for Best Practices, 2010). Teachers are tasked with using scientifically based strategies to teach mathematical word problem solving to all students (Individuals with Disabilities Education Act, 2004), yet there is a lack of specificity on what those are and their effectiveness for students with ASD.

The learning characteristics of students with ASD compound their difficulty in both school and real-world mathematics tasks, as they may lack the metacognitive skills necessary to plan and execute problem solving. Jitendra and colleagues (2016) suggest mathematics is particularly challenging for students with deficits in working memory, language, and attentive behavior, as is characteristic of students with ASD. Students with ASD also exhibit deficits in executive functioning skills, which are linked to mathematical ability (Bull

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& Scerif, 2001). This impacts their ability to make a plan, organize important information, attend to a task for a prolonged period of time, and self-monitor their progress (Hart Barnett & Cleary, 2015).

Despite its importance, practitioners have few research-based models for teaching students with ASD to solve word problems. Hart Barnett and Cleary (2015) conducted a systematic literature review to examine the effectiveness of mathematics interventions for students with ASD. Of the 11 studies that met their inclusion criteria, four taught word problem solving. Based on their analysis, Hart Barnett and Cleary (2015) suggest that both visual representations and cognitive strategy interventions were effective in teaching mathematics skills to students with ASD. The authors suggest future researchers should teach higher-order mathematical skills (e.g., problem solving) to students with ASD, as recommended by the NCTM (2000), after they found most of the interventions reviewed focused on computation and procedures in mathematics. However, a limitation of this review is that authors did not address quality of included studies. While these findings provided the field with information on the extant research on teaching mathematics, they did not analyze results through the lens of quality indicators. Without knowing the quality of research, practitioners and researchers are unable to make informed decisions about what works, for whom, under what conditions (Rao et al., 2017). This is particularly important when considering effectiveness for individuals with ASD who have varying levels of support needs.

King et al. (2016) used the What Works Clearinghouse quality indicators (WWC; Kratochwill et al., 2013) to analyze published mathematics intervention studies for students with ASD, identifying 14 high-quality (i.e., met WWC pilot standards) single case articles that reported relevant results for 57 participants with ASD. The majority of the studies focused on computation or functional skills (n = 22; 78%). Far fewer (n = 2; 7%) focused on word problem solving. In these two studies, strategy instruction and modeling resulted in positive effects. While the number of intervention studies teaching mathematics to students with ASD is increasing (Hart Barnett & Cleary, 2015; King et al., 2016), prior reviews did not identify a significant quantity of studies targeting problem solving to draw conclusions on effective practices. As a result, consumers of this research may have difficulty making judgments about what might work for whom under what conditions.

Purpose of the Current Review

Given the complex cognitive processes required for problem solving, many students with ASD will not make adequate progress without high quality instruction (Spooner et al., 2017). The purpose of this review is to synthesize the experimental research on teaching mathematical word problem solving to students with ASD using the Council for Exceptional Children ([CEC], 2014) quality indicators. CEC outlines five classifications, including evidence-based practices, potentially evidence-based practices, mixed effects, insufficient evidence, or negative effects. Our intent was to tease out answers to the question "What works for whom under what conditions?" by analyzing experimental research on teaching word problem solving to individuals with ASD. We were guided by the following research questions:

1. To what extent do studies teaching mathematical word problem solving to students with autism spectrum disorder meet the Council for Exceptional Children's (2014) quality indicators of methodologically sound studies?
2. What are the characteristics of the students included in high quality studies that taught mathematical word problem solving to students with autism spectrum disorder?
3. Under what conditions (e.g., tasks, settings, and instructors) have students with autism spectrum disorder been taught mathematical word problem solving?

Method

Inclusion Criteria

Considering the focus of this literature review on intervention studies that taught mathematical word problem solving to students with

ASD, studies had to meet the following inclusion criteria: (a) published or accepted for publication in a peer-reviewed journal between 1975 and April 2020 or be a dissertation or thesis made publicly available during the same time frame; (b) include at least one participant with a diagnosis of ASD; (c) use a recognized experimental or quasi-experimental design; (d) have a dependent variable that measured word problem solving; and (e) disaggregate data for participants with ASD.

Search Procedures

Published articles were initially identified through a simultaneous search of electronic databases (Education Resources Information Center, InfoTrac, and Psych Info). Combinations of the following terms were used: disability area (*ASD, Asperger, developmental disability)* topic of instruction (*mathematics, algebra, geometry, problem solving, arithmetic, word problem*), and materials (*graphic organizer, manipulatives, technology, calculator*). Authors searched ProQuest for theses and dissertations published through April 2020 using the same search terms. A hand search was completed through the following special education and journals for articles that did not appear in the electronic search: *Remedial and Special Education, Research & Practice for Persons with Severe Disabilities, The Journal of Special Education, Exceptional Children, Journal of Autism and Developmental Disorders, Journal of Special Education Technology, Focus on Autism and Other Developmental Disabilities, and Education and Training in Autism and Developmental Disabilities.* Finally, an archival search of the references of included studies was conducted to find any studies that may have been missed in the electronic or hand searches. This search generated a total of 330 published articles and 120 unpublished dissertations and theses after all duplicates were removed. In the first round of screening, we screened articles out based on titles and abstracts that clearly did not meet inclusion criteria, which eliminated 385 manuscripts, retaining a total of 65 studies. In the second round of screening, two members of the research team read the full text of the remaining studies to determine whether they met all inclusion criteria. A total of 19 unduplicated studies (16 published articles, three unpublished dissertations) met inclusion criteria following this second round of screening. An additional article was identified by a final archival search, resulting in 20 included studies. We calculated interrater reliability by taking the number of agreements divided by the number of agreements plus disagreements, multiplied by 100. Agreement during the second round of screening for 100% of articles was 100%.

Coding for Quality Indicators

A three-level coding system was used as suggested by Ledford and Gast (2018): (1) study characteristics, (2) study rigor, and (3) study outcomes. We assessed rigor and outcomes using the Council for Exceptional Children's (CEC) quality indicators (QI). As explained by Cook et al. (2015), the CEC EBP standards include 28 total QIs across eight areas: context and setting, participants, intervention agents, description of practice, implementation fidelity, internal validity, outcome measures/dependent variables, and data analysis. CEC guidelines require studies to meet all QIs in each of the 8 areas to be considered methodologically sound.

Authors evaluated study outcomes as either positive, neutral/mixed, or negative using the CEC (2014) guidelines. For single case studies, effects are classified based on both participants for whom a functional relation was established as well as the direction of the functional relation based on standard methods of visual analysis (Ledford & Gast, 2018). When a functional relation was established and results in a meaningful therapeutic change in the targeted dependent variable with at least three replications of effect, the study was deemed to have positive effects. When a functional relation was established with a nontherapeutic change across three cases, the study was deemed to have negative effects. A study was classified as neutral or mixed effects when criteria for neither positive nor negative effects were met.

While not required by the CEC guidelines, we chose to calculate an effect size estimate for the included single-case studies using Tau-U. Creating an appropriate method for calculating effect sizes for single-case research has proven difficult because typical statistical methods cannot be used, such as ordinary least squares regression, due to a violation of assumptions (Parker et al. 2011). Non-overlapping measures have been created, but often have issues based on a 100% ceiling being reached and not accounting for trend. Tau-U is a non-overlapping data method that is more like regression then other non-overlap methods. It addresses many difficulties created by other non-overlap methods such as: not hitting the 100% ceiling, calculating trend, and controlling for a trend in baseline (Parker et al., 2011). Authors extracted data from the provided graphs to an excel spreadsheet and then the inputted the information in the online calculator (Vannest et al., 2016). IOA was conducted on data extraction and Tau-U calculation for 50% of the single-case articles and agreement was at 100%. Authors used guidelines from Vannest and Ninci (2015) to interpret the estimated effect of interventions with small (below .20), moderate (.20 - .60), large (.60 - .80), and very large (<.80).

In order for a study to be considered methodologically sound, all eight QIs needed to be met and effects had to be positive (Cook et al., 2015). Interrater reliability for coding QIs was collected for 100% of the included studies using an item-by-item agreement method across the eight QIs, with 92% agreement across QIs. Consensus on each disputed QI for each study was met through review of criteria, the article, and discussion.

Determining Level of Evidence

After each included study was coded, they were evaluated to determine the level of evidence for instructional practices using the CEC (2014) guidelines. The criteria for "evidence-based" includes only articles that are methodologically sound (i.e., met all eight QIs and had positive effects). A practice can be deemed "evidence-based" if there are two group studies with at least 60 participants, five single case studies with a total of 20 participants, or a combination of one group (30 participants) and three single case (10 participants) studies. Practices can be classified as "potentially evidence-based" if they are supported by (a) one methodologically sound group comparison study with random assignment to groups and positive effects, (b) two or three methodologically sound group comparison studies with non-random assignment to groups and positive effects, (c) two to four methodologically sound single case studies with positive effects, or meet at least 50% of the criteria in items a-c and do not include studies with negative effects.

Results

Included Studies

See Table 1 for QIs met and unmet for all 20 included studies and Table 2 for the characteristics of all 20 included studies along with effect sizes. Of those 20 studies, 19 used single-case methods and one used a group design. Eighteen met the CEC (2014) criteria for high quality studies (marked by asterisk in Table 2), indicating they were methodologically sound, had positive effects, and met all quality indicators specified for the relevant research design.

"What Works": Evidence-Based Practices for Teaching Word Problem Solving

Six practices met the CEC (2014) criteria for classification as evidence-based: task analysis, system of least prompts, graphic organizers, explicit instruction, schema based instruction, and technology-aided instruction. Every high quality study included multiple evidence-based practices, as they were used in combination in "treatment packages". For example, Chapman and colleagues (2019) used system of least prompts to teach steps of a task analysis for solving linear equations and provided students with a graphic organizer to support filling out the equations. Table 3 shows the practices used in each high quality study and a sum of the evidence supporting classification (i.e., number of high quality studies and number of participants with ASD).

Task analysis (TA) was defined as the process of breaking down a chained task into smaller steps to receive individualized instruction (Collins, 2012). Fourteen high-quality

TABLE 1

Quality indicators met and unmet for all included studies

Quality Indicator	*Bdouck & Long (2020)*	*Burton et al. (2013)*	*Casner (2016)*	*Chapman et al. (2019)*	*Cox & Root (2020)*	*Gilley et al. (2020)*	*Kasap & Ergenekon (2017)*	*Levingston et al. (2009)*	*Ley Davis (2016)*	*Peltier (2020)*	*Rockwell et al. (2011)*	*Root et al. (2017)*	*Root, Cox, et al. (2018)*	*Root, Henning, et al. (2018)*	*Root & Browder (2019)*	*Root et al. (2019)*	*Saunders (2014)*	*Whitby (2013)*	*Yakubova et al. (2015)*	*Yakubova et al. (2020)*
1.0 Context and Setting	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2.0 Participants	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3.0 Intervention Agent	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4.0 Description of Practice	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
5.0 Implementation Fidelity	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
6.0 Internal Validity	x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
7.0 Outcome measures	x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
8.0 Data Analysis	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Effects	P	P	M	P	P	P	P	M	P	P	P	P	P	P	P	P	P	P	P	P
Effect size*	1	1	.78	.95	1	1	1	.96	1	.95	.70	1	.87	.96	.91	.96	1	.91	1	.97
Total QIs met	8	8	5	8	8	8	8	6	8	8	8	8	8	8	8	8	8	8	8	8

Note. P = positive effects, M = mixed effects, N = negative effects. Methodologically sound studies meet all 8 quality indicators for relevant research design and have positive effects (CEC, 2014). *Effect size for group design is Cohen's D, for single-case Tau-U.

TABLE 2

Characteristics of all included studies

Reference	*Participants w/ASD & Settings*	*Design*	*IV, Math Content, and Interventionist*	*DV*	*Results (Effects)*
Bouck & Long (2020)*	*N* (ASD/Total) = 1/3 IQ (ASD): NS Grade: MS Gender (ASD): 1F Ethnicity (ASD): 1W Setting: Other, 1:1	Multiple probe across participants	IV: Schematic diagram and task analysis to solve discount problems involving percent of change Content: Multiplicative Interventionist: Researcher	Percentage of task analysis steps completed independently correct	All students acquired skill of solving with schema and generalize to real world problems
Burton et al. (2013)*	*N* (ASD/Total) = 3/4 IQ (ASD): 61, 76, 85 Grade: MS Gender (ASD): 3M Ethnicity (ASD): NS Setting: MS SPED, 1:1	Multiple baseline across participants	IV: Video self-modeling (VSM) how to estimate cost of purchase and amount of change Content: Additive Interventionist: Para, Teacher	Percent of correct responses across 7 step task-analysis	All students met mastery criteria; participants and paraeducators reported favorable responses on social validity; effects maintained after removal of VSM (Positive)
Casner (2016)	*N* (ASD/Total) = 12/27 IQ (ASD): NS Grade: ELEM, MS Gender (ASD): NS Ethnicity (ASD): NS Setting: GE, WG	Mixed Methods: Qualitative and quasi-experimental group	IV: Schema-based instruction to solve additive word problems (group, compare, change) Content: Additive Interventionist: Teacher	Pre-test/post-test on: (a) word problems solved correctly, (b) AIMSweb M-CAP CBM	Improvement pre/post for word problem solving, not significant difference for Math CBM (Mixed)
Chapman et al. (2019)*	*N* (ASD/Total) = 1/3 IQ (ASD): 40 Grade: HS Gender (ASD) = 1M Ethnicity (ASD): NS Setting: HS SPED, 1:1	Multiple probe across participants	IV: System of least prompts to teach task analysis for solving a linear equation problem Content: Algebra Interventionist: Researcher	Number of task analyzed steps completed independently	Participants increased steps of task analysis completed independently correct, all were able to solve generalization problems in post-test (Positive)
Cox & Root (2020)*	*N* (ASD/Total) = 2/2 IQ (ASD): NS Grade: MS Gender (ASD): 1M, 1F Ethnicity (ASD): 1 W, 1 MR Setting: H, L, 1:1	Reversal	IV: Modified Schema-Based Instruction to solve proportion word problems with extraneous information Content: Multiplicative Interventionist: Researcher	Points earned on a 4-point researcher created rubric for problem solving flexibility and communication	Both participants used multiple strategies, explained reasoning, and answered problems accurately when they had access to task analysis and diagrams (Positive)

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TABLE 2 (Continued)

Reference	Participants w/ASD & Settings	Design	IV, Math Content, and Interventionist	DV	Results (Effects)
Gilley et al. (2020)*	*N* (ASD/Total) = 1/3 IQ (ASD): NS Grade: T Gender (ASD): 1F Ethnicity (ASD): 1W Setting: Other, 1:1	Multiple probe across participants	IV: Modified Schema-Based Instruction with self-graphing and goal setting to solve multiplicative word problems Content: Multiplicative Interventionist: Researcher	Steps of task analysis solved independently correct, total problems solved, and generalization of problem solving	All participants increased steps completed independently correct, solved problems, and generalized to solving a word problem about a recipe when supports were faded
Kasap & Ergenekon (2017)*	*N* (ASD/Total) = 3/3 IQ (ASD): NS Grade: 1 ELEM, 2 MS Gender (ASD): 3F Ethnicity (ASD): NS Setting: Home, 1:1	Multiple probe across participants	IV: Schema-based instruction to solve comparison word problems Content: Additive Interventionist: Researcher	Percent of correct responses	Students increased correct responses, generalized to missing variable in difference values, maintained 1, 3, and 5 weeks post-intervention (Positive)
Levingston et al. (2009)	*N* (ASD/Total) = 1/1 IQ (ASD): NS Grade: Elem Gender (ASD): 1M Ethnicity (ASD): NS Setting: GE, 1:1	Multiple baseline across behaviors (precurrent behaviors)	IV: Teaching overt precurrent behaviors to solve multiplication and division word problems Content: Multiplicative Interventionist: Teacher	Percent of correct responses for precurrent behaviors	Students increased correct responses, generalized to untaught precurrent behaviors (Neutral)
Ley Davis (2016)*	*N* (ASD/Total) = 1/3 IQ (ASD): 55 Grade: MS Gender (ASD): 1M Ethnicity (ASD): 1B Setting: Other, 1:1	Multiple probe across participants	IV: Modified schema-based instruction to teach change word problems Content: Additive Interventionist: Peer	Steps of problem solving task analysis, total problems solved	Peers were able to implement intervention with high fidelity; all participants learned to solve problems correctly, maintained effects (Positive)
Peltier (2020)*	*N* (ASD/Total) = 2/12 IQ (ASD): NS, 83 Grade: Elem Gender (ASD): 2M Ethnicity (ASD): 1W, 1H Setting: SPED, SG	Multiple probe across behaviors	IV: Schema-based instruction to teach immediate, generalized, and combined structured group, change, and compare word problems Content: Additive Interventionist: Teacher	Percent of points earned for independent correct steps of problem solving	Teachers were able to implement with fidelity in small groups, students learned to solve generalized and combined problem structures (Positive)

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TABLE 2 (Continued)

Reference	*Participants w/ASD & Settings*	*Design*	*IV, Math Content, and Interventionist*	*DV*	*Results (Effects)*
Rockwell et al. (2011)*	*N* (ASD/Total) = 1/1 IQ (ASD): NS Grade: Elem Gender (ASD): 1F Ethnicity (ASD): NS Setting: Home, 1:1	Multiple probe across behaviors (problem types)	IV: Schema-based instruction to solve additive word problems (group, change, and compare) Content: Additive Interventionist: Researcher	Points earned on a 3-point rubric across two problems; generalization to problems with missing variables in other locations	Student learned to independently solve all three problem types; able to generalize to problems with variable in initial and medial location; maintained treatment effects 6-weeks post-intervention (Positive)
Root et al. (2017)*	*N* (ASD/Total) = 3/3 IQ (ASD): 46, 55, 58 Grade: ELEM Gender (ASD): 3M Ethnicity (ASD): 2W, 1H Setting: Other, 1:1	Multiple probe across participants & alternating treatment design	IV: Modified schema-based instruction with and without virtual manipulatives to solve compare word problems Content: Additive Interventionist: Researcher	Steps of problem solving task analysis	All students increased independent problem solving; two students more independent in virtual condition; effects maintained and all preferred virtual condition; teachers rated favorably on social validity (Positive)
Root, Cox, et al. (2018)*	*N* (ASD/Total) = 3/3 IQ (ASD): NS Grade: 2MS, 1 HS Gender (ASD): 2M, 1F Ethnicity (ASD): 3W Setting: Other, 1:1	Multiple probe across participants	IV: Modified schema-based instruction with calculator to solve percent of change word problems Content: Multiplicative Interventionist: Researcher	Steps of problem solving task analysis	Students increased independent problem solving; generalization to natural stimuli; students able to reason about having enough money for purchase (Positive)
Root, Henning, et al. (2018)*	*N* (ASD/Total) = 3/3 IQ (ASD): NS Grade: Elem Gender (ASD): 2M, 1F Ethnicity (ASD): 3W Setting: SPED, 1:1	Multiple probe across participants	IV: Modified schema-based instruction to solve algebraic word problems Content: Algebra Interventionist: Researcher	Steps of problem solving task analysis; total problems solved; discrimination of problem type	Students increased independent problem solving and were able to discriminate problem type after explicit training (Positive)

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TABLE 2 (Continued)

Reference	*Participants w/ASD & Settings*	*Design*	*IV, Math Content, and Interventionist*	*DV*	*Results (Effects)*
Root & Browder (2019)*	*N* (ASD/Total) = 3/3 IQ (ASD): 50, 53, 58 Grade: MS Gender (ASD): 3F Ethnicity (ASD): 3W Setting: Other, 1:1	Multiple probe across participants	IV: Modified schema-based instruction with technology-based task analysis to solve algebraic word problems Content: Algebra Interventionist: Researcher	Steps of problem solving task analysis, total problems solved	Students increased independent problem solving (Positive)
Root, Cox, & Gonzalez (2019)*	*N* (ASD/Total) = 3/3 IQ (ASD): NS Grade: ELEM Gender (ASD): 2M, 1 F Ethnicity (ASD): 2W, 1 B Setting: Other, 1:1	Multiple probe across participants	IV: Technology-based modified schema-based instruction to solve additive comparison word problems involving data analysis Content: Data Analysis Interventionist: Researcher	Steps of problem solving task analysis	Students increased independent problem solving; generalization to data sets found in social studies text (Positive)
Saunders (2014)*	*N* (ASD/Total) = 3/3 IQ (ASD): 55, 40, 46 Grade: Elem Gender (ASD): 3M Ethnicity (ASD): 2W, 1H Setting: SPED, 1:1	Multiple probe across participants	IV: Modified schema-based instruction delivered via computer-based video instruction to solve additive (group and change) word problems Content: Additive Interventionist: Computer / Researcher	Steps of problem solving task analysis; total problems solved	Students mastered solving group and change word problems and were able to generalize from computer-based to paper-based problems (Positive)
Whitby (2013)*	*N* (ASD/Total) = 3/3 IQ (ASD): 90, 94, 107 Grade: MS Gender (ASD): 3M Ethnicity (ASD): NS Setting: SPED, 1:1	Multiple probe across participants	IV: Solve It! Problem Solving Routine solving 1, 2, and 3-step word problems Content: NS Interventionist: Researcher	Percent correct on word problems during CBM and generalization to state accountability test	Students increased percent correct in word problem solving; students did not maintain strategy use; participants scored higher than peers on state assessment items by end of intervention (Positive)

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TABLE 2 (Continued)

Reference	*Participants w/ASD & Settings*	*Design*	*IV, Math Content, and Interventionist*	*DV*	*Results (Effects)*
Yakubova et al. (2015)*	*N* (ASD/Total) = 3/3 IQ (ASD): 71, 82, 79 Grade: HS Gender (ASD): 3M Ethnicity (ASD): NS Setting: Other, 1:1	Multiple probe across participants	IV: Point-of-view video modeling instruction with a problem-solving checklist to solve word problems with mixed fractions Content: Fractions Interventionist: Researcher	Percent of correctly completed subtraction equations involving mixed fractions with unlike denominators	Students increased percent of problems solved; two participants maintained effects; teachers and students rated mostly positively on social validity (Positive)
Yakubova et al. (2020)*	*N* (ASD/Total) = 3/3 IQ (ASD): NS Grade: MS Gender (ASD): 2M, 1F Ethnicity (ASD): 2W, 1A Setting: SPED, 1:1	Multiple probe across participants	IV: Point-of-view video modeling instruction with problem-solving checklist and concrete manipulatives to solve fraction word problems with like denominators Content: Fractions Interventionist: Researcher	Percentage accuracy of solving addition and subtraction problems with like denominators	Students learned to solve fraction problems; two participants generalized to improper fractions (Positive)

Note. * = Methodologically sound via CEC standards; ELEM = elementary, MS = middle school, HS = high school, T = transition program, W = white, B = black, MR = multi-racial, A = Asian, H = Hispanic, SPED = special education, Other = other location in school, GE = general education, H= home, L = library, N/A = does not apply, because the study was not methodologically sound, NS = not specified, “Effects” on student outcomes are determined only for the methodologically sound studies per CEC (and are under the “Results” heading).

TABLE 3

Identified evidence based practices

	Task Analysis	*System of Least Prompts*	*Graphic Organizers*	*Explicit Instruction*	*Schema-Based Instruction*	*Technology-Based Instruction*
Bouck & Long (2020)	X	X	X	X	X	X
Burton et al. (2013)	X					X
Chapmnan et al. (2019)	X	X	X			
Cox & Root (2020)	X	X	X	X	X	
Gilley (2020)	X	X	X	X	X	X
Kasap & Ergenekon (2017)			X	X	X	
Ley Davis (2016)	X	X	X	X	X	
Peltier et al. (2020)			X	X	X	
Rockwell et al. (2011)			X	X	X	
Root et al. (2017)	X	X	X	X	X	X
Root, Cox, et al. (2018)	X	X	X	X	X	X
Root, Henning, et al. (2018)	X	X	X	X	X	
Root & Browder (2019)	X	X	X	X	X	X
Root, Cox, & Gonzalez (2019)	X	X	X	X	X	X
Saunders (2014)	X	X	X	X	X	X
Whitby (2013)				X		
Yakubova et al. (2015)	X					X
Yakubova et al. (2020)	X			X		X
Total number of high-quality studies	14	11	14	15	13	10
Total number of participants with ASD	33	30	30	35	29	26
CEC Classification	EBP	EBP	EBP	EBP	EBP	EBP

studies involving 33 participants with ASD used a TA both to break down the problem into discrete steps for the purpose of teacher instruction (e.g., Burton et al., 2013; Chapman et al., 2019) as well as for student self-instruction (e.g., Cox & Root, 2020; Ley Davis, 2016). Gilley et al. (2020) taught students to not only self-monitor using a TA, but to identify whether each step was completed "by myself" or "with help", add the total number of steps completed independently, and self-graph those steps using an excel sheet on an iPad. Participants then used the data to set goals for future sessions.

System of least prompts (SLP) was defined as the provision of the opportunity to perform the target behavior with the least amount of assistance (natural stimuli) on each trial before presenting increasingly more intrusive prompts (Collins, 2012). Eleven high quality studies used SLP with 30 students with ASD. All studies used a three-level hierarchy, which either consisted of a verbal, specific verbal, and then model prompt (e.g., Root & Browder, 2019) or verbal, gesture plus verbal, and then model (Chapman et al., 2019).

Graphic organizers were defined specifically for mathematics as a diagram that shows the relative positions of the quantities and their relationships to one another to help students conceptually understand and solve a problem (Ives & Hoy, 2003). Graphic organizers were used in 14 high quality studies with 30 participants with ASD. Several studies used manipulatives in combination with graphic organizers to support student's procedural and conceptual knowledge (e.g., Root et al., 2017; Saunders, 2014). Others provided participants with a visual support for the equation (e.g., Bouck & Long, 2020; Chapman et al., 2019).

Explicit instruction was defined as a series of supports and scaffolds where students are guided through the learning process in small steps with clear explanations and demonstrations of the targeted skill and provided with practice and feedback until mastery is achieved (Archer & Hughes, 2011), and was used in 15 of the high quality studies with 35 students with ASD. Specifically, the model-lead-test explicit instruction procedure was used in each study.

Schema-based instruction has four key components: (a) visual diagrams to show the relationships between quantities in the word problems; (b) a heuristic to remember the problem solving process, (c) the use of explicit instruction to teach the problem solving process, and (d) metacognitive strategy instruction (Jitendra et al., 2016). A total of 29 students were involved in 13 high quality studies that used both traditional schema-based instruction (e.g., Kasap & Ergenekon, 2017; Peltier et al., 2020; Rockwell et al., 2011) and an enhanced version coined "modified schema-based instruction" (e.g., Cox & Root, 2020; Ley Davis, 2016; Saunders, 2014) to teach both additive and multiplicative problem types.

Technology-aided instruction (TAI) was defined as any electronic item, equipment, application, or virtual network that is a central feature of an intervention and is used intentionally to increase/maintain, and/or improve capabilities (Odom et al., 2015). A total of 10 high-quality studies used TAI to teach word problem solving skills to 26 students with ASD. Forms of TAI included calculators (Bouck & Long, 2020; Gilley et al., 2020; Root, Cox, et al., 2018; Yakubova et al., 2015), iPads (Burton et al., 2013; Gilley et al., 2020; Root et al., 2017; Root, Cox, et al., 2018; Root & Browder, 2019; Root et al., 2019) and desktop computers (Saunders, 2014). Four studies used technology to provide video modeling (Burton et al., 2013; Saunders, 2014; Yakubova et al., 2015; Yakubova et al., 2020).

"For Whom": Characteristics of Students Included in High-Quality Studies

A total of 42 students with ASD participated in high-quality research studies on teaching mathematical word problem solving, including 16 elementary students (grades K-5), 20 middle school studies (grades 6–8), five high school students (grades 9–10) and one student in a postsecondary transition program. Of those who reported IQ, about a third of the participants were reported to have a comorbid intellectual disability, including ten with moderate intellectual disability and three with mild intellectual disability. An IQ was not reported for 21 participants (50%) across 12 high quality studies. Thirteen high quality studies reported disaggregated ethnicity of participants with ASD, which included 21 white students, two black students, three Hispanic students, and one multi-racial student. All studies reported gender of included students, the majority of whom were male ($n=28$, 66%). Three high quality studies reported including a student who was an English Language Learner (Root et al., 2017; Saunders, 2014; Yakubova et al., 2020).

"Under What Conditions": Tasks, Settings, and Instructors in High Quality Studies

The level of detail reported on the problem solving tasks varied, though all but one high quality study provided some degree of specification on the math content targeted in the word problems. Whitby (2013) only specified problems were "one, two, and three steps" and aligned with state standards. As shown in Table 2, additive problem types were the most common ($n=7$, 38%), followed by multiplicative problems ($n=4$; 22%), algebra ($n=3$, 16%), fractions ($n=2$, 11%) and data analysis ($n=1$; 5%). Of the 18 high quality studies, 13 (72%), stated how problems were written and 12 (66%) gave an example. Half of the high-quality studies ($n=9$) did not specify whether problems were repeated, while two studies (11%) reported they repeated word problems and seven (38%) specified word problems were not repeated. Researchers were the most common intervention agent (83%, $n=15$), with one study using a paraeducator and special education teacher (Burton et al., 2013), a special education teacher delivering instruction in one study (Peltier et al., 2020), and one utilized peers (Ley Davis, 2016). All but one high quality studies were conducted one-on-one with the interventionist, with Peltier et al. (2020) teaching students in small groups. Instructional settings varied and included the special education classroom, another environment in the school, a public library, and the participants' home. No high-quality studies took place in the general education classroom.

Discussion

The purpose of this review was to answer "What works for whom under what conditions?" in the area of mathematical word problem solving, extending the work of prior reviews on experimental studies teaching mathematics to students with ASD. Prior reviews focused on broad mathematics skills and specifically cited the need for research with an "explicit emphasis on word problems" (King et al., 2016, p. 17), as at their time of publication there were an insufficient number of studies to warrant such a narrow focus. Further, the current review used CEC (2014) standards to evaluate quality of included studies.

Overall, mathematical problem solving for students with ASD is receiving increased attention from researchers in the field of special education, as no studies could be found that directly taught or measured mathematical word problem solving skills prior to 2011. Most of the included studies met quality indicators and were considered "methodologically sound" by the CEC (2014) standards. This may be a result of the relative age of the studies being well after initial quality indicators work by Horner, Gersten, and their respective colleagues in 2005. This general adherence to quality standards reflects a response to the urge of authors in prior reviews to conduct experimental studies with quality indicators at the forefront of their design (King et al., 2016). The growing research in this area is promising given the status of problem solving as the "cornerstone" of mathematical learning (NCTM, 2000).

The "What"

With an increase in both the quantity and quality of studies investigating intervention strategies to teach mathematical word problem solving skills to students with ASD, evidence from this synthesis puts six practices over CEC's minimal threshold for classification as evidence-based: task analysis, system of least prompts, graphic organizers, explicit instruction, schema-based instruction, and technology-based instruction. However, as shown in Table 3, all included high-quality studies used at least two evidence-based practices, with several incorporating all six practices in a multi-component treatment package (e.g., modified schema-based instruction). As a result, the individual effects of each component of these treatment packages is unknown, as is a common shortcoming of research in this area and consistent with findings of prior reviews (e.g., Spooner et al., 2019). The impact of this on practitioner's understanding of the value added by each component, and therefore their instructional decision making, was discussed by multiple research teams, yet no researchers to date have conducted a component analysis to address this limitation. Based on this body of evidence, we are not able to state whether practices in isolation would be evidence-based for teaching word problem solving to learners with ASD, or if all practices are necessary for students to experience positive learning outcomes. Yet we must recognize that some of the practices would be illogical to present in isolation. For example, it is not likely that graphic organizers alone would be effective for individuals with ASD without some sort of instruction, be it systematic (i.e., system of least prompts), explicit (i.e., direct instruction), or a combination of the two. Relatedly, the math content of the word problems varied, and therefore there is not sufficient evidence to tie practices to specific targeted content, such as algebra. The results of this review do highlight the growing emphasis on problem solving that was called for in prior reviews (e.g., King et al., 2016; Spooner et al., 2019). In addition, this synthesis adds to the body of research on effectiveness of systematic and explicit instruction for students with ASD (Hart Barnett & Cleary, 2015; King et al., 2016), while also demonstrating the efficacy of strategies primarily associated with students with learning disabilities, such as schema-based instruction (Jitendra et al., 2016). This synthesis demonstrates these established practices are effective for higher-level skills than have previously been attempted for students with ASD (King et al., 2016).

Defining "Works"

The CEC (2014) guidelines provide specific quality indicators related to both measurement of an intervention and evidence that it "works". All high quality studies had to meet these indicators and have positive effects. These high quality studies could then contribute evidence toward a "what" being classified as evidence-based. What the guidelines do not mandate is consistency in how these "what's" are measured. Given the narrow focus of this review on mathematical word problem solving, we were interested to see how this was defined and measured by included high quality studies. The most common dependent variable broke problem solving down into component steps and was referred to as either a task analysis or rubric (see Table 2).

Specifying "for Whom"

The participants in high quality studies represent the heterogeneity of students with ASD, indicating that presence of a co-morbid intellectual disability, where they receive instruction, or participation in a state's alternate assessment should not preclude an individual with ASD from learning to solve mathematical word problems. Students with ASD with more extensive support needs can gain independence in mathematical problem solving if the targeted mathematical content is reduced in complexity (i.e., decreased quantities) and procedural supports are provided (i.e., concrete manipulatives, color-coded graphic organizers, student-friendly task analysis). The work of Rockwell et al. (2011), Peltier et al. (2020), and Whitby (2013) indicate students with ASD who have less extensive support needs can demonstrate grade level achievement at levels commiserate with peers and generalize skills to untaught problem types with less explicit instruction or procedural supports.

Analysis of "under What Conditions"

Included high quality studies varied in how much detail was given regarding the specifics of the problem solving tasks. Exactly how word problems were formatted or written and whether or not they were repeated was not consistently explained. While studies still met QIs as specified by Cook et al. (2015), providing additional details would support implementation and replication. Spooner et al. (2017) argue that these variables are influential in the success of students with problem solving and serve as a way to make problem solving accessible.

Although participants in included high quality studies were reported to receive supports along the full continuum of services no research was conducted in general education settings. This is an unfortunate finding, as students with ASD have greater success in less restrictive education settings (Kurth, 2015). Supporting meaningful educational progress in the least restrictive environment for students with ASD will therefore require the identification of effective instructional strategies that have been tested in general education settings. The findings of Ley Davis (2016) indicate peer-mediated instruction may be a viable strategy for providing access to general curriculum content (i.e., word problem solving) in an inclusive setting.

Relatedly, all but one study was conducted in a one on one setting and with researchers as the most predominant intervention agent. Findings of Peltier et al. (2020) are promising, indicating that special education teachers can deliver instruction to small groups of students with high degrees of fidelity. Without more research on word problem solving in natural settings (e.g., small and whole groups in special and general education classrooms) with natural intervention agents (e.g., special education teachers, paraeducators, and peers), the generalizability of these findings to non-research conditions is unknown.

Recommendations for Practice

Results of this review provide evidence that students with ASD can benefit from learning mathematics through problem solving. When students are taught through a problem solving approach, they learn mathematics through real contexts, problems, situations, and models (Van de Walle et al., 2010). Procedural and conceptual knowledge are not bifurcated; contexts and models provide meaning as students apply a range of procedures toward a solution. By using mathematics word problems related to students' everyday life, educators can help students know when and why to use mathematical skills (Spooner et al., 2017).

Educators should use the effective practices identified in this review to teach mathematical problem solving, considering the needs of students when making instructional decisions about the targeted mathematical content of word problem solving as well as the format of instructional supports. Students who have more extensive support needs may also have deficits in language and will benefit from preteaching content such as vocabulary (e.g., Gilley et al., 2020; Root & Browder, 2019; Root, Cox, et al., 2018) or a reduction in complexity of the language in the mathematics problems by using a structured format (Spooner et al., 2017). Although some students may be able to acquire problem-solving skills at a faster rate, they still benefit from explicit instruction and explicit supports (e.g., Rockwell et al., 2011; Whitby, 2012).

Limitations

Related to the method we used to conduct the systematic review, we did not calculate inter-rater agreement for the initial screening process, which may have resulted in an oversight of articles that met our inclusion criteria. We chose to use the CEC (2014) quality indicators as they allow synthesis of both group and single-case research designs, but they do not directly assess social validity with a distinct set of quality indicators (as they were with Horner et al., 2005), although guidelines state that all studies must have socially important outcomes and the magnitude of change in outcome variables must be socially valid. Methods of obtaining social validity were inconsistent across included studies and while most did include at least one measure, future research should seek input from all relevant stakeholders. Although limited self-awareness of individuals with ASD may decrease validity of direct social validity measures (Whitby, 2013), they are nonetheless a worthwhile pursuit. Practices identified as "evidence-based" in this review are based on the specific disability group of students with ASD, but not age or characteristics within the broad group of individuals with ASD. Expanded research is needed for more specific answers to the question of "for whom".

As previously mentioned, all included high quality studies used treatment packages as the independent variable, meaning interventions combined multiple practices. This is a noted limitation in the field and without a component analysis it is difficult to ascertain the impact of practices in isolation. Given the use of these treatment packages, participant heterogeneity, and a low sample size, conducting a meta-analysis or analyzing moderating or mediating variables did not seem appropriate.

Implications for Future Research

Future research should report all relevant participant characteristics, which we would argue includes gender, ethnicity, presence (or absence) of comorbid disabilities, as well as present performance related to targeted skill (in this case, mathematics), whether through current IEP goals or scores on standardized measures. This thorough reporting will increase generalizability and transparency for the sake of replication. Relatedly, the lack of specificity of exact content and format of mathematics problems in many of the included studies in this review was problematic. Future research should explicitly state the content and format of word problems. In interventions on problem solving, materials are just as important to describe as the methods and measures. Including figures as much as possible, for example when graphic organizers are used, will ease replication and use of findings by educators. Finally, there is a need for expansion in focus on mathematical content and practices in word problem solving research for students with ASD. There are a multitude of mathematical standards and skills that are unexplored by research for this population. Findings of this review have to be considered in light of this heterogeneity. Future research should include the range of individuals with ASD, examining the efficacy of identified practices and other innovative approaches for students at all grades and across mathematics standards.

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