# Effects of a Word-Problem Intervention on Word-Problem Language Features for Third-Grade Students with Mathematics Difficulty

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Abstract

Word problems require students to read a language-based problem, identify necessary information to answer a prompt, and perform calculation(s) to develop a problem solution. Solving word problems proves particularly challenging for students with mathematics difficulties because skill in reading, interpretation of language, and mathematics is required for word-problem proficiency. We examined whether 2 versions of a word-problem intervention increased students' understanding of 3 word-problem language features: *naming a superordinate category*, *identifying irrelevant information*, and *providing a word-problem label*. At pre- and posttest, 145 3rd-grade students solved word problems and answered questions about word-problem language. Students who participated in the word-problem interventions demonstrated improvement on identifying irrelevant information and providing word-problem labels over students in the business-as-usual condition. We did not identify group differences related to naming a superordinate category. These results suggest the importance of explicit teaching of language comprehension features within word-problem intervention.

*Keywords:* language; learning difficulties; mathematics; word problems

# Effects of a Word-Problem Intervention on Word-Problem Language Features for Third-Grade Students with Mathematics Difficulty

State and national standards and high-stakes assessments require students to demonstrate mathematics competency by solving written language-based problems (i.e., word problems) in the elementary grades (e.g., National Council of Teachers of Mathematics, 2006; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Unfortunately, national data suggests elementary students with disabilities are underprepared to meet these demands, with word-problem performance below grade level proficiency and significantly lower than students without disabilities (U.S. Department of Education, 2017). Students with or at-risk for learning disabilities in mathematics (i.e., mathematics difficulty; MD) also utilize less efficient strategies for problem solving, including procedures that may be more consistent with younger, typical mathematics learners (e.g., counting all items rather than counting on from a number; Geary, Hoard, Byrd-Craven, & DeSoto, 2004). Importantly, lower performance in word-problem solving may impact students' later mathematics success in school, job opportunities, and salary later in life (Murnane, Willett, Braatz, & Duhaldeborde, 2001; Ritchie & Bates, 2013; Wei, Lenz, & Blackorby, 2013).

## Word Problems and Students with MD

Students with MD experience difficulty with word problems due to the complexity of word-problem solving, which involves reading and understanding the language-based scenario of the problem, recognizing the unknown (i.e., what needs to be solved), identifying important and irrelevant information, selecting a process or strategy to solve for the unknown, and solving for the unknown (Stevens & Powell, 2016; Wang, Fuchs, & Fuchs, 2016). Reading a word problem may serve as the initial hurdle for students with MD because approximately half of students with

MD also experience reading difficulty (Peterson et al., 2017; Wilson et al., 2015). Students must also understand word-problem specific language and vocabulary (Capraro, Capraro, & Rupley, 2012), which proves especially challenging for students with MD (Forsyth & Powell, 2017). Students with MD demonstrate lower performance on word problems than calculation tasks (Fuchs, Fuchs, et al., 2008; Wei et al., 2013), which may be due to the additional language demands associated with word-problem solving.

Researchers have developed targeted interventions to support students with MD to improve their word-problem solving performance (Krawec, Huang, Montague, Kressler, & Melia de Alba, 2012; Swanson, Orosco, & Lussier, 2014). Notably, students with MD have responded favorably to intensive interventions focused on instruction about word-problem schemas (Fuchs, Fuchs, Finelli, Courey, & Hamlett, 2004; Fuchs, Seethaler, et al., 2008; Griffin & Jitendra, 2009; Jitendra et al., 2013; Powell et al., 2015), which are specific word-problem types, or structures, well established in previous research (Carpenter, Hiebert, & Moser, 1981; Riley & Greeno, 1988). In schema instruction, students learn to identify a word problem as belonging to a specific type (i.e., schema) and follow a set of steps to develop a problem solution specific to the schema. Explicit schema instruction provides students with knowledge of the problem's structure, a framework for organizing the information in the problem based on the identified structure, and a method for solving the problem using an equation or graphic organizer specific to a word-problem schema (Fuchs et al., 2014; Xin & Zhang, 2009). In the early elementary grades, student learn three additive word-problem schemas: Total problems, also called combine or part-part-whole problems (i.e., parts are put together for a total), Difference problems, also called compare problems (i.e., two amounts are compared for a difference), and Change problems (i.e., a starting amount that increases or decreases to a new amount; Kintsch & Greeno, 1985).

**Relationships Among Text Processing, Language, and Word-Problem Solving**

As described, current evidence suggests word-problem interventions focused on schema instruction prove effective for improving the word-problem performance of students with MD (Jitendra et al., 2013; Powell et al., 2015); however, students' language comprehension challenges may negatively impact their word-problem performance (Fuchs, Fuchs, Compton, Hamlett, & Wang, 2015; Fuchs, Gilbert, Fuchs, Seethaler, & Martin, 2018). To support students with the language in word problems, Kintsch and Greeno (1985) provided a processing model specifically for mathematics word problems that simultaneously assists students with comprehension of text and an understanding of the mathematics. In this model, students construct a *problem representation* by transforming text into a series of known statements or observations about language of the text. Then, students develop a *problem model*, which guides students to make inferences, create connections among the quantities presented in the problem, and formulate and execute a solution (Kintsch, 1988).

Word-problem solving serves as a form of text comprehension, and understanding language proves integral to students' mathematics word-problem solving performance (Boonen, van der Schoot, van Wesel, de Vries, & Jolles, 2013; Björn, Aunola, & Nurmi, 2016; Decker & Roberts, 2015; de Koning, Boonen, & van der Schoot, 2017; Fuchs et al., 2018). Importantly, students with language deficits exhibit lower word-problem performance (Fuchs, Fuchs, et al., 2008; Fuchs et al., 2006). Furthermore, research evidence suggests students require word-problem specific language comprehension to build a word-problem model above and beyond general language comprehension (Fuchs et al., 2015; Fuchs et al., 2018). Students may enter school with general language comprehension for the vocabulary presented in word problems, but later develop word-problem specific language comprehension for those same terms (e.g., getting *more* of an item versus having *more than* someone else; Fuchs et al., 2015; Kintsch & Greeno, 1985).

**Challenging Word-Problem Language Features for Students with MD**

The complexity of word problems may be influenced by the language, both general and mathematics-specific, used within the word problem's text (Daroczy, Wolska, Meurers, & Nuerk, 2015; Fuchs et al., 2015). For the purpose of this paper, we examined three word-problem specific language comprehension features contributing to the complexity of word problems: *naming a superordinate category*, *identifying irrelevant information*, and *providing a word-problem label*.

**Naming a superordinate category.** When solving a word problem, students need to identify basic-level items (e.g., cats, dogs) and may need to recognize superordinate categories (e.g., pets) associated with basic-level items. When learning non-mathematical language (e.g., in a language arts classroom), students typically acquire knowledge about basic-level items before learning about the construction of superordinate categories (Liu, Golinkoff, & Sak, 2001; Mervis & Crisafi, 1982; Sophian & McCorgray, 1994). Naming a superordinate category proves an important language feature within word problems because it signals whether students recognize the association among several basic-level items. In a study of adults, those who practiced identifying superordinate categories before solving word problems outperformed adults who practiced naming basic-level items on a measure of word-problem solving (Schley & Fujita, 2014). In this way, the priming of superordinate categories assisted with reading and solving word problems.

We hypothesized students need to understand the relation among basic-level and superordinate items described in the word problem; otherwise, students may experience difficulty identifying the relevant information needed for problem solution or labeling the solution correctly. Competence with identifying a superordinate category also helps students recognize which terms may be irrelevant within a word problem, an area of difficulty for students with MD (Passolunghi, Cornoldi, & De Liberto, 1999; Swanson et al., 2014), and a topic we discuss in the next section.

**Identifying irrelevant information.** In addition to understanding the relationship among basic and superordinate category items in the problem scenario, students often are expected to identify irrelevant information (Krawec, 2012). In a word problem (e.g., *The baker made 36 cupcakes, 72 brownies, and 12 pies. The baker used 30 cups of sugar. How many desserts did the baker make?*), students must identify *30 cups* as irrelevant information not needed to answer the word-problem question. Irrelevant information provided in the text of the problem or an accompanying visual (i.e., graph or figure) increases the difficulty level of a mathematics problem or word-problem solving (Berends & van Lieshout, 2009; Kaminski & Sloutsky, 2013; Wang et al., 2016).

When a word problem contains irrelevant information, students are required to process more text and distinguish relevant information from irrelevant information (Jarosz & Jaeger, 2019). Students also may place greater burden on working memory capacity when determining the relevant and irrelevant information within a word problem (Swanson, Lussier, & Orosco, 2015). We hypothesized students may experience greater word-problem difficulty when word problems feature irrelevant information because of these additional language-based and cognitive demands.

**Providing a word-problem label.** To interpret a word problem and provide a problem solution, students also must identify a label(s) corresponding with quantities within the word problem and the numerical answer (Griffin & Jitendra, 2009). For a word problem (e.g., *The baker made 36 cupcakes on Saturday and 106 cupcakes on Sunday. How many cupcakes did the baker bake?*), students provide a numerical answer and a label: 142 *cupcakes*. Labeling allows students to establish connections among the key quantities in the problem. That is, in the previous example, students connected the quantities related to *cupcakes*. In another problem (e.g., *The baker made 36 cupcakes, 72 brownies, and 12 pies. How many desserts did the baker make?*), students identify *desserts* as the superordinate label and understand *desserts* comprises the basic-level items of *cupcakes*, *brownies*, and *pies*.

Because students with MD may not provide a label without prompting, many word-problem interventions teach students to use labels as part of the word-problem process (Fuchs, Seethaler, et al., 2008). We hypothesized students may demonstrate a stronger understanding of the word-problem prompt if they provide an appropriate word-problem label. Labeling may also aid students in mathematical communication through activities such as mathematical writing (Powell & Hebert, 2016).

**Purpose and Research Question**

Complex language features may impact students' word-problem solving performance as well as transfer to novel word problems, even if the schema is known (Wang et al., 2016). We designed two variations of a word-problem intervention and included interventionist-led discussions about language features in word problems to help students with MD construct problem representations and problem models. Given the important role of language within word-problem solving (Daroczy et al., 2015), we aimed to identify whether the word-problem interventions increased students' understanding of word-problem solving language with regard to (a) naming superordinate categories, (b) identifying irrelevant information, or (c) providing a word-problem label. The following research question guided this study: What is the effect of a word-problem intervention on word-problem specific language comprehension for third-grade students with MD?

# Method

## Context and Setting

We recruited elementary schools from a large urban school district in the Southwest of the United States. The school district served over 80,000 students. In 2017, the district reported 55.5% of students as Hispanic, 29.6% as Caucasian, 7.1% as African American, and 7.7% as belonging to another racial or ethnic category. In the district, 27.1% of students qualified as English learners, and 12.1% received special education services. Overall, 52.4% of students qualified as economically disadvantaged.

## Participants

We recruited third-grade teachers for study participation from 13 different elementary schools within the district. During the 2017-2018 school year, we worked in 51 classes with 44 teachers. Several schools used departmentalization (i.e., the same teacher taught multiple mathematics classes), which accounted for the differences in the numbers of teachers and classes. From these 51 classes, interventionists screened 818 third-grade students.

As part of whole-class screening, interventionists administered a measure of *Single-Digit Word Problems* (Jordan & Hanich, 2000). We used a measure of problem solving to screen for difficulty in the area of the mathematics content of the intervention. For study eligibility, we identified 236 students who answered 7 or fewer items correctly (out of 14) as experiencing mathematics difficulty (MD). Before randomization, interventionists administered individual pretesting across a four-week span. During this time, we determined 77 students as ineligible for the following reasons: limited English proficiency, disability and receiving other services, relocation to another school, teacher-identified behavior issues, too many students with MD in a classroom, or unable to schedule. We blocked on classrooms and randomly assigned the 159 remaining students to one of three conditions: Pirate Math Equation Quest (PMEQ; $n$ = 60), Pirate Math without Equation Quest (PM-alone; $n$ = 38), and a BAU ($n$ = 61).

The present study was part of a larger, three-year study about the efficacy of word-problem intervention with and without an algebraic reasoning component (Powell et al., 2019). In the present study, we assigned more students into the PMEQ and BAU conditions because of oversampling of PM-alone during the previous school year. We only measured and analyzed mathematics language during the 2017-2018 school year, which is the focus of this manuscript.

From the start of intervention through posttesting, nine PMEQ students, four PM-alone, and one BAU student left the study due to moving, extreme behavioral challenges, 30-day suspension, and protective custody due to abuse in the home. This resulted in 8.8% overall attrition and 15.0% attrition for PMEQ, 11.3% for PM-alone, and 1.7% for BAU. Table 1 presents the demographic information for the 145 students who completed posttesting. At pretest, we calculated the average age of students as follows: 8 years, 9 months for PMEQ; 8 years, 8 months for PM-alone; and 8 years, 8 months for BAU. For the 88 students identified as English learners, Texas English Language Proficiency Assessment System (TELPAS) ratings (1 = beginning, 2 = intermediate, 3 = advanced, 4 = advanced high) averaged: 1.93 for PMEQ, 1.83 for PM-alone, and 1.81 for BAU.

<<Table 1 inserted here>>

**Mathematics Instruction for Students with MD**

All students with MD participated in regular mathematics instruction provided by their general education teacher. In the district, teachers primarily used the *GoMath!* to guide mathematics instruction. Students in the PMEQ and PM-alone conditions also received supplemental, individual tutoring about word-problem solving. The interventionists did not provide tutoring during the students' regular mathematics instruction to ensure students continued to fully participate in the district's mathematics curriculum.

**Interventionists**

We recruited 15 interventionists to conduct the pretesting, tutoring, and posttesting. All interventionists were females who were pursuing or had obtained a Master's or doctoral degree in an education-related field. Interventionists identified as Caucasian (73.3%; $n$ = 11), Hispanic (13.3%; $n$ = 2), Indian American (6.7%; $n$ = 1), and African American (6.7%; $n$ = 1). Throughout the year, interventionists participated in trainings to ensure they were highly prepared to implement all aspects of the intervention. Before the school year began, interventionists participated in three, 3-hr pretesting trainings. In early October, the team participated in two, 1.5-hr tutoring trainings related to the content of the intervention and Total problems. Two subsequent 1.5-hr tutoring trainings followed in November to introduce Difference problems and in January to introduce Change problems. Lastly, interventionists participated in one, 1.5-hr posttesting training meeting in March.

**Intervention**

Interventionists conducted sessions three times per week for 30 min a session for a total of 45 sessions during the school year. The interventionists worked with students in a quiet place outside of the classroom (e.g., school library, conference room, extra classroom). The majority of interventionists tutored between 6 to 8 students. We assigned interventionists to tutor both PMEQ and PM-alone students to ensure even quality of interventionists between the two conditions.

PMEQ and PM-alone students participated in five activities for each session: (1) Math Fact Flashcards, (2) Equation Quest or Pirate Crunch (3) Buccaneer Problems, (4) Shipshape Sorting, and (5) Jolly Roger Review. Only one activity (i.e., Equation Quest or Pirate Crunch) differed for students in the two intervention conditions. In the following sections, we describe each of the five activities (see Powell et al. [2019] for greater detail).

**Math fact flashcards.** To increase math fact fluency, interventionists displayed a set of math fact flashcards to students during two, 1-min timings. Students answered as many flashcards as they could in 1 min. After 1 min, interventionists and students counted the number of flashcards answered correctly. Students then completed another 1-min timing to determine if they could beat their previous score, and graphed the highest score from the two trials. Math fact flashcards lasted approximately 3 min.

**Equation Quest.** For PMEQ students only, Equation Quest served as the second activity of each intervention session. For approximately 3 to 5 min each session, interventionists provided instruction on solving equations and interpreting the equal sign as a relational symbol. Interventionists reintroduced the equal sign and taught students to understand the meaning of the equal sign as *the same as*. Students learned the equal sign acts as a balance between two sides of an equation and does not solely signal a calculation. To understand the equal sign as a relational symbol, students solved standard and nonstandard equations with concrete manipulatives (e.g., balance scale and blocks), hand-drawn pictures, or equations presented with numbers and symbols. Students also learned a set of steps to balance equations with a variable (i.e., “X”), which involved isolating the variable and emphasizing that whatever calculation is performed on one side of the equal sign is also performed on the other side of the equal sign (e.g., subtract 4 from both sides). Students practiced isolating the variable with both standard and nonstandard equations.

**Pirate Crunch.** For PM-alone students only, Pirate Crunch was the second activity of each intervention session. For approximately 3 to 5 min each session, interventionists provided a mathematical review activity for students to complete. Pirate Crunch activities addressed concepts of telling time, money, geometry, perimeter, area, place value, and fractions through pencil and paper tasks.

**Buccaneer Problems.** The third activity for each session consisted of interventionist-led schema instruction through a series of three Buccaneer Problems. Note, PMEQ and PM-alone students received identical Buccaneer Problems. Interventionists provided explicit, scaffolded instruction on how to set up and solve word problems by schema (i.e., Total, Difference, and Change). Students learned to attack any word problem by RUNning through the problem: *R*ead the problem, *U*nderline the label and cross out irrelevant information, and *N*ame the problem type (i.e., choose the correct schema to use). This attack strategy guided the construction of a problem representation. After determining the schema of the word problem, students developed a problem model based on the schema. Students learned to use an equation to represent the problem and to mark “X” to represent the missing information. The interventionists introduced the Total schema during session 5, the Difference schema in session 17, and the Change schema in session 34. From session 39 until the end of intervention, Buccaneer Problems included a comprehensive review of the three schemas. Figure 1 displays examples of Total, Difference, and Change problems used during Buccaneer Problems. The interventionist and student usually worked through the Buccaneer problems for approximately 12 to 15 min during the session.

<<Figure 1 inserted here>>

Notably, the Buccaneer Problems addressed the following language comprehension features during word-problem instruction: *naming superordinate categories*, *identifying irrelevant information*, and *providing a word-problem label*. After the interventionist presented a word problem, students followed the RUN attack strategy to guide the process of working through a word problem. The initial part of the *U* prompted students to underline the label(s). Interventionists explained all complete word-problem answers required a number and a label (e.g., 94 *trips*). Additionally, interventionists instructed students to analyze the word-problem question to understand specifically what the question asked. Once students identified the correct label(s), which could be a basic-level label or superordinate label, they underlined the label(s) and referred back to the underlined word(s) when writing the label answer. Identifying and underlining the label(s) in the word problem also helped students to name a superordinate category by determining if the label(s) referred to a basic-level item or superordinate category.

During the second part of the *U* in the RUN attack strategy, students learned to identify and cross out any irrelevant information in the word problem. Interventionists explained to students that irrelevant information described extra information not necessary to solve the problem and intended to trick the problem solver. Interventionists taught students to refer to the label(s) when searching for irrelevant information; numbers not referring to the label(s) could be irrelevant information. Students scanned each number in the problem and crosschecked the numbers with the label(s). Students deemed any numbers not referencing the label(s) as irrelevant, and students crossed out this information. Interventionists also explained to students that irrelevant information could be presented in a graph or table and directed students to check for irrelevant information in graphs, tables, and in the word problems.

Related to naming a superordinate category, interventionists discussed basic-level and superordinate terms when describing schemas. When students *N*amed the problem type, the interventionists displayed a poster entitled, “What Do You Ask Yourself?” When reading the poster, students asked the following questions with accompanying gestures to determine the problem type: Are we putting parts together for a Total? Are we comparing two amounts for a Difference? Is there a start amount that increases or decreases to a new amount? These questions helped students identify the correct schema and subsequently think about the related basic-level items described in the word problem.

Focusing on a compare sentence in Difference problems provided an additional opportunity for students to practice naming a superordinate category. Interventionists taught students the most important attribute in a Difference problem was the compare sentence. Students learned to find the compare sentence and interpret compare terms (e.g., *more, fewer, older, shorter*) to determine which quantities were greater and less and whether the difference was provided or missing. As students solved Difference problems, they circled the compare word, bracketed around the compare sentence, and labeled the greater amount (i.e., G) and lesser amount (i.e., L). These steps aided students in naming basic-level items (i.e., G and L) into a superordinate category of finding the difference between two amounts. Note, even though interventionists engaged in discussions about compare terms, interventionists never linked specific words with a specific schema, which is an ineffective word-problem practice (Powell & Fuchs, 2018).

**Shipshape Sorting.** The fourth activity each session, Shipshape Sorting, was a timed activity that allowed students to practice identifying word-problem schemas learned during the Buccaneer Problems. Interventionists set the timer for 1 min and read a word-problem card aloud before handing the card to the student and asking the student to sort the card by schema. Students determined whether the card was a Total, Difference, or Change problem. Within the timed sorting and interventionist feedback, Shipshape Sorting lasted approximately 3 min.

**Jolly Roger Review.** The final activity of each session, the Jolly Roger Review, included a brief, timed paper-and-pencil review of the session content. Students worked for 1 min to answer math facts, solve computation problems, or write appropriate equations for the three word-problem schemas. Then, students worked for 2 min to solve a word problem using the schema steps taught during the Buccaneer Problems. The interventionist provided feedback to students at the end of the 3 min for approximately 5 min of time spent on the Jolly Roger Review.

## Business-as-usual

Students in the BAU condition did not receive any intervention from our research team. These students received regular classroom mathematics instruction and may have received supplemental intervention from teachers in their school. Classroom word-problem instruction for students in the BAU condition incorporated attack strategies (e.g., RICE: Read and restate, Illustrate, Calculate, Explain and Edit), key word clues (e.g., *altogether* means *add*), and practice in applying problem-solution rules, as self-reported by participating teachers. Notably, none of the core mathematics classroom practices included schema instruction or focus on language comprehension features of word problems.

## Fidelity of Implementation

We collected fidelity of implementation in several ways. First, for pretesting and posttesting, the interventionists recorded all testing sessions. We randomly selected >20% of audio recordings for analysis, evenly distributed across interventionists, and measured fidelity to testing procedures against detailed fidelity checklists. We measured pretesting fidelity at 99%

(*SD* = 0.018) and posttesting fidelity at 99% (*SD* = 0.012).

Second, we measured fidelity of implementation of the interventions. The Project Manager conducted in-person fidelity observations once every three weeks for every interventionist. We also measured fidelity of intervention implementation through analysis of audio-recorded sessions. We audio-recorded every intervention session, and selected >20% of audio-recorded sessions for analysis, evenly distributed across interventionists. Fidelity averaged 98% (*SD* = 0.041) for in-person supervisory observations and 98% (*SD* = 0.038) for audio-recorded intervention sessions.

Third, all 15 interventionists tracked the number of sessions for their PMEQ and PM-alone students. We designed the intervention for students to finish at least 45 sessions with a maximum number of sessions at 51. The average PMEQ student completed 47.5 days of intervention (range 38 to 50 with *SD* = 1.9), and the average PM-alone student completed 47.8 days of intervention (range 40 to 50 with *SD* = 1.6).

**Internal Validity**

As described, students in the BAU condition did not receive the word-problem intervention for our research team. To control for interventionists providing intervention to students in both active word-problem conditions, the interventionists used separate color-coded packets of materials for the PMEQ and PM-alone students. During the initial trainings, we emphasized the importance of only using PMEQ strategies with students in the PMEQ condition and vice versa for PM-alone students. The lesson guides also included separate script sections for PMEQ and PM-alone students. Lastly, the in-person observations by the Project Manager ensured interventionists used the appropriate materials for each student. We did not identify any crossover mistakes during our in-person fidelity observations.

**Measures**

**Pretesting measures.** We used a measure of *Single-Digit Word Problems* as the primary measure for identifying students with MD (Jordan & Hanich, 2000). Interventionists administered this measure as the first test in the whole-class pretesting session. *Single-Digit Word Problems* included 14 one-step word problems involving sums or minuends of 9 or less categorized into the Total, Difference, and Change schemas. Interventionists read each word problem aloud and could re-read each problem up to one time upon student request. We scored *Single-Digit Word Problems* as the number of correct responses (maximum = 14). We calculated Cronbach's α on this sample as .89.

During the third and final individual pretesting session, interventionists administered the *Third-Grade Mathematics Language Assessment* (Fuchs, Powell, & Berry, 2017), a third-grade version of a first-grade language measure designed by Lynn Fuchs and her colleagues at Vanderbilt University. For the *Third-Grade Mathematics Language Assessment*, interventionists administered three subtests. On *Naming a Superordinate Category*, students provided a written superordinate category for a group of three basic-level terms (e.g., cat, hamster, dog). After the interventionist reviewed two sample problems, students worked individually for 2 to 3 min. Students received 1 point for each correct superordinate category. Cronbach's α was .87 with a maximum score of 12. On *Identifying Irrelevant Information*, students identified irrelevant numbers by crossing out numbers and words in a word problem. After the interventionist reviewed two sample problems, students worked for 2 to 3 min individually. Students earned 1 point for crossing out the irrelevant information in each problem. The maximum score was 8 with Cronbach's α was .82. On *Providing a Word-Problem Label*, students provided a written label for eight word problems; four of the prompts required a superordinate label and four required a basic-level label. After the interventionist reviewed a sample problem, students worked for 2 to 3 min individually. Students received 1 point for each correct label. We scored for correct labels with a maximum score of 8. Cronbach's α was .77.

**Posttesting.** Interventionists conducted five, 55-min posttest sessions with groups of four or fewer students. Interventionists administered the *Mathematics Language Assessment* during the fourth session. Interventionists followed identical procedures established during pretesting.

**Scoring.** Two interventionists independently entered scores on 100% on the test protocols for each outcome measure on an item-by-item basis into an electronic database, resulting in two separate databases. We compared the discrepancies between the two databases across each outcome measure and rectified any inconsistencies to reflect the original response. Original scoring reliability was 96.4% for pretesting and 99.9% for posttesting.

## Procedure

During the first week of September, interventionists administered whole-class pretesting in one, 55-min session. Identification of students with MD occurred shortly thereafter, with four weeks of individual pretesting during the last two weeks of September and the first two weeks of October. During the third week of October, approximately 4 to 6 days after pretesting, tutoring began and occurred three times per week for 16 weeks, concluding the third week in March. Approximately 4 to 6 days after the last tutoring session, posttesting occurred. Interventionists administered posttesting over four weeks, beginning the last week of March and ending the third week of April. Interventionists pre- and posttested BAU students in the same time frame as the tutored students.

## Data Analysis

We used ANOVA to identify differences among conditions at pretest. To control for pretest performance, we used ANCOVA with pretest as a covariate to determine differences among conditions at posttest. Then, we conducted post-hoc pairwise comparisons with a Bonferroni correction to understand differences between conditions at posttest. At posttest, we used a *p*-value significance threshold of $p = .01667$ (i.e., .05 / 3) to determine significance (McDonald, 2014). We calculated effect sizes (ES) using Cohen's *d* by subtracting unadjusted means and dividing by the pooled standard deviation.

In the primary manuscript from the larger study, we identified a significant sequential mediation model for students participating in PMEQ in which equal-sign knowledge mediated equation solving, which, in turn, mediated word-problem performance (Powell et al., 2019). Because the PMEQ condition demonstrated superior word-problem performance compared to students in the PM-alone and BAU conditions, we analyzed the two active tutoring conditions separately.

## Results

### Comparability at Pretest

Table 2 displays the means and standard deviations for all measures by condition. To ensure the sample of students with MD performed similarly at pretest, we conducted a one-way ANOVA with *Single-Digit Word Problems* as the outcome. We detected no significant differences among the three conditions at pretest, $F(2, 142) = 0.970$, $p = .382$.

We conducted similar analyses for each of the subtests of the *Mathematics Language Assessment* and identified no significant differences among conditions at pretest for *Naming a Superordinate Category*, $F(2, 142) = 0.949$, $p = .390$; *Identifying Irrelevant Information*, $F(2, 142) = 0.850$, $p = .430$; or *Providing a Word-Problem Label*, $F(2, 142) = 1.981$, $p = .142$.

<<Table 2 inserted here>>

**Posttest Differences**

We did not detect a significant difference among conditions on *Naming a Superordinate Category*, $F(2, 141) = 1.698$, $p = .187$. Notably, on *Identifying Irrelevant Information*, we identified a statistically significant difference among the three conditions, $F(2, 141) = 24.028$, $p < .001$. Post-hoc comparisons indicated the average posttest score for *Identifying Irrelevant Information* was significantly greater for PMEQ students ($M_{\text{diff}} = 2.28$, CI [1.34, 3.21], $p < .001$) and PM-alone students ($M_{\text{diff}} = 2.51$, CI [1.45, 3.56], $p < .001$) than for BAU students with ESs of 1.01 and 1.27, respectively. We identified no difference between PMEQ and PM-alone students.

We also noted a statistically significant difference among the three conditions on *Providing a Word-Problem Label*, $F(2, 141) = 13.591$, $p < .001$. Post-hoc comparisons indicated posttest *Label* scores were significantly greater for PMEQ students ($M_{\text{diff}} = 1.55$, CI [0.66, 2.44], $p < .001$; ES = 0.86) and PM-alone students ($M_{\text{diff}} = 1.84$, CI [0.85, 2.83], $p < .001$; ES = 0.98) than for students in the BAU. Similar to *Identifying Irrelevant Information*, we identified no difference in the posttest scores of PMEQ and PM-alone students.

We conducted an analysis on the posttest scores of the *Providing a Word-Problem Label* items requiring a basic-level or superordinate response. Four items asked for a basic-level response, and we detected no significant differences among conditions on the basic-level responses, $F(2, 141) = 2.859$, $p = .061$. Even though not significant, we calculated an ESs of 0.53 comparing PM-alone to BAU students and 0.32 comparing PMEQ to BAU students. We identified significant differences among conditions on the superordinate responses, $F(2, 141) = 15.149$, $p < .001$. In the post-hoc comparisons, PMEQ students outperformed BAU students ($M_{\text{diff}} = 1.275$, CI [0.64, 1.91], $p < .001$; ES = 0.98), and PM-alone students outperformed BAU students ($M_{\text{diff}}$ = 1.275, CI [0.56, 1.99], $p < .001$; ES = 0.90). We noted no difference between PMEQ and BAU students.

## Discussion

In this study, we investigated whether two variations of word-problem intervention implemented with third-grade students with MD led to improved word-problem language comprehension for the following features: *Naming a Superordinate Category, Identifying Irrelevant Information,* and *Providing a Word-Problem Label*. We conducted this analysis because (a) an understanding of word-problem language is a prerequisite for successful word-problem solving (Björn et al., 2016, Decker & Roberts, 2015), (b) students with MD experience difficulty transforming the text of word problems into proper problem representations (Fuchs et al., 2015), and (c) word problems require specific language comprehension above and beyond general reading comprehension (Fuchs et al., 2018).

Before investigating posttest differences, we noted no significant differences among conditions at pretest on *Single-Digit Word Problems* or any of the three subtests of the *Third-Grade Mathematics Language Assessment*. We attributed these results to the random assignment to conditions, and hence interpret any posttest differences to the implementation of intensive word-problem interventions.

For *Naming a Superordinate Category*, we did not identify significant differences among conditions. Interventionists did not explicit teach students to name superordinate categories from a set of basic-level items, but interventionists and students discussed basic-level items and superordinate categories within the context of a word problem. We hypothesized practice with identifying labels may have transferred to greater understanding of naming superordinate categories, which was not the case across the two word-problem conditions. Future research should explore whether naming superordinate labels for basic-level items serves as an important skill within mathematics problem solving, and, if so, design explicit opportunities for students to practice naming within a word-problem intervention.

In the word-problem interventions, interventionists also provided explicit instruction on identifying and crossing out irrelevant information, which led to significant differences at posttest on *Identifying Irrelevant Information* favoring the PMEQ and PM-alone students over students in the BAU. We included an explicit instructional component related to irrelevant information because irrelevant information increases the level of difficulty of a word problem (Wang et al., 2016). We embedded the focus on irrelevant information within the word-problem attack strategy (i.e., RUN) that students employed when they started to solve a word problem and construct a problem representation. In the attack strategy, students learned to crosscheck all numbers in the word problem with the label(s), and cross out any irrelevant information not corresponding with a label. By crossing out irrelevant information, students minimized the text requiring attention when constructing the problem model.

We also identified a significant difference at posttest on *Providing a Word-Problem Label* favoring students in PMEQ and PM-alone. Part of our attack strategy (i.e., RUN) encouraged students to identify a label(s), and interventionists also encouraged students to provide a word-problem label with the numerical answer to the word problem. We included an explicit focus on the label(s) of a word problem to support students in identifying relevant numbers for creating a problem representation leading to problem solution. If students understood a problem was about *desserts* before writing an equation representing the problem model and solving this equation, students focused on numbers related to desserts, even if not specifically labeled *desserts* in the problem (e.g., *pies*, *cookies*). Based on our analysis of

*Providing a Word-Problem Label* posttest scores, this instruction on label(s) improved pre- to posttest scores for students participating in the word-problem intervention.

On *Providing a Word-Problem Label*, four of the items required a basic-level response, and four items required a superordinate response. As students typically acquire knowledge about basic-level items before superordinate items (Liu et al., 2001), we explored labeling performance differences by response type (i.e., basic-level versus superordinate labeling). At pretest, the basic-level items improved the overall *Label* score. For example, of the average 3.98 score on *Providing a Word-Problem Label* for PMEQ students, the basic-level average score was 3.22, accounting for over 80% of the overall *Label* score. We noted the same pattern of results for PM-alone and BAU students. Therefore, superordinate labeling accounted for the majority of growth at posttest for PMEQ and PM-alone students. We calculated ESs of 1.08 and 1.31 for superordinate labeling growth from pre- to posttest for PMEQ and PM-alone students, respectively; BAU students demonstrated ES growth of 0.25 on superordinate labeling. Even though our word-problem interventions did not explicitly teach students about the difference between basic-level and superordinate categories, by reading and processing different schemas of word problems for 16 weeks and engaging in discussions about word-problem language with an interventionist, students became more familiar with the language, both basic-level and superordinate, of word problems.

**Limitations**

Before concluding, we note several limitations to the present study. First, students only responded to items on *Single-Digit Word Problems* and the *Third Grade Mathematics Language Assessment* using written responses. Some students may have benefitted from providing oral responses in a structured interview format. This opportunity could prove important for students with MD with comorbid reading or writing difficulty as well as English learners. Second, our *Third Grade Mathematics Language Assessment* measured word-problem language comprehension in only a few areas. Future research should target other aspects of mathematics language, such as interpretation of mathematics vocabulary, integral to the word-problem process. We also suggest investigating how readability and complexity of general English language within mathematics word problems influences word-problem performance. Third, students in the BAU did not receive supplemental intervention with regularity similar to the PMEQ and PM-alone students. Future research must investigate whether our results can be attributed to our intervention strategies and implementation or whether performance differences emerged only because we provided additional instruction beyond the general education mathematics classroom.

**Conclusion**

We designed and implemented two versions of a word-problem intervention. After implementation of the intervention, we determined word-problem language comprehension about identifying irrelevant information and providing a word-problem label improved regardless of which word-problem intervention version students received. Without the word-problem intervention, however, student understanding of specific language constructs within word problems remained similar from pre- to posttest. To adequately prepare students with MD for the language demands presented within word problems, students benefit from explicit modeling and practice related to identifying irrelevant information and providing word-problem labels.

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Table 1
*Demographic Information by Condition*

| | PMEQ ($n$ = 51) | | PM-alone ($n$ = 34) | | BAU ($n$ = 60) | |
|---|---|---|---|---|---|---|
| Variable | $n$ | (%) | $n$ | (%) | $n$ | (%) |
| Female | 32 | 62.7 | 19 | 55.9 | 35 | 58.3 |
| Race | | | | | | |
| African American | 10 | 19.6 | 2 | 5.9 | 8 | 13.3 |
| Asian American | 0 | 0.0 | 1 | 2.9 | 2 | 3.3 |
| Caucasian | 3 | 5.9 | 0 | 0.0 | 1 | 1.7 |
| Hispanic | 31 | 60.8 | 27 | 79.4 | 42 | 70.0 |
| Multi-racial | 5 | 9.8 | 4 | 11.8 | 5 | 8.3 |
| Other | 2 | 3.9 | 0 | 0.0 | 0 | 0.0 |
| School-identified disability | 8 | 15.7 | 7 | 20.6 | 4 | 6.7 |
| English learner | 31 | 60.8 | 21 | 61.8 | 37 | 61.7 |
| Retained | 4 | 7.8 | 4 | 11.8 | 8 | 13.3 |

*Note.* PMEQ = Pirate Math Equation Quest; PM-alone = Pirate Math without Equation Quest; BAU = business-as-usual comparison.

Table 2

*Pre- and Posttest Performance on Outcome Measures by Condition*

| | PMEQ ($n$ = 51) | | PM-alone ($n$ = 34) | | BAU ($n$ = 60) | |
|---|---|---|---|---|---|---|
| Measure | *M* | *SD*[a] or *SE*[b] | *M* | *SD*[a] or *SE*[b] | *M* | *SD*[a] or *SE*[b] |
| *Single-digit Word Problems* | | | | | | |
| Pretest (unadjusted) | 4.71 | 1.74 | 5.24 | 1.71 | 4.97 | 1.74 |
| *Mathematics Language Assessment* | | | | | | |
| *Naming a Superordinate Category* | | | | | | |
| Pretest (unadjusted) | 8.65 | 2.74 | 8.97 | 2.73 | 8.18 | 2.81 |
| Posttest (unadjusted) | 9.51 | 2.45 | 9.56 | 2.89 | 8.38 | 3.55 |
| Posttest (adjusted) | 9.43 | 0.34 | 9.27 | 0.42 | 8.61 | 0.32 |
| *Identifying Irrelevant Information* | | | | | | |
| Pretest (unadjusted) | 3.43 | 2.08 | 4.03 | 1.98 | 3.70 | 2.13 |
| Posttest (unadjusted) | 6.10 | 2.17 | 6.50 | 1.93 | 3.90 | 2.16 |
| Posttest (adjusted) | 6.17 | 0.29 | 6.40 | 0.35 | 3.90 | 0.26 |
| *Labeling* (overall) | | | | | | |
| Pretest (unadjusted) | 3.98 | 1.62 | 3.53 | 1.62 | 3.37 | 1.69 |
| Posttest (unadjusted) | 5.59 | 1.91 | 5.71 | 1.68 | 3.80 | 2.22 |
| Posttest (adjusted) | 5.45 | 0.27 | 5.74 | 0.33 | 3.90 | 0.25 |
| *Basic-Level Labeling* | | | | | | |
| Pretest (unadjusted) | 3.22 | 1.14 | 3.03 | 1.24 | 2.82 | 1.41 |
| Posttest (unadjusted) | 3.39 | 0.98 | 3.62 | 0.78 | 2.97 | 1.56 |
| Posttest (adjusted) | 3.33 | 0.17 | 3.61 | 0.20 | 3.02 | 0.15 |
| *Superordinate Labeling* | | | | | | |
| Pretest (unadjusted) | 0.76 | 1.14 | 0.50 | 0.83 | 0.55 | 0.85 |
| Posttest (unadjusted) | 2.20 | 1.50 | 2.09 | 1.50 | 0.83 | 1.30 |
| Posttest (adjusted) | 2.13 | 0.19 | 2.14 | 0.24 | 0.86 | 0.18 |

*Note.* PMEQ = Pirate Math Equation Quest; PM-alone = Pirate Math without Equation Quest; BAU = business-as-usual comparison.

[a]Standard deviation for unadjusted means.

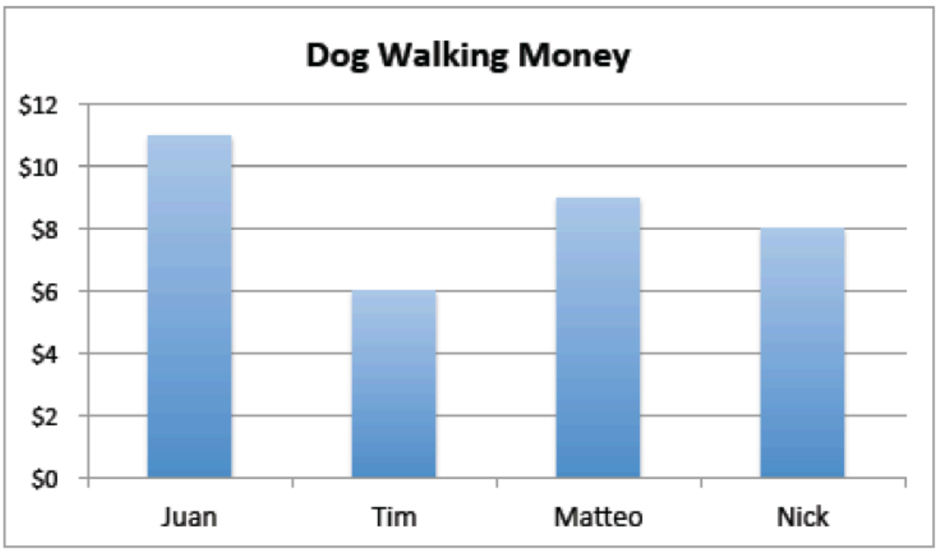
[b]Standard error for adjusted means.

**TOTAL**

The table shows the animals on Farmer Mack's farm. If he has 15 cows and horses, how many cows does he have?

| | |
|---|---|
| Horses | 7 |
| Pigs | 3 |
| Cows | |
| Goats | 2 |

**DIFFERENCE**




How much less money did Tim earn than Juan?

**CHANGE**

Molly had 12 daisies. Then, she gave some to her mom for Mother's Day. Now, Molly has 4 left. How many daisies did Molly give to her mom?

*Figure 1.* Examples of word problems from Buccaneer Problems.