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Promoting Access to Common Core Mathematics for Students with Severe Disabilities Through Mathematical Problem Solving

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Abstract

There is a need to teach the pivotal skill of mathematical problem solving to students with severe disabilities, moving beyond basic skills like computation to higher level thinking skills. Problem solving is emphasized as a Standard for Mathematical Practice in the Common Core State Standards across grade levels. This article describes a conceptual model for teaching mathematical problem solving to students with severe disabilities based on research from a multiyear project. The model proposed incorporates schema-based instruction combined with evidence-based practices for teaching academics to this population, and includes technology supports and self-monitoring. The purpose is to teach students to recognize underlying problem structures in word problems for better generalizability to real-world situations. This article outlines the existing evidence for teaching problem solving to students with disabilities, the conceptual model for teaching mathematical problem solving to students with severe disabilities, and the implications of the model for practitioners and future researchers.

Keywords

mathematics, mathematical problem solving, severe disabilities

Mathematical problem solving is a pivotal skill that has been touted as the cornerstone of mathematical learning (National Council of Teachers of Mathematics, 2000). Problem solving is to mathematics as comprehension is to reading; just as decoding and fluency build an individual's ability to better understand and use text, numeracy and calculation enhance problem solving. The Common Core State Standards in Mathematics (CCSSM) place high value on problem solving as a critical mathematical skill and have included problem solving as one of their eight Standards for Mathematical Practice (National Governors Association for Best Practices & Council of Chief State School Officers, 2010). The CCSSM include both standards for mathematical practice and content standards. As the CCSSM standards across the domains of mathematics define the content students are expected to learn, the CCSSM standards of mathematical practice describe the processes and proficiencies that should be emphasized in mathematics education and what "mathematically proficient students" should be able to do throughout their K-12 education. The CCSSM emphasizes an in-depth understanding of mathematics that will allow *all* students to thrive in the 21st century, including students with severe disabilities (i.e., students with moderate intellectual disability [ID], severe ID, autism spectrum disorder [ASD], and comorbid ID, or students taking alternate

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assessment aligned to alternate achievement standards). As a standard of mathematical practice, problem solving should be emphasized in mathematics instruction because it is a foundational skill that must be applied across all domains of mathematics and through all grade levels, even for students with severe disabilities (National Governors Association for Best Practices & Council of Chief State School Officers, 2010). Without this higher level thinking skill, students' mathematical application skills are extremely limited.

For students with severe disabilities, the ability to apply mathematical problem-solving skills to a job, during leisure activities, or in independent living situations, will build independence and lead to a greater quality of life. As a broad term, problem solving is a self-determination skill (Wehmeyer, Shogren, Zager, Smith, & Simpson, 2010) that is both used in and enhanced by mathematics. Yet, research by Kearns, Towles-Reeves, Kleinert, Kleinert, and Thomas (2011) found in a sample of 12,649 students with severe disabilities across seven states, only a small percentage (4%-8%) of students were able to apply computational procedures to solve real-world or routine word problems from a variety of contexts. However, in this same sample, a much larger percentage (32%-57%) of students could complete computational procedures with or without a calculator. Teaching calculation without problem solving only shows students how to solve problems ("plug and chug"), and not when or why to apply these skills to everyday life.

Successful problem solvers are able to combine both conceptual and procedural knowledge to solve real-world problems (Jitendra, 2008). Conceptual knowledge reflects knowledge about the relationships or foundational ideas of a topic, and is essential to being able to generalize problem solving to real-world situations (Van de Walle, Karp, & Bay-Williams, 2010). Procedural knowledge is demonstrated by fluency in the use of rules and procedures in carrying out mathematical processes and the symbolism used to represent mathematics (Van de Walle et al., 2010). There are many cognitive processes occurring when solving word problems, such as comprehending the problem text, creating a mathematical representation of the problem, developing a plan to solve, executing the plan, and interpreting the solution, which present challenges for students with disabilities who have executive functioning and self-regulation difficulties (Fuchs & Fuchs, 2007). When thinking in behavioral terms, mathematical problem solving is a chained task, with each phase dependent upon successful completion of the previous step for correct execution and ultimate arrival at a correct answer (Jitendra, Griffin, Deatline-Buchman, & Sczesniak, 2007). The chained nature of problem-solving tasks means that errors in any stage or step of the process will prevent successful demonstration of conceptual and/or procedural knowledge. To be effective mathematical problem solvers, students with disabilities, especially those with severe disabilities, will need high-quality, explicit and systematic instruction on following the steps of the chained task of mathematical problem solving with repeated opportunities for practice (Browder, Jimenez, Spooner, et al., 2012; Browder, Spooner, Ahlgrim-Delzell, Harris, & Wakeman, 2008).

Two traditional approaches to problem-solving instruction often lead to errors for students with disabilities. The four-step strategy (i.e., understand the question, devise a plan, carry out the plan, and look back and reflect; Pólya, 1945) most commonly found in textbooks across the United States is too general, requires a number of metacognitive skills, and does not provide the support students with disabilities need (Jitendra, 2008). The keyword strategy, in which students are taught to recognize keywords associated with an operation (e.g., *in all, altogether, total* indicate an addition problem; *left, remain, difference* indicate subtraction), is misleading and produces errors, as it may lead to using the wrong operation and many problems are written without keywords (Jitendra & Star, 2011; Van de Walle et al., 2010). Furthermore, the keyword strategy does not provide students with the conceptual understanding they need to generalize problem-solving skills to real-world scenarios (Jitendra & Star, 2011). Gersten et al. (2009) found that problem-solving programs for students with learning disabilities, which included visual representations paired with heuristics and direct instruction, had the strongest effect sizes. Although this meta-analysis targeted high-incidence disabilities, much can be gleaned from and applied to learners with severe disabilities to help them be independent problem solvers as well.

Schema-based instruction (SBI) is one evidence-based strategy for teaching mathematical problem solving to students with high-incidence disabilities (Jitendra et al., 2015). SBI uses a conceptual teaching approach that combines mathematical problem-solving and reading comprehension strategies (Jitendra, 2008). SBI emphasizes conceptual understanding by enhancing comprehension to ensure students can effectively create representations of the problem situation, thus developing an understanding of the underlying problem structure. Focus on conceptual understanding of problem structure is imperative to successful problem solving because most errors in word problem solving are not due to computation errors, but rather a misunderstanding of the problem situation (Jitendra, 2008). In SBI, students are taught the semantic structure of word problems through analysis of the text. This analysis teaches students to identify quantitative relations between sets or actions between sets, which are used to create a visual model of these relationships (Jitendra, 2008). SBI is thought to be effective because it lessens the dependency on working memory and helps students visually map out the problem structure to solve problems successfully.

Problem-solving experiences in school settings are typically structured in the format of story or word problems. Van de Walle and colleagues (2010) suggested learning to solve story problems is the basis for learning to solve real-world mathematical problems. Story problems present situations requiring a mathematical solution (Stein, Kinder, Silbert, & Carnine, 2006). Teaching problem solving through story problems promotes generalization of skills to real-world applications of mathematics, which is of utmost importance when prioritizing and selecting mathematical content to teach students with severe disabilities (Browder, Jimenez, Spooner, et al., 2012; Browder, Jimenez, & Trela, 2012). Instruction needs to be not only explicit but also contextually meaningful.

The learning characteristics of students with severe disabilities present challenges to mathematical problem solving in school-based and real-world tasks. Students with severe disabilities often have limited background knowledge, working memory deficits, weak number sense, language difficulties, and reading deficits that make problem solving more difficult. The linguistic requirements of story problems can be complex such as length, grammatical and semantic complexity, mathematical vocabulary, and the order in which the key information appears in the problem (Fuchs & Fuchs, 2007). We hypothesized that with strong, empirically based instructional supports in place, taking into account the learning characteristics of this population, students with severe disabilities could become effective problem solvers.

Prior research has shown SBI can be effective in teaching students with developmental disabilities, such as ASD and moderate ID, to solve word problems (Neef, Nelles, Iwata, & Page, 2003; Rockwell, Griffin, & Jones, 2011). While the results of these two studies are promising in terms of teaching arithmetic word problems to students with developmental disabilities, participants had prerequisite skills that are not characteristic of most students with severe disabilities, including independently reading word problems and fluency with math facts. The first studies to teach word problem solving to students with severe disabilities found a treatment package that included task analytic instruction on how to use graphic organizers and manipulatives effective in teaching students to solve story problems (Browder, Jimenez, & Trela, 2012; Browder, Trela, et al., 2012; Jimenez, Browder, & Courtade, 2008). In these studies, students were not taught to analyze the text and determine the problem type prior to solving, but rather they were taught to transfer information to the graphic organizer and solve using a "plug and chug" model with manipulatives. Although these studies were promising for teaching the higher level thinking skill of problem solving, they were solely procedural based with no focus on teaching students to conceptually understand the problem structure, which is most important for being able to generalize to solving real-world problems (Van de Walle et al., 2010). This gap in pedagogical knowledge warranted further investigation into how to teach students with severe disabilities to both conceptually understand mathematical problem-solving tasks and carry out procedures to find solutions to real-world mathematical problems.

The Solutions Project, a 4-year, federally funded project by the Institute of Education Sciences, National Center for Special Education Research (Grant No. R324A130001), was designed to develop methods for teaching students with severe disabilities to become proficient problem solvers who can generalize their mathematical problem solving to the real world. The purpose of this article is to outline a conceptual model for teaching mathematical problem solving to students with severe disabilities, named modified schema-based instruction (MSBI), which is based on findings from multiple studies that were conducted under The Solutions Project as shown in Table 1. In the table, key components of each study are presented (e.g.,

Table 1. Summary of Studies in The Solutions Project Supporting the Conceptual Model.

CCSS	Reference	Settings and participants	Intervention	Dependent variable	Results
CCSS.MATH.PRACTICE. MP1, MP2, MP4	Browder et al. (2017); this study was the primary foundational study in The Solutions Project	Eight students with moderate ID in elementary/middle self-contained classrooms in a large, urban school district	MSBI using a student task analysis, graphic organizers, and manipulatives to teach group, change, and compare problem types and discrimination between problem types	The number of steps completed independently during teacher instruction, total number of problems solved, the number of discriminations between problem type, and generalization to the SMART Board and real-world video-simulation problems	Functional relation between MSBI and students' word problem-solving abilities across four demonstrations
CCSS.MATH.PRACTICE. MP1, MP2, MP4, CCSS.1.OA.A.1, CCSS.4.OA.A.3	Root, Browder, Saunders, and Lo (2017)	Three elementary students with ASD and moderate ID in a large, urban district	MSBI to teach the compare problem type using virtual and concrete manipulatives	The total number of points awarded per problem for steps solved independently on the task analysis	A functional relation was found between MSBI and the use of concrete and virtual manipulatives, and the students' ability to solve mathematical word problems
CCSS.MATH. CONTENT.EE.A.1	Root, Saunders, Spooner, and Brosh (2017)	Three middle school students with Down syndrome and moderate ID in a large, urban district	MSBI using a calculator to solve personal finance word problems with two-digit numbers and decimals to teach the change problem type	The number of steps solved independently across two problems, total number of problems solved, the number of discriminations, and generalization to the iDevice (iPhone/iPad)	Functional relation between MSBI and students' ability to solve word problems with two-digit numbers and decimals and generalization to the iDevice
CCSS.MATH.PRACTICE. MP1, MP2, MP4	Ley Davis, Spooner, and Saunders (2017)	Four middle school students with moderate/severe ID and five general education peers in a large, urban school district	MSBI targeting the change problem type delivered by general education peer tutors	The number of steps completed independently during MSBI, the cumulative number of problems solved, and generalization across peer tutors	A functional relation was found between peer-mediated MSBI and mathematical problem solving with four demonstrations of effect across students
CCSS.MATH. CONTENT.6.EE.A.1	Root and Browder (2017)	Three middle school students with ASD and moderate ID in a large, urban district	MSBI targeting the group problem type with numerals missing in the medial and final position	The number of steps completed independently during MSBI, the cumulative number of problems solved, and generalization	A functional relation between MSBI and algebraic mathematical problem solving with three demonstrations of effect

(continued)

Table 1. (continued)

CCSS	Reference	Settings and participants	Intervention	Dependent variable	Results
CCSS.MATH.PRACTICE. MP1, MP2, MP4, CCSS.1.OA.A.1, CCSS.4.OA.A3	Saunders, Browder, Root, and Brosh (2017)	Three elementary students with ASD and mild/moderate ID (two students were ELLs) in a rural district	MSBI using a student task analysis, graphic organizers, and manipulatives to teach group, change, and compare problem types, and discrimination between problem types	The number of steps completed independently during teacher instruction, total number of problems solved, the number of discriminations between problem types, and generalization to the SMART Board/iPad and real-world video-simulation problems	Functional relation between intervention and students' word problem-solving abilities, and generalization to the SMART Board/iPad and real-world video-simulation problems
CCSS.MATH.PRACTICE. MP1, MP2, MP4, CCSS.1.OA.A.1, CCSS.4.OA.A3	Saunders, Lo, and Browder (2017)	Three elementary students with ASD and moderate ID in a large, urban district	Computer-based video instruction to deliver MSBI to teach group and change problem types and discrimination between problem types	The number of steps completed independently during computer-based video instruction, the cumulative number of problems solved and discriminations, and generalization to paper-and pencil format	A functional relation was found between MSBI delivered through computer-based video instruction and students' problem solving of group and change problem types and discriminating between problem types
CCSS.MATH.PRACTICE. MP1, MP2, MP4, CCSS.1.OA.A.1, CCSS.4.OA.A3	Saunders, Spooner, and Ley Davis (2017)	Three middle school students with moderate ID in a large, urban district	Video prompting with systematic instruction to teach real-world problem solving of video-simulation change problems	The number of steps completed independently, the cumulative number of problems solved and discriminations, and generalization to paper-and-pencil format	A functional relation was found between video prompting and students' mathematical problem-solving skills. Participants were able to solve the video problems using the finger counting strategy taught through first-person perspective video modeling

Note. CCSS = Common Core State Standards; ID = intellectual disability; MSBI = modified schema-based instruction; ASD = autism spectrum disorder; ELLs = English language learners.

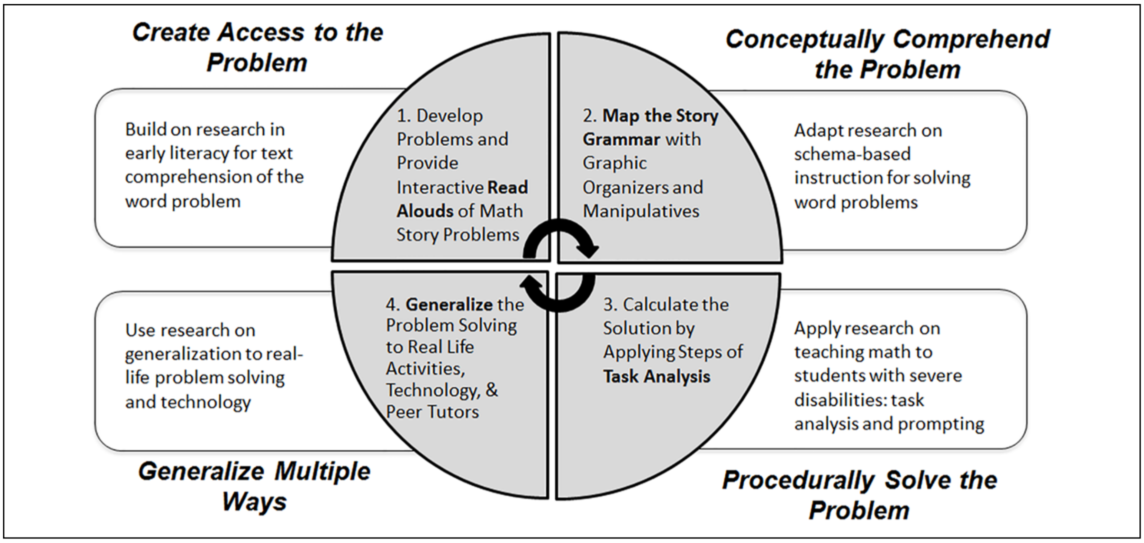

Figure 1. Conceptual model for teaching arithmetic problem solving to students with severe disabilities.
Note. The four main components are shown in large black font. The gray circular area briefly describes the action taken within that component, and the white area tells the area of research from which that component is drawn.

CCSSM, investigators, design, intervention, dependent variables, summary of outcomes). MSBI takes into account the learning characteristics of students with severe disabilities and incorporates empirically sound strategies with a focus on conceptually understanding problem structures and generalizing to real-world problem solving. MSBI teaches both conceptual and procedural knowledge through problem solving by combining SBI, an evidence-based practice for teaching mathematical problem solving to students with learning disabilities (Jitendra et al., 2015), with established evidence-based practices for teaching mathematics to students with severe disabilities (Browder et al., 2008; Spooner, Root, Saunders, & Browder, 2017), and teaching in a contextually meaningful way. This article synthesizes the existing evidence from The Solutions Project into one cohesive model for using MSBI to teach mathematical problem solving to students with severe disabilities. The proposed model is expected to be a useful tool for guiding practitioners and future researchers on implementing MSBI with students with severe disabilities to increase their problem-solving skills and access to the CCSSM (see Table 1).

Conceptual Model

It has been established that students with severe disabilities can learn mathematics (Browder et al., 2008). To do so, the instruction must be delivered in an explicit and systematic manner with many opportunities for practice, and the content must be taught in smaller chunks and in ways that are contextually meaningful for students with severe disabilities.

The conceptual model for MSBI is comprised of four components, each of which draws upon a research base as shown in Figure 1. The model begins with creating access to the problem by providing an interactive read aloud of a math story, building upon research in early literacy on comprehension of text. To teach students to conceptually comprehend the problem, they map the story grammar using graphic organizers and represent the quantities in the problem using manipulatives, strategies adapted from research on SBI. To support students in procedurally independently solving the problem, they are taught to calculate the solution by applying steps of the task analysis, a strategy supported by research on teaching mathematics to students with severe disabilities. Finally, it is important for students with severe disabilities to generalize problem solving skills in multiple ways, including to real-life activities, technology platforms, and with peer tutors. Each of these components will be described in detail.

Create Access to the Problem

To create access to mathematical problem solving for students with severe disabilities, first problems must be developed in an accessible format and then students must be provided access to the math story problems through an interactive read aloud. This component of the conceptual model is based on research in the area of writing word problems (Xin, Wiles, & Lin, 2008) and read alouds to support comprehension for students with severe disabilities (Hudson & Test, 2011).

Problem development. Developing problems in an accessible format requires selecting the targeted problem type, anchoring the instruction with thematic problems, structuring the problem in a way that is easily accessible for emerging readers or nonreaders, and then making careful considerations when writing the word problems to ensure they meet the needs of students with severe disabilities and are free of bias. Table 2 provides specific information and examples to support the following section.

Problem type selection. Because solving problems using a conceptual approach may be a new concept for students with severe disabilities, we recommend starting with problem types that target addition and subtraction. The three arithmetic problem types include (a) *Group*: part–part–whole problems, (b) *Change*: joining and separating problems, and (c) *Compare*: comparison of quantity problems (Marshall, 1995). Group problems involve combining two or more small groups into one larger group, emphasizing the part–part–whole relationship, and are solved by addition. Compare problems require finding the difference between two different sets that are related in some way regardless of whether the question is asking "how many more" or "how many fewer," and are solved by subtraction. Change problems illustrate a dynamic process, where an initial quantity is either increased or decreased over time to result in a final quantity, and are solved by either addition or subtraction depending on the change action in the problem. See "problem type selection" in Table 2.

Anchoring instruction with thematic problems. Providing a context in mathematics is essential to making it meaningful and concrete (Bottge, 1999). Browder, Jimenez, Spooner, et al. (2012) and Carpenter and Moser (1984) recommended keeping the target skill the same but changing the context to maintain motivation, promote generalization, and provide the necessary repeated opportunities for practice. For example, in The Solutions Project studies, multiple themes were developed to anchor instruction by a group of elementary and middle school special education teachers from a nearby large urban school district. These teachers identified word problem themes related to their students' interests (e.g., video games, trains), places in the community they may have visited on field trips or frequented with their parents (e.g., museum, zoo, farm), leisure activities (e.g., bowling, basketball), and applications to daily living skills (e.g., household chores, cooking). The teachers wrote multiple word problems related to each theme. See "anchoring instruction with thematic problems" in Table 2.

Problem structure. Consideration of problem structure is an important step when providing access to word problems for students with severe disabilities. The semantics traditionally found within a word problem can be quite complex and serve as a barrier to problem solving for students with severe disabilities. Using suggestions from prior research, we propose using a more structured format to provide better access to story problems (Xin et al., 2008). In The Solutions Project, problems followed a structured, four-line format consisting of (a) an anchor sentence to give context to the problem, (b) two sentences that identified what was happening in the problem, and (c) a final question with the label of what the students were solving for. Examples of problems following this structure for each problem type are shown in Table 2 under "problem structure."

The sentence length, syntax, and vocabulary level should be consistent across problems (Carpenter & Moser, 1984). We recommend using sentences that are short, use words that are easy to decode (Stein et al., 2006), and depict objects or scenarios students are familiar with (Xin et al., 2008). Because MSBI teaches students to conceptually understand the problem, they do not rely on "key" words to solve problems. For

Table 2. Guidelines for Writing Word Problems.

Description of guideline	Examples	
Problem type selection		
Follow the specific formula for each problem type. The information presented in each problem follows the metacognitive strategy instruction and teaches students rules for solving each problem type	Group	Group problems combine two distinct things (parts) into one large group (whole)
	Compare	Compare problems involve two people or objects comparing the amounts of one thing, or one person or object comparing the amounts of two things
	Change	Change problems involve one thing, which either increases (change-addition) or decreases (change-subtraction) in value
Anchoring instruction with thematic problems		
Create thematic word problems to provide a meaningful and motivating context. Anchor the instruction by introducing the theme at the start of the lesson through engaging pictures, videos, objects, and movement	"Today's problems are going to be about a basketball game. Have you ever been to a basketball game? Let's watch a short video showing a basketball game before we begin!"	
Problem structure		
Each word problem is presented in a structured four-sentence format. The first sentence provides context to the problem. The second and third sentences identify the first and the second key noun, the action verb, and the quantities for solving. The last sentence asks the questions with the label of what students are solving for. The order of information is presented in the same order that is recorded on the graphic organizer and on the number sentence	Group	1. "Sara went to the grocery store." 2. "Sara bought 3 apples." 3. "She also bought 2 oranges." 4. "How many pieces of fruit did she buy?"
	Compare	1. "Omar and Jasmine went to the arcade." 2. "Omar won 5 tickets." 3. "Jasmine won 2 tickets." 4. "How many more tickets did Omar win?"
	Change	1. "Jose was carrying sodas for his friends." 2. "Jose was carrying 7 sodas." 3. "He spilled 3 sodas." 4. "How many sodas does Jose have left?"
Considerations for writing word problems		
The use of common and specific language	Use popular and high preference objects and familiar names (e.g., classmates, family). Use high-frequency sight words, easy to decode words, and common categories when possible (e.g., "dog, cat, pets"). Do not include extraneous numerals or information	
Avoid keywords	Differentiation between problem type is based on conceptual understanding of problem structure. Keywords do not always reflect problem type (e.g., "more" can appear in both change-addition problems and compare problems, but they are solved by addition and subtraction, respectively).	
The use of verbs that indicate clear action	Use verbs that students can role-play with manipulatives or objects. Addition verbs include make, combine, put together, pick up, and add more. Subtraction verbs include take away, lose, break, spill, and pay.	
Purposeful number selection	Use numbers that reflect student numeracy abilities. Begin with one-digit numbers represented as Arabic numerals with a maximum sum of 10 and no differences of 0	
Specific placement of numbers within word problems	Alternate placement of larger and smaller numbers in addition to sentences, but always place the larger number first in subtraction problems. Begin instruction with the missing quantity in the final position	
Check for bias	Equal use of female and male characters and themes. Avoid gender, cultural, or racial stereotypes. Use scenarios that all students, including culturally and linguistically diverse students, can relate to or understand. Use scenarios that are relevant and meaningful for students	

example, although some problems may include words such as "total" and "more," students should not be taught those words that are synonymous with an operation, as is typical in the keyword strategy (Van de Walle et al., 2010). When writing word problems, common verbs should be chosen that clearly indicate an action (Stein et al., 2006).

Word problems should use quantities that are considerate of the early numeracy skills of students with severe disabilities, including number identification and conservation. Word problems should be carefully screened to ensure they realistically depict situations involving quantities less than 10 to facilitate the use of manipulatives. By strategically placing important information in the word problems, students encounter numbers in the order they would be used in the number sentence. For example, placing the larger quantity first in change-subtract and compare problems allows students to correctly set up subtraction equations. Additional supports for students with severe disabilities include using Arabic numerals and presenting the missing quantity in the final position of a standard format equation (e.g., 4 + 1 = ?). In addition, pictures can be placed above the nouns in the second and third sentences to help nonreaders comprehend what the story was about. For example, in the problem: "John is picking apples. John has five green apples. John has two red apples. How many apples does John have in all?" a picture of a green and a red apple could be placed above the corresponding nouns. This limited use of picture support provides enough visual support to help memory recall of key information from the word problem while encouraging listening comprehension and can easily be faded (Root & Browder, 2017).

Finally, word problems should be accessible for diverse students with severe disabilities by using scenarios that are relevant and meaningful for all students and free from bias. Careful consideration should be made to ensure word problems equally use female and male characters; are written to be free of gender, cultural, or racial stereotypes; and use scenarios that are germane for students with severe disabilities who are culturally and linguistically diverse (see Table 2).

Interactive read alouds of math story problems. Read alouds are an evidence-based practice for students with severe disabilities (Hudson & Test, 2011) and control for the literacy barrier many students with severe disabilities face in solving word problems by creating access to the problems for students who are emerging readers or nonreaders. Students should be taught to request a read aloud from the instructor if they need help reading the problem. This requirement for students to request assistance is an important feature of MSBI, as it promotes independence and self-advocacy. Emerging and fluent readers should be given the opportunity to read the problem themselves first, with assistance from the teacher provided as needed. Then the teacher should provide a second read aloud of the problem, during which the students are instructed to just listen. This approach allows students to practice independence in reading the problem while still providing support for students with limited reading skills with a reread for listening comprehension.

Conceptually Comprehend the Problem

Modifying traditional SBI for students with severe disabilities. Traditional SBI teaches students to comprehend the underlying problem structure through four essential components: (a) visual diagrams known as schemas to show the relationships between quantities in the word problem, (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., 2013; Powell, 2011). MSBI maintains the four essential components of SBI, but makes modifications to address learning characteristics of students with severe disabilities, including reading deficits, working memory deficits, and weak numeracy skills.

Instead of having students draw schemas, as is typical in SBI for students with high-incidence disabilities, premade graphic organizers should be provided for each problem type that includes visual supports, such as color coding and picture cues, in addition to showing the relationship between quantities in the problem type. The spaces on the graphic organizers should be large enough for the manipulatives to fit when creating sets. Rather than using a heuristic like the mnemonic "RUNS" (i.e., "*R*ead the problem," "*U*se a diagram," "*N*umber sentence," and "*S*tate the answer"; Rockwell et al., 2011), which would hold little meaning for a nonreader or emerging readers who cannot identify the first letter of each word, or remember what each letter stands for, a task analysis should be used as the heuristic. In The Solutions Project, students were taught to use an 11-step task analysis for solving a word problem that could be applied across the problem types. We recommend using a total task presentation to maintain the purpose behind the problem-solving task—to arrive at a solution.

MSBI not only maintains the use of explicit instruction (e.g., model, lead, test) but also embeds systematic instruction (e.g., constant time delay and system of least prompts) with error correction and feedback. Metacognitive strategy instruction is achieved by (a) providing a student task analysis, which dually serves as a self-monitoring checklist in which students were taught to self-instruct and monitor their own problem solving; (b) rules with hand motions and sayings that were taught to aid in memory of problem types; and (c) modeling scripted think alouds for the discrimination of problem type process, as well as for choosing the operation for solving. The task analysis provides students with the needed information to perform the multistep task, and the self-instruction and self-monitoring reduce dependency on the teacher. The rules reflect the problem type, and the hand motions can be done over top of the graphic organizer to show the relationship between quantities. For example, in *Group* problems, the students in The Solutions Project were taught "small group, small group, BIG group" while holding up each fist in an "O" and then bringing the hands together to make a large O with thumbs and fingers touching to represent the part–part–whole relationship. For students who had difficulty with spoken language and/or motor planning, approximations for the rules and hand motions were sufficient. Finally, a think aloud is when the teacher provides an oral explanation of how to determine the problem type or operation using the structural features or information from the word problem (Jitendra et al., 2015). Saunders, Lo, and Browder (2017) found that students used the scripted think alouds when solving problems during probes. For additional information on each of these components, see Table 1.

Progression through problem types. Different variations in progression through problem types have been used in the literature (e.g., *change, group, compare*, Jitendra, 2008; *group, change, compare*, Rockwell et al., 2011). One primary difference in mathematical skills between students with high-incidence disabilities, or those at risk for math failure, and students with severe disabilities is the lack of fact recall, or even procedural fluency to utilize a quick strategy for solving an addition or subtraction problem. In light of this, we recommend progressing from group problems, which are solved by addition, to compare problems, which are solved by subtraction, to change problems in which the student has to determine whether the problem requires solving via addition or subtraction. In addition, Rockwell et al. (2011) recommended adding a discrimination training component where problem types were explicitly taught using a sorting activity as belonging to the targeted problem type or not based on salient features in the underlying problem structure. Saunders, Lo, and Browder (2017) replicated this recommendation by teaching discrimination first and then procedural solving second within the same unit. They found that students with severe disabilities did not acquire this discrimination of problem type as rapidly as Rockwell et al. (2011).

One potential explanation for this is the relationship between conceptual and procedural knowledge. Researchers in mathematics have found the development of conceptual and procedural knowledge influence one another, but children's initial conceptual knowledge predicted greater gains in procedural knowledge and sequential gains in procedural knowledge that resulted in conceptual gains (Rittle-Johnson, Siegler, & Alibali, 2001). To reduce the cognitive demands required of discriminating problem type *and* solving a problem while first acquiring the skill of mathematical problem solving, we recommend teaching each problem type to mastery prior to introducing discrimination. In our experience, students had some experience with addition, whereas they had less experience with subtraction, and little to no experience with word problem solving. Therefore, we started with the additive problem type (group), then moved into teaching subtraction (compare), prior to teaching discrimination between problem types. We recommend progressing through units in a very explicit manner targeting either an operation (+/−) or discrimination of problem type or operation, using this sequence: (a) teaching *group* problem solving to mastery, (b) teaching *compare* problem solving to mastery, (c) teaching discrimination of *group* and *compare* problems while continuing to review how to solve each type, (d) teaching *change-addition* problems to mastery, (e) teaching *change-subtraction* problems to mastery, (f) teaching discrimination of operation between *change-addition* and *change-subtraction* problems with attention to the change action in the problem, and finally (g) teaching discrimination of all three problem types using a sorting activity and randomly selecting various problem types to solve. The sequence was tested and refined over the course of The Solutions Project, and students were most successful using the aforementioned (Browder et al., 2017; Saunders, Browder, et al., 2017).

Procedurally Solve the Problem

MSBI not only keeps the explicit instruction used in typical SBI but also incorporates evidence-based practices for teaching mathematics to students with severe disabilities based on the findings of Browder et al. (2008), which identified repeated opportunities for practice and systematic instruction with error correction and feedback as evidence-based for students with severe disabilities. In MSBI, systematic instruction techniques include the use of scripted systematic instruction of steps of a task analysis for solving problems using an embedded system of least prompts and planned error correction and feedback.

Task analysis. The use of a task analysis is not a new strategy in the field of severe disabilities, but MSBI is one of the first academic interventions to provide the task analysis to students with severe disabilities to facilitate self-instruction. The task analysis should be presented in a student-friendly format (referred to as the "self-instruction checklist") and feature pictures paired with each step to support emerging readers. The 11 steps of the student checklist used in The Solutions Project included (a) read the problem; (b) circle the "whats"; (c) find the label in the question; (d) identify whether the problem is talking about things that are the same, different, or comparing quantities using more or fewer; (e) use rules specific to problem type; (f) choose graphic organizer; (g) circle the numbers; (h) fill in the number sentence; (i) add or subtract?; (j) make sets using counters; and (k) solve and write the answer. To promote the development of self-monitoring skills, the self-instruction checklist had space for students to check off each step as it was completed. This additional support not only helps to transfer control of discriminative stimuli away from a teacher prompt to the task analysis to promote self-instruction (Browder & Shapiro, 1985) but also assists in facilitating executive functioning required in mathematical problem solving.

Explicit instruction and systematic instruction. Explicit instructional strategies consist of the instructor modeling the targeted behavior(s), guided practice, independent practice, and continuous feedback on skill performance (Stein et al., 2006). We recommend a "model-lead-test" procedure with reinforcement and immediate error correction. Discrimination training, a form of explicit instruction, also should be incorporated as a component of the instruction to teach students to decide when to and when not to apply the strategy (i.e., determine the problem type and decide when to add or subtract).

In The Solutions Project, students were provided with 2 days of modeling each step of the chained task for problem solving across a minimum of two problems with an opportunity for them to immediately practice each step. Then, teachers faded their support, giving the instructional cue, "Solve this problem," and providing students with an opportunity to respond first before intervening. For no responses or if students were unsure, after a designated wait time of 3 to 5 s depending on age and ability of students, teachers employed the system of least prompts, moving through scripted procedures for three prompt levels. The first prompt level was a gesture to the step on the student's checklist combined with a nonspecific verbal prompt of reading the step aloud to the student. The second prompt level was a more specific verbal prompt, which included a reread of the step and provided additional information to help the student perform the step. For example, Step 3 instructed students to find the label in the question. For a specific verbal prompt, the teacher would say, "Step 3 says find the label in the question. The label is the word after 'how many . . .' The label is what you are solving for." The last prompt was model retest, where the teacher demonstrated the skill and then immediately gave the student the opportunity to perform the skill. Using the same example, the teacher would locate the question in the word problem and text point to each word as he or she reads, stopping on the label and emphasizing it (e.g., touch "how," read "how," touch "many," read "many," touch the label word and leave finger there, and read with emphasis "[insert noun; e.g., *snacks*]"). Then the student would repeat the label and fill it in on the blank in the number sentence following, where the final answer would be placed.

Error correction. While MSBI relies on a system of least prompts for prompting and feedback during acquisition, it is important to note that when students make an error (such as writing the wrong label), we recommend immediately providing an error correction in the format of a model and retest versus going through the entire prompting hierarchy as is traditionally done in a system of least prompts. This immediate error correction is important in mathematics so the learner does not have the opportunity to repeat the same mistake or elicit a new error (Stein et al., 2006). For example, in The Solutions Project, if a student wrote some other word than the label (e.g., "snacks"), then the teacher would erase the student's answer and go straight to the model prompt above (e.g., reading "how many *snacks*" and pointing to the word "snacks"). Then the teacher would immediately provide a retest, stating the instructional cue again, "Now you find and write the label in the question" with an opportunity for the student to locate and write the correct label.

Planned fading of behavior-specific praise. Fading of teacher support and feedback should be carefully planned to promote independent problem solving. In The Solutions Project, the teacher initially coached the student through solving the steps of the task analysis by providing behavior-specific praise for each step (e.g., Great job finding the label in the question! The label is *what* we are solving for?). Once students began to show mastery of steps that repeated across problem types (i.e., 2 days solving independently correct), behavior-specific feedback was only delivered for critical steps (e.g., determining the problem type and the operation for solving). Ultimately, behavior-specific praise was only given for completing the entire problem independently and correctly. If individual students needed additional motivation tools, such as praise for on-task behavior (e.g., "You are working so hard!) or a token economy for problems solved, teachers were permitted to utilize them.

Other evidence-based strategies for students with severe disabilities. In consideration of students' need for repeated opportunities for practice, we theorized that creating multiple themes with multiple problems generated for each theme would address the need for repetition, while maintaining student interest and promoting generalization. Concrete manipulatives, a newly established evidence-based practice for students with severe disabilities, should be used to adjust for the lack of fact recall, as well as to demonstrate the conceptual understanding required for effective problem solving (Spooner, Root, et al., 2017).

Generalize Multiple Ways

Finally, it is well documented in the literature that students with severe disabilities have difficulty generalizing newly acquired skills without training (Stokes & Baer, 1977). Generalization is essential for students to be effective problem solvers in the real world. Multiple methods of promoting generalization were included in The Solutions Project, including generalizing across materials (problems on the SMART Board and iPad; Browder et al., 2017; Saunders, Browder, et al., 2017); generalizing to video-simulation problems, where mathematical problems students may encounter in the real world were recorded on video and played for the students to solve (Saunders, Spooner, & Ley Davis, 2017); and generalizing across mathematical standards to algebraic problems with missing initial and medial quantities (Root & Browder, 2017). In addition, one study evaluated peer-mediated delivery of MSBI (Ley Davis et al., 2017). The study found that peers were able to deliver MSBI with high levels of fidelity, and social validity results indicated that teachers and paraeducators believed peer-delivered instruction on mathematical problem solving to be important and effective. This finding is important given the recent calls for more research with students with severe disabilities in inclusive settings (Hudson, Browder, & Wood, 2013).

Considerations for Implementing MSBI

Students with severe disabilities are a heterogeneous group of individuals who vary not only in their physical and cognitive abilities but also by their preferences and learning histories. Despite their diversity, Snell (2003) reminded us these students have a "common capacity to learn" (p. 210). While entry points to mathematical problem solving will vary among students, educators can use data to determine the need for remediation or to move forward. When data indicate a lack of meaningful progress, educators should consider what adjustments might be needed to remediate skills (Collins, 2012), including preteaching skills needed for a unit (Saunders, Lo, & Browder, 2017), teaching steps in isolation using a massed-trial format (Saunders, Lo, & Browder, 2017), modifying materials (Browder et al., 2017), and tightening prompting (Browder et al., 2017). When data show students are ready to move forward, fading of supports is another important consideration when implementing MSBI. One way to consider which supports to fade is to analyze typical mathematics instruction used in general education, such as removing some of the parameters put in place regarding the structure of the word problem (e.g., removal of picture supports, transitioning from a four-line format to a paragraph format more typical of general education textbooks). Root and Browder (2017) found that middle school students with severe disabilities could solve word problems without picture supports with problem displayed on a worksheet (see Table 1). Mathematical word problems in general education also typically use quantities above 10, especially in upper elementary and middle school. Root, Saunders, et al. (2017) found that middle school students with moderate ID could be taught to solve *change* problems targeting personal finance with larger numbers and decimals using a calculator. Another suggestion may be to transition to more efficient methods for solving than manipulatives which take time to place and move once students have shown conceptual understanding. Saunders, Browder, et al. (2017) found that students were able to reduce time to solve problems by using dot notation once they had mastered solving problems using manipulatives on the graphic organizers to show their conceptual understanding.

Implications for Practice

Problem solving is a foundational mathematics skill required for students to better access the CCSSM. Yet, as Kearns et al. (2011) pointed out, the mathematical skills of students with severe disabilities are quite discouraging. There is a need for more effective mathematics instruction for students with severe disabilities, particularly targeting higher level thinking skills, such as problem solving. This does not have to be a dichotomous approach. Practitioners can continue to work on foundational mathematics skills, such as number sense and calculation, within the context of teaching problem solving. The MSBI model encompasses many numeracy and calculation skills within it, such as number identification, creating sets, and adding and subtracting. As shown in Table 1, this model also simultaneously addresses many CCSSM. This can be expanded to other standards across domains as well. For example, when viewing a bar graph in data analysis, students can use various problem types to solve questions related to interpreting the data on the graph (e.g., when shown a graph of pets in the home, students could use their problem-solving skills to determine how many pets students own altogether).

As students progress through grade levels, the CCSSM increases in difficulty and complexity. When considering arithmetic, one-step problem solving, and students in middle and high school, this deviates from the expectations in the CCSSM. On the contrary, if students have been taught this foundational approach to problem solving, they may be able to use these skills with other supports, such as a calculator, to perform more complex problems that are better aligned with grade-level expectations in the CCSSM (Root, Saunders, et al., 2017).

Implications for Research

The MSBI has just begun to scratch the surface in developing higher level mathematical skills for students with severe disabilities. Several questions remain unanswered that need additional research to extend and refine this model.

- *Can it be replicated?* To be established as a research-based and/or evidence-based practice, this model needs to be replicated in other geographical regions of the United States and by additional research teams.
- *Can the expectations be increased by fading supports?* The students in all studies of The Solutions Project made progress, but can even more be accomplished (see Table 1)? Can supports be faded? Can students use more efficient strategies for solving than manipulatives? Results from Root and Browder (2017) and Saunders, Browder, et al. (2017) show promise, but additional research is needed in this area.
- *Can students with severe disabilities, who may not have the precursor skills and need more time or additional supports, make progress with MSBI?* This is an area that needs additional research.

Technology is likely one method for accommodating for these differences. For example, if a student does not have picture-symbol recognition or emergent literacy skills, using a computerized task analysis with a read-aloud function like Saunders, Lo, and Browder (2017) did would ameliorate the lack of precursor skills required for independent problem solving.
- *Does MSBI directly influence real-world mathematical problem solving?* Browder et al. (2017); Saunders, Browder, et al. (2017); and Saunders, Spooner, and Ley Davis (2017) found that students could solve video-simulation problems, but this needs to be measured directly in the community and environment that students encounter in their everyday lives outside of the school setting.

Conclusion

Although problem solving is emphasized throughout all domains and is a standard of mathematical practice in the CCSSM, teaching mathematical problem solving to students with severe disabilities is a relatively new topic. It is of utmost importance that we as educators maintain high expectations and do not place a ceiling on the mathematical learning potential of students with severe disabilities. We should continue to investigate methods for improving the quality of mathematics education and progress in CCSSM for this population. Preparing students for the 21st century is not just a Common Core State Standards phenomenon for typically developing students. Rather, we need to continue to prepare students with severe disabilities for the 21st century, providing them with skills that lead to greater independence and more opportunities, while maintaining high expectations. Improving mathematical competence will help.

Authors' Note

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