Word-Problem Performance Differences by Schema:

An Analysis of Students With and Without Mathematics Difficulty

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Abstract

Word-problem features such as text complexity, charts and graphs, position of the unknown, calculation complexity, irrelevant information, and schemas impact word-problem performance. We compared the word-problem performance of typically achieving (TA) students and students with mathematics difficulty (MD). First, we measured the word-problem performance of all students for schemas and position of the unknown. Then, the performance of students with MD for schemas, position of the unknown, irrelevant information, and charts or graphs. Across schemas, while TA students outperformed students with MD, all students typically scored higher on Change and Difference problems than Total problems. For position of the unknown, students often scored highest on problems with the final position unknown. Students with MD also demonstrated higher scores on problems with irrelevant information than charts and graphs. Although patterns emerged, not all problems followed the same trends, suggesting further research should investigate the impact of word problem features on word-problem accuracy.

Keywords: irrelevant information, position of the unknown, schemas, word problems

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In the United States, students demonstrate mathematics proficiency by solving mathematical word problems (Powell et al., in press). We define a *word problem* as a mathematics problem embedded within written text. Although students solve word problems in the early elementary grades (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), the formal measurement of mathematics through word-problem solving typically begins in Grade 3 (Powell et al., in press). For many students, word-problem solving proves challenging (Van Dooren et al., 2010), especially for students with mathematics difficulty (MD; Freeman-Green et al., 2015; Griffin et al., 2018).

In this study, we analyzed the word-problem performance of a representative sample of third-grade students. On a word-problem measure with 8 items, we examined whether the schema of a word problem impacted responses. We also examined whether other features of word problems, such as position of the unknown, influenced correct response rates. We compared typically-achieving students (TA) to students with MD on these 8 items. Then, we conducted a similar analysis on 13 novel word-problem items and investigated the performance of students with MD (without a comparison to TA). In this introduction, we discuss MD. Then, we review the word-problem schemas and describe several factors within word problems that may increase complexity. Finally, we present the purpose of the study and the research questions.

Mathematics Difficulty

Students with MD typically perform below TA students across mathematics skills. Students with MD make more errors than students with TA students in early numeracy skills such as counting fact retrieval, number-set identification, mathematics fact fluency, place value, and understanding mathematics operation signs (Andersson, 2010; Cirino et al., 2015; Geary et al., 2007). Students with MD also perform below TA students on multi-digit calculation tasks, approximation calculation tasks, and telling time (Andersson, 2010; Fuchs et al., 2005). In word-problem solving, students with MD, compared to TA students, experience higher rates of difficulty in mathematics language and word-problem tasks (Andersson, 2010; Cirino et al., 2015; Fuchs et al., 2005; Swanson & Sachse-Lee, 2001; Toll & Luit, 2014).

Not only do students with MD exhibit intensive mathematics needs, but they also tend to demonstrate lower scores on phonological awareness, working memory, nonverbal intelligence, nonverbal problem solving, and attention tasks than TA students (Barnes et al., 2020; Fuchs et al., 2005). Students at risk for MD also experience lower reading skills than students not at risk for MD (Barnes et al., 2020). Furthermore, students with MD experience higher rates of ADHD and social difficulty than TA students (Willcutt et al., 2013; Willcutt et al., 2019).

MD impacts a variety of students across grades and demographic profiles (National Center for Education Statistics, 2019). Across the United States, MD is particularly prominent for Black and Hispanic students. In fourth grade, while 52% of White students, 69% of Asian students, and 44% of multi-racial students performed at or above proficiency in mathematics, only 20% of Black students and 28% of Hispanic students performed at or above proficiency (National Center for Education Statistics, 2019). Similarly, in fourth grade, while 44% of monolingual English speakers performed at or above proficiency in mathematics, only 16% of English learners performed at or above proficiency in mathematics (National Center for Education Statistics, 2019).

In sum, students with MD may exhibit lower performance on mathematics tasks, and MD may be attributable to mathematics skills, demographics, or other factors. Students with MD may experience difficulty with many mathematics tasks but particularly word-problem solving. In the next section, we focus on word problems and the categorization of word problems by schema.

Word-Problem Schemas

As defined by Marshall (1995), a schema acts as “a vehicle of memory” that allows for a student to organize similar experiences in a way that can translate to other similar experiences (p. 39). We define a schema as the underlying conceptual structure within a word problem, and that schema can be used to solve word problems with a similar structure. Recognizing common schemas provides less stress for students’ cognitive load (Kalyuga et al., 1998). In the literature, three common schemas represent addition and subtraction word problems: Change, Difference, and Total (Carpenter et al., 1981). Students often learn the fundamentals of these schemas in kindergarten (e.g., putting together, comparing, adding on, taking away; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and then learn more complex varieties of each schema as they progress through the elementary grades.

With the Change schema, students have a start amount that changes to a new result. There are Change problems that feature an increase in the change. These may also be named *join* problems (Steinberg, 1985). Similarly, there are Change problems that show a decrease in the change. These may be called *separate* problems (Steinberg, 1985). In Change word problems, as demonstrated in Tables 2 and 3, the unknown may be the start amount, the change amount, or the end amount. Starting in Grade 3, many Change problems have more than one change. With the Difference schema, students compare a greater amount to a lesser amount for a difference. The Difference schema may be referred to as *compare* (Riley & Greeno, 1988) or *comparison* (Carpenter et al., 1981). Tables 2 and 3 model Difference word problems. In Difference word problems, the unknown may be the difference, the greater amount, or the lesser amount. With the Total schema, students have parts that are put together for a total. The Total schema may also be named the *part-part-whole* schema (Carpenter et al., 1981) or the *combine* schema (Riley & Greeno, 1988). As demonstrated in Tables 2 and 3, in a Total word problem, the unknown may be the total or the unknown may be one of the parts. Starting in Grade 3 (ages 8 to 9), many Total problems feature more than two parts.

When students recognize a word problem as belonging to a familiar schema (e.g., this is a Total problem), they can use a learned schema strategy to solve the problem. Schema strategies include using a schema equation (Fuchs et al., 2014; Powell et al., 2021) and/or a graphic organizer (Cox & Root, 2020; Jitendra et al., 2007; Peltier et al., 2021) to represent the information from the word problem. This equation or organizer can then help students solve the word problem by helping them organize the relevant information from the problem and ignore irrelevant information. An understanding of the common schemas in word problems can contribute to improved word-problem performance for elementary students, both TA and those with MD (Cook et al., 2020; Jitendra et al., 2015; Peltier & Vannest, 2017).

With the three schemas representing different conceptual meanings, researchers have investigated student performance across the three additive schemas. With 7- to 9-year-old students in Spain, Garcia et al. (2006) noted students demonstrated higher performance on Total and Change problems compared to Difference problems. Gvozdic and Sander (2020) noted a similar pattern with students ages 6 and 7 in France. With 8- and 9-year-old students in the United States, Powell et al. (2009) noted similar performance across the Change, Difference, and Total schemas for TA students and students with MD. In each of these analyses, authors compared performance across schemas but authors did not analyze other factors that could influence word-problem performance. In the following section, we describe several factors that could increase the complexity of setting up and solving word problems.

Possible Factors Contributing to Word-Problem Complexity

Word-problem solving may challenge students because of the multiple skills used to solve a word problem (Powell, 2011). Solving a word problem correctly involves execution of a number of steps to interpret the problem, make a plan, and solve the problem (Björn et al., 2016). Word-problem performance may be impacted by reading and language skill (Fuchs et al., 2015). Researchers have explored the influence of reading and language on word-problem performance in many other studies.

In the present study, we focused on factors within a word problem that could contribute to the complexity of the word problem. Several contributing factors include irrelevant information, text complexity, visuals, position of the unknown, and calculation complexity (Pongsakdi et al., 2019; Powell et al., 2009; Wang et al., 2016). Beyond the reading of the problem, these factors could contribute to the difficulty level of a word problem and the likelihood of solving the problem successfully.

Irrelevant information is information in the word problem that is unnecessary to solve the problem correctly. Types of irrelevant information include irrelevant linguistic information, irrelevant numerical information, and irrelevant charts or graphs. Students have greater difficulty solving word problems with irrelevant information (Flores et al., 2016; Ng et al., 2017). Often, students use all of the relevant and irrelevant numerical information presented in the word problem rather than exclusively using only the relevant numerical information (Flores et al., 2016). Furthermore, students with MD struggle with identifying irrelevant information within a word problem (Passolunghi et al., 1999). Problems with irrelevant information call on students to activate word-problem knowledge, calculation fluency, listening recall, language, and nonverbal reasoning (Wang et al., 2016). Unnecessary numerical information also increases word-problem difficulty for students who experience difficult with working memory (Swanson et al., 2015). Students make more errors when the distracting information is unrelated to the main story (Jarosz & Jaeger, 2019). Most findings suggest that irrelevant information influences the complexity of a word problem (Wang et al., 2016), yet this is not universally accepted. For example, Pongsakdi et al. (2019) determined irrelevant linguistic and mathematical information made no difference for word-problem complexity.

Several word-problem elements can influence *text complexity*, leading to potential impacts on word-problem accuracy. First, students need to understand complex technical vocabulary specific to mathematics (e.g., *trapezoid* or *perimeter*) and vocabulary used in common English but using a specific mathematics definition (e.g., *increase* or *difference*). Second, students must understand grammatical structures within the text of the word problem because complex mathematical noun phrases can differ from common use (e.g., *place* or *product*; Schleppegrell, 2007). Third and fourth, the number of words or the number of pronouns within a word problem may affect text complexity (Walkington et al., 2018). For example, word problems with higher rates of pronouns (e.g., *they* or *it*) contributed to greater word-problem accuracy (Walkington et al., 2018). One common strategy students use to solve word problems is linking a keyword (e.g., *altogether*) with a specific operation (e.g., *altogether* means to *add*; Karp et al., 2019), yet, this strategy does not lead to a correct problem solution most of the time (Powell et al., in press). This keywords strategy also can contribute to text complexity.

Inclusion of *visuals* may impact word-problem solving. Dean and Malik (1986) compared performance on Change problems presented with text or pictures. On average, students performed higher on the problems presented with pictures. Driver and Powell (2015) noted the same when comparing equation-solving performance with pictures and without pictures. Students demonstrated significantly higher scores on items with pictures, and this pattern of performance held for TA students and students with MD. While many other researchers have administered word-problem measures with pictures or charts and graphs (e.g., Fuchs et al., 2008; Goodrich & Namkung, 2019; Jitendra et al., 2007), we identified no other studies in which authors analyzed the impact of visuals.

Position of the unknown within a word problem may contribute to the complexity of a word problem. When solving equations, students perform higher on equations with an unknown sum or difference than on equations with an unknown addend, minuend, or subtrahend (Powell et al., 2016). The same holds true for word problems. For example, both Garcia et al. (2006) and Powell et al. (2009) determined word problems with an unknown sum or difference had a greater likelihood of a correct response than word problems with the unknown in other positions. Problems with the unknown terms at the beginning of the problem tend to be more complex than problems with the unknown quantity at the end of the problem (Garcia et al., 2006). In both of these studies, the authors compared the performance of TA students and students with MD. On average, more TA students solved the word problems correctly, but the patterns related to position of the unknown remained the same between TA students and students with MD.

Calculation complexity may be another factor that contributes to the complexity of word problems. Many students may write an equation and add, subtract, multiply, or divide to answer the word-problem prompt. We located no studies in which authors examined calculation complexity, but we pose this as a potential challenge within word-problem solving because of performance patterns students have demonstrated when solving equations. Students tend to have higher accuracy rates on problems with addition calculation than subtraction calculation (Nelson & Powell, 2018). Additionally, students also tend to perform lower on calculation problems with regrouping compared to problems without regrouping as well as on calculation problems with multiple digits in each number compared to single digits (Cawley et al., 1996; Nelson & Powell, 2018). When considering the calculation performance of students with MD, this group of students has demonstrated lower correct rates of response than students without such difficulty (Cawley et al., 1996; Chong & Siegel, 2008; Mabbott & Bisanz, 2008; Tolar et al., 2016); therefore, calculation complexity within word-problem solving may impact students with MD more than students with TA.

Purpose and Research Questions

For this study, we examined how schemas impacted student performance on word problems. We also examined how position of the unknown, irrelevant information, and charts and graphs impacted student performance on word problems.

1. Is there a difference in word-problem performance between TA students and students with MD?
2. Are there similar trends in success rates between TA students and students with MD when analyzing problems by schema type and position of the unknown?
3. What is the success rate of solving word problems by schema type, position of the unknown, irrelevant information, and charts and graphs for students with MD?

Method

Context and Setting

We collected the data for this analysis across three cohorts of Grade 3 students in the 2015-16, 2016-17, and 2017-18 school years. The data we collected for this analysis comprised a portion of the screening and pretesting data collection for a larger intervention study (Powell et al., 2021). All students attended one of 26 elementary schools in a large, urban public school district in the Southwest of the United States. This public school district served over 80,000 students. On average, the district reported 55.5% of students as Hispanic, 29.6% as White, 7.1% as African American, and 7.7% as belonging to another race or ethnic category. Overall, 27.1% of students identified as dual-language learners, 52.4% qualified as economically disadvantaged, and 12.1% received special education services. The district's graduation rate was 90.7%. Before conducting this study, we received approval from our university's Institutional Review Board and the school district's office of research and evaluation.

Participants

The participants in this analysis were all third-grade students who participated in screening and pretesting for an intervention study about word-problem solving. We collected all of this data before the intervention; therefore, this data represents typical word-problem performance of students in general education mathematics classrooms. In the intervention, we provided word-problem instruction to students with MD (Powell et al., 2021). To determine the group of students with MD, we administered a screening session to all students with consent (N = 2,841) in September of the school year. During this screening session, we administered *Single-Digit Word Problems* (Jordan & Hanich, 2000) and *Texas Word Problems – Brief*, the first measure used in this analysis (Powell & Berry, 2015). We identified students with MD as performing below a cut-score of 7 points (out of 14) on the *Single-Digit Word Problems* measure. This cut-off score of 7 represented performance at or below the 25th percentile, and we determined this cut-off score by analyzing performance within this sample of students. The 25th percentile is a common cut-off score in research related to MD (Geary et al., 2012; Hecht &

Vagi, 2010). Then, we administered two more word-problem measures (*Texas Word Problems – Part 1* and *Part 2*; (Powell & Berry, 2015) to the 692 students with MD, the second measure used in this analysis.

Table 1 shows the demographics of the students. We were unable to collect full demographic information from one of the cohorts; therefore, we display some demographic information as not reported.

Measures

For identifying students with MD, we used *Single-Digit Word Problems* (Jordan & Hanich, 2000). This is a researcher-created measure that was not developed by our research team. This measure has been widely used over the last two decades (Branum-Martin et al., 2012; Fuchs et al., 2018; Wang et al., 2016). *Single-Digit Word Problems* included 14 one-step word problems involving sums or minuends of 9 or less categorized into the Change, Difference, and Total schemas. Examiners 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 for the full sample at .88 (Powell et al., 2021).

We administered three additional measures of word-problem solving. We administered the *Texas Word Problems – Brief* to all students, and we administered the *Texas Word Problems – Part 1* and *Part 2* to students with MD. In this study, we analyzed student performance on the *Texas Word Problems – Brief* and the *Texas Word Problems – Part 1* and *Part 2*.

Texas Word Problems – Brief

The *Texas Word Problems – Brief* included eight additive schema word-problem questions requiring two-digit addition and subtraction calculations. We classified the problems into Change, Difference, and Total problems based on the additive schemas recommended by Kintsch and Greeno (1985). The eight-problem measure included four Change problems, three Difference problems, and one Total problem.

Table 2 lists each problem according to schema and position of the unknown. The Change problems consisted of two Change increase problems and two Change decrease problems. One Change increase problem had a start amount unknown and the second Change increase problem had an end amount unknown. One Change decrease problem featured a start amount unknown and the other Change decrease problem featured a change amount unknown. The Difference problems consisted of one problem with the greater amount unknown, one problem with the lesser amount unknown, and one problem with the difference unknown. The one Total problem consisted of a part unknown. All problems were one-step word problems that did not include irrelevant information or charts or graphs. Problem word length ranged from 18 to 34 words and numbers, and students had to interpret mathematics language in each of the problems (e.g., *more*, *fewer*, *now*, and *start*). In the eight word problems, five of the problems required regrouping to accurately complete the calculation.

The measure was printed on two pages with four problems on each page with a space below each problem for students to solve the problem and a dark horizontal line separated each problem. Students either scored a zero (incorrect response) or a one (correct response) on each problem. The total score was out of eight with each problem worth one point. Cronbach's α on the sample of all students who took the *Texas Word Problems – Brief* was .80.

Texas Word Problems – Part 1 and Part 2

The *Texas Word Problems – Part 1* and *Part 2* included 18 additive and multiplicative schema word-problems requiring two-digit addition and subtraction calculations or multiplication and division calculations. For our analysis, we focused on the 13-additive single-step word problems on the *Texas Word Problems – Part 1* and *Part 2*. The assessments also included four two-step additive word problems and one single-step multiplicative word problem.

The 13 single-step additive schema word problems consisted of six Change problems, three Difference problems, and four Total problems. Table 3 lists each problem according to problem type and position of the unknown. The six Change problems included three Change increase problems and three Change decrease problems. In the three Change increase problems, one problem featured a start amount unknown, one problem had a change amount unknown, and one problem had an end amount unknown. The Difference problems consisted of one problem with a greater amount unknown, one problem with a lesser amount unknown, and one problem with a difference unknown. In the four Total problems, one problem featured a total unknown and three problems featured a part unknown. Additionally, six of the single-step additive schema problems included charts or graphs and five included irrelevant information. Four of which included both irrelevant information and charts or graphs. Problem word length ranged from 17 to 32 words and numbers, with many problems involving interpretation of mathematics language (e.g., *risen, total, fewer,* and *more*). In the 13 word problems, five of the problems required regrouping to accurately complete the calculation.

Participants completed the *Texas Word Problems – Part 1* on one day and the *Texas Word Problems – Part 2* on a second day. The two parts of the assessment each included nine problems with two problems on each page, except the last page had one problem. A blank area below each problem provided space for the students to solve the problem, and a dark line separated each problem. The total score was out of 18 with each problem worth one point. Students either scored a zero (incorrect response) or a one (correct response) on each problem.

Cronbach's α on the sample of students with MD who took the pretest for the 13 single-step additive schema problems in the *Texas Word Problems – Part 1* and *Part 2* was .54.

Procedure

Examiners employed as graduate research assistants administered all screening and pretesting sessions before the beginning of the intervention. Examiners received training on administration of the tests during two, 2-hour sessions conducted in early September of the school year. Before administering the measures to students, examiners practiced with one another and conducted a practice testing session with the project manager.

Examiners administered the screening in whole-class sessions with classrooms of Grade 3 students prior to the start of the intervention. During a screening session administered in mid-September, all students answered questions on the *Texas Word Problems – Brief* assessment. Then, students classified as MD participated in the *Texas Word Problems – Part 1* and *Part 2* during two separate pretesting sessions during September and October prior to the start of the intervention. Examiners conducted these testing sessions individually with each student. All testing sessions occurred within a 7-week window. Although the data from the *Texas Word Problems – Brief* and *Texas Word Problems – Part 1* and *Part 2* were part of a larger study (Powell et al., 2021), we collected all of this data before the initiation of the intervention.

Fidelity of Test Implementation

At pretesting, examiners recorded all testing sessions. We randomly selected 19.90% of audio recordings for analysis, evenly distributed across examiners, and measured fidelity to testing procedures against detailed fidelity checklists. We measured pretesting fidelity at 98.50% (*SD* = 0.03).

Data Analysis

We used SPSS to calculate the means and standard deviations for all students, students with TA, and students with MD across the *Texas Word Problems – Brief* and *Texas Word Problems – Part 1* and *Part 2*. For the *Texas Word Problems – Brief*, we measured the means and standard deviations across the three additive schemas and for each individual problem. We followed the same procedure for all students (N = 2,841). Then, we ran the analysis again with the students categorized as: TA (n = 2,149) and MD (n = 692). We compared TA versus MD using ANOVA and calculated Cohen's d for effect sizes. For the *Texas Word Problems – Part 1* and *Part 2*, we conducted the data analysis for all the students with MD who took the assessment (n = 692). We calculated the means and standard deviations for all problems with charts and graphs, and all problems with irrelevant information.

Results

Results included the means and standard deviations for each individual problem and across schema category: Change, Difference, and Total.

TA Students and Students with MD: Schemas and Position of the Unknown

With the first two research questions, we examined differences in word-problem performance between TA students and students with MD. We investigated whether similar trends in success rate occur between TA students and students with MD by schema type and position of the unknown. Table 2 features the means and standard deviations by schema and for each individual problem on the *Texas Word Problems – Brief*. Table 2 also provides data about the comparisons for TA versus MD. The *Texas Word Problems – Brief* results addressed student accuracy based on schema and position of the unknown information for TA students and students with MD.

For all students, Change (*M* = 0.45) and Difference (*M* = 0.43) problems resulted in a comparable difficulty level. All students performed lower on the one Total problem (*M* = 0.25). The TA students performed higher than the students with MD across schemas. TA students exhibited the same accuracy rates for both Change and Difference problems (*M* = 0.53). The TA students performed lower on the Total problem (*M* = 0.32) than the Change and Difference problems. The students with MD also scored higher on the Change (*M* = 0.18) and Difference problems (*M* = 0.15) than on the Total problem (*M* = 0.03).

Across all four Change problems, TA students outperformed students with MD, with an overall effect size (ES) of 1.33 and ESs for individual problems between 0.48 to 1.09. When examining which Change problems were easier for students, TA students and MD performed higher on Change problems with the change and end amount unknown than on problems with the start amount unknown. In fact, TA students performed at the same level for the Change increase problem with the end amount unknown and the Change decrease problem with the change amount unknown (*M* = 0.71). Students with MD performed slightly higher on the Change increase with the end amount unknown (*M* = 0.29) than on the Change decrease problem with the change unknown (*M* = 0.23). All students demonstrated lower performance on two Change problems with an unknown start amount.

Across the three Difference problems, TA students demonstrated a significant advantage compared to students with MD with an overall ES of 1.36 and ESs ranging from 0.70 to 1.26 across the individual problems. TA students and students with MD scored higher on problems with a greater and lesser amount unknown than on problems with a difference unknown. The TA students performed highest on the Difference problem with the greater amount unknown (*M* = 0.69) and slightly lower on the problem with the lesser amount unknown (*M* = 0.58). The students with MD also scored the highest on the Difference problem with the greater amount unknown (*M* = 0.36) and lower on the problem with the lesser amount known (*M* = 0.08).

On the *Texas Word Problems – Brief*, there was one Total problem. TA students outperformed students with MD (ES = 0.83). With only one Total problem, the difficulty level between Total problems based on position of the unknown could not be determined. On this problem, with an unknown part, the TA students performed higher (*M* = 0.32) than the students with MD (*M* = 0.03).

Students with MD

With the third research question, we examined the success rate of solving word problems by schema type, position of the unknown, irrelevant information, and charts or graphs for students with MD.

Schemas and Position of the Unknown

Table 3 features the means and standard deviations by schema and for each individual problem for the students with MD on the *Texas Word Problems – Part 1* and *Part 2*. First, we measured performance by schema and position of the unknown. Students with MD performed similarly on the Change (*M* = 0.26) and Difference problems (*M* = 0.24). The students with MD performed the lowest on the Total problems (*M* = 0.08).

Within Change problems, performance differed based on type of change and position of the unknown. Students with MD performed lower on the Change increase problems than the Change decrease problems. For the Change decrease problems, the students with MD scored the same on the problem with an end amount unknown and change amount unknown (*M* = 0.48). Students performed lower on the Change decrease problem with the start amount unknown (*M* = 0.29). For the Change increase problems, the students with MD performed highest on the problem with the end amount unknown (*M* = 0.26) and lower on the problem with a start amount unknown (*M* = 0.04). The students with MD performed the lowest on the Change increase problem with the change amount unknown (*M* = 0.02).

For Difference problems, the students with MD performed higher on problems with greater and lesser amounts unknown than problems with the difference unknown. The students with MD scored the highest on the problem with the greater amount unknown (*M* = 0.47). They performed lower on the problem with the lesser amount unknown (*M* = 0.22) and the lowest on the problem with the difference unknown (*M* = 0.04).

For the Total problems, students with MD typically performed lower on problems with a part unknown. The students with MD scored the lowest on two problems with the parts unknown (*M* = 0.02, 0.01). They scored higher on the problem with the total unknown (*M* = 0.10) and the highest on one problem with a part unknown (*M* = 0.18).

Irrelevant Information and Charts or Graphs

We also used the *Texas Word Problems – Part 1* and *Part 2* to measure performance of students with MD on problems with irrelevant information, charts and graphs, or both. On average, students with MD performed higher on problems without irrelevant information or charts and graphs (*M* = 0.28) compared to problems with irrelevant information, charts and graphs, or both irrelevant information and charts and graphs (*M* = 0.13).

When analyzed by problems with irrelevant information, charts and graphs, or both, students with MD performed the highest on the two problems with only irrelevant information (*M* = 0.31). They performed lower on problems with both irrelevant information and graphs or charts (*M* = 0.04). The students with MD performed the lowest on the one problem with only a graph or chart (*M* = 0.02).

When we analyzed by individual problem, the students with MD still performed higher on the two problems with only irrelevant information than the problems with charts and graphs or both irrelevant information and charts and graphs. On one of the problems with irrelevant information (Change decrease with an end amount unknown), the students with MD scored an average accuracy rate of 0.48. On the second problem with irrelevant information (Change increase with an end amount unknown), the students with MD scored an average accuracy rate of 0.26. For the problem with only a chart or graph, the students with MD scored an average accuracy rate of 0.02 (Total with a part unknown). For the four problems with irrelevant information and a chart or graph, the students with MD scored average accuracy rates of 0.10 (Total with a total unknown), 0.04 (Difference with a difference unknown), 0.02 (Change increase with a change amount unknown), and 0.01 (Total with a part unknown).

Discussion

Schemas, position of the unknown, irrelevant information, and charts and graphs (Garcia et al., 2006; Powell et al., 2009; Wang et al., 2016) all have the potential to impact student scores while solving word problems. First, in our analysis, we measured word-problem performance for TA students and students with MD. Second, we compared the performance of TA students and students with MD on word problems based on schema and position of the unknown. Third, we measured performance of students with MD on word problems by schema type, position of the unknown, irrelevant information, and charts and graphs. Schema type alone cannot determine word-problem difficulty level (Garcia et al., 2006; Krawec, 2014), so in examining position of the unknown, irrelevant information, and charts and graphs, we attempted to build a better understanding of the word-problem features challenging TA students and students with MD.

Although patterns emerged, not all problems followed the observed patterns. This likely occurs due to the individual factors unique to each problem (Pongsakdi et al., 2020).

TA Students and Students with MD

Schemas

We first compared performance on word problems for TA students and students with MD. The TA students outperformed the students with MD on all word problems, with ESs ranging from 0.48 to 1.26. These results coincide with previous research indicating that TA students outperform students with MD on all word-problem types (Kingsdorf & Krawec, 2014; Pongsakdi et al., 2020). The difference in performance between TA and MD may be due to TA students using more advanced word-problem processing strategies, such as paraphrasing strategies and visually representing relevant information (Krawec, 2014).

For schema type, when categorized as TA students and students with MD, students in both groups performed higher on Change and Difference problems than on the Total problem. These findings build on past research. Although Garcia et al. (2006) determined that schema structure alone did not distinguish word-problem difficulty, they measured Change problems to be different from the other problem types. Our findings differ from those of Garcia et al., with the TA students and students with MD scoring comparably on Change and Difference problems and lower on the Total problem.

Along with word-problem schemas, we also measured performance for TA students and students with MD based on position of the unknown for each word problem. For TA students and students with MD, we only compared performance based on position for Change and Difference problems because the *Texas Word Problems – Brief* included only one Total problem.

Position of the Unknown

The TA students outperformed the students with MD when analyzing word-problem accuracy rate based on position of the unknown. Yet, TA students and students with MD exhibited the same patterns of performance regarding position of the unknown. Both TA students and students with MD performed lower on Change problems with a start amount unknown than on Change problems with either a change or end amount unknown. These results coincide with previous conclusions that problems with an unknown in the first place (i.e., the start amount unknown) challenge students more than problems with the second or final position unknown (Garcia et al., 2006). The same pattern occurs for solving calculation problems: equation performance is related to position of the unknown and position of the solution (Weaver, 1973).

For Difference problems, the TA students and students with MD performed higher on problems with a greater or lesser amount unknown than problems with a difference unknown (i.e., the final position). Therefore, the pattern of TA students and students with MD scoring lowest on problems with the difference unknown contradicts the pattern observed for Change problems and previous research (Garcia et al., 2006). Although the pattern may be due to how students interpret problems with a difference unknown, this pattern more likely occurs due to the other features of the problem.

Other features that may have impacted student performance on the Difference problem with the difference unknown that we did not measure include irrelevant information (Wang et al., 2016), text complexity (Schleppegrell, 2007; Walkington et al., 2018), or calculation complexity (Nelson & Powell, 2018). Beyond these factors, other components of each of the word problems may contribute to the difficulty level of the word problem. For example, in our prior research we noted many students employ a word-problem strategy of taking two numbers presented in the problem and adding the numbers together (Powell et al., 2020). In our analysis of the eight word problems, we noted the two highest scores (*M* = 0.61) for problems in which addition of the two numbers in the problem would lead to a correct problem solution (59 + 34 for the problem about Alfred; 23 + 14 for the problem about the library).

This theory does not align with the problem with a *M* of 0.59 about Jack (38 – 14) or the problem about the grocery store (74 – 22) with a *M* of 0.46. However, both of these problems in which students could subtract for a correct problem solution featured clear language signaling subtraction: *bought* for Jack's problem and *fewer* for the grocery store problem. As many students look to keywords to determine which operation to use in a word problem (Karp et al., 2019), word problems with a keyword that students can link to a specific operation (e.g., *fewer* means to subtract) could be easier than problems in which the keyword does not lead to a correct problem solution. As noted by Powell et al. (in press), keywords tend to work in single-step simpler problems but do not lead to successful problem solving on multi-step problems.

Students with MD

Schemas

For students with MD, we examined word-problem performance based on schemas, position of the unknown, irrelevant information, and charts and graphs. For schemas, the students with MD demonstrated the same pattern on the *Texas Word Problems – Part 1* and *Part 2* as all the students exhibited on the *Texas Word Problems – Brief.* The students with MD performed comparably on the Change (*M* = 0.26) and Difference (*M* = 0.24) problems and lower on the Total problems. Within the Change problems, the students performed higher on the Change decrease problems than on the Change increase problems. These results slightly differ from previous research indicating that students with MD achieve higher on Change problems than Difference problems, and students with MD performed comparably on Difference and Total problems (Powell et al., 2009). The results do align with previous reports that students perform considerably higher on Change problems than Total problems (*M* = 0.08). Due to the limited amount of previous research examining performance rates across schemas (Garcia et al., 2006; Powell et al., 2009), these results add clarification that Change problems differ from Total problems. The inconsistency of Difference problems in this analysis from previous research may demonstrate that students with MD truly struggle more with Total problems than Difference problems. Alternatively, the patterns we measured with Difference problems may be due to other features in the sampled word-problems.

Position of the Unknown

For position of the unknown, the patterns varied based on schema, demonstrating that position of the unknown may interact with schemas to impact problem difficulty for students with MD. For Change increase and decreases problems, students with MD performed higher on problems with an end amount unknown than on problems with a start amount unknown. Students with MD performed highest on the problem with an end amount unknown (*M* = 0.26) and lower on the problems with the start amount unknown (*M* = 0.04) and change amount unknown (*M* = 0.02). Alternatively, for the Change decrease problems, students with MD performed at the same level for the problem with a change amount unknown (*M* = 0.48) and the problem with an end amount unknown (*M* = 0.48). These patterns indicate that students performed higher on problems with the end amount unknown (i.e., final position) than problems with the start amount unknown (i.e., first position) coincide with student performance on the *Texas Word Problems – Brief* and previous research stating that students perform lower on problems with the first position unknown than the final position unknown (Garcia et al., 2006; Powell et al., 2009). Yet, the Change problems with a change unknown did not always follow this pattern. This variation likely occurs because of other word-problem features within the problem, such as charts and graphs or language (Karp et al., 2019). Students with MD scored lower on the change increase problem with the change unknown ($M = 0.02$) than on any other change problem. This likely occurred due to the chart presented along with the word-problem text. Alternatively, the students performed comparatively on the change decrease problem with the change unknown ($M = 0.48$) as on the change decrease problem with the end unknown. In fact, performance on these two problems was the highest on the assessment. This change decrease with an unknown change problem included clear language representing subtraction in the problem: *gave/give* (*give* means subtract). Similar to student performance on the *Texas Word Problems – Brief*, students with MD might be utilizing the keyword strategy (Karp et al., 2019).

For Total problems, students with MD typically performed lower on the problems with a part unknown (i.e., first and second position) than with a total unknown (i.e., final position). For all but one Total problem, the students with MD performed lower on the problems with a part unknown ($M = 0.01$; 0.02, 0.18) than the problem with a total unknown ($M = 0.10$), indicating that problems with a part unknown challenge students more than problems with a total unknown. These results aligned with the previous trends with students performing lower on problems with the first position unknown than problems with the unknown in the second or final position (Garcia et al., 2006; Powell et al., 2009). The one Total problem with a part unknown in which students scored higher than the problem with the total unknown likely occurred because the problem about Donna and Natasha with a part unknown was the only Total problem without irrelevant information or a chart or graph. This aligns with previous research reporting that students perform lower on word problems with irrelevant information than on word problems without irrelevant information (Flores et al., 2016; Ng et al., 2017).

For the Difference problems, students with MD performed the highest on the problem with the greater amount unknown (i.e., first position; $M = 0.47$), slightly lower on the problem with the lesser amount unknown (i.e., second position; $M = 0.22$) and the lowest on the problem with the difference unknown (i.e., final position; $M = 0.04$). These results coincided with the results for TA students and students with MD on the *Texas Word Problems – Brief*. Although this contradicts previous research (Garcia et al., 2006; Powell et al., 2009), it may indicate that position of the unknown pairs with the other word-problem features. For instance, students with MD performed the lowest on the problem with the difference unknown, but this problem also involved irrelevant information and a graph (Wang et al., 2016). Additionally, students performed highest on the difference problem with the greater amount unknown ($M = 0.47$). This was also one of the highest scores across the assessment. In the difference problem with the greater amount unknown, addition of the two numbers would lead to the correct problem solution (24 + 45). This aligns with student scores on the *Texas Word Problems – Brief* and our prior research indicating the tendency for students to add the two presented numbers together (Powell et al., 2020).

Irrelevant Information and Charts or Graphs

Seven of the 13 single-step word problems *Texas Word Problems – Part 1* and *Part 2* included irrelevant information, charts and graphs, or both. Students with MD performed higher on the problems without irrelevant information and charts and graphs than problems with these features. This aligns with previous research where students performed higher on problems without irrelevant information than on problems with irrelevant information (Flores et al., 2016; Ng et al., 2017).

We also examined whether irrelevant information, charts and graphs or both challenged students with MD the most. The students with MD performed the highest on the problems with irrelevant information only. They performed lower on the problems with charts and graphs or both irrelevant information and charts and graphs. The presence of irrelevant information and charts and graphs may impact students' need to activate word-problem knowledge and nonverbal reasoning skills (Wang et al., 2016). Past research has not investigated the impact of charts and graphs on word-problem performance, but the findings here indicate that students perform lower on problems with charts and graphs than on problems with irrelevant information. Charts and graphs may add an extra strain on word-problem knowledge, calculation fluency, and nonverbal reasoning (Wang et al., 2016) because charts and graphs provided multiple pieces of information.

Implications for Research and Practice

Researchers should continue to investigate differences between TA students and students with MD across different types of word problems. Such investigations will lead to a stronger understanding of the patterns observed in this analysis for student performance in schema type, position of the unknown, irrelevant information, and charts and graphs. Although further research will enhance the understanding of how TA students and students with MD perform across word problems, from our current research we can make several recommendations for practice.

First, we demonstrated that TA students outperformed students with MD on word-problem tasks. Therefore, it is important to provide targeted instruction in word-problem solving to students with MD (Fuchs et al., 2021). Second, we determined that students with MD show variations in performance based on schema type, but their performance is consistently low across schema types. Their performance across schemas suggests that students with MD need to practice all schema types rather than focusing more on one type versus another. Third, for position of the unknown, our analysis indicated that, generally, TA students and students with MD demonstrated greater success on problems with the unknown in the final position. This trend indicates that both TA students and students with MD would benefit from practicing equations and word problems where they must find the unknown in the first or second position of standard equations (e.g., 3 + __ = 12; Powell et al., 2021; Powell & Fuchs, 2010). Fourth, students with MD performed lower on problems with irrelevant information or charts and graphs. These results indicate it is important for students to practice identifying irrelevant information and interpreting data presented within charts and graphs. For example, when solving word problems, we recommend students always start with identifying if the problem has a chart or graph and then numbering the chart or graph (Powell et al., 2021). We also recommend for students to identify the irrelevant information and immediately cross it out (Powell et al., 2021).

Limitations

Before concluding, we identify several limitations for this study. First, *Texas Word Problems – Part 1* and *Part 2* produced a low reliability score of .54. This reliability is below typical thresholds for acceptability (Yang & Green, 2011). We hypothesized the low reliability might be related to a homogeneous sample (i.e., students with MD) answering difficult questions on a word-problem measure. As shown in Table 3, the average number of correct responses by schema was less than 25% for Change and Difference problems and 8% for Total problems. This indicates that most students with MD answered these items incorrectly. As described in the literature (Streiner, 2003), a homogeneous sample typically demonstrates a lower Cronbach's alpha than a heterogenous sample. Interestingly, with this sample of students with MD, we provided word-problem intervention to two-thirds of the students (after we collected the data analyzed in this study; Powell et al., 2021). At posttest, on the *Texas Word Problems – Part 1* and *Part 2,* we calculated a reliability of .75. At this posttest, the sample of students included greater heterogeneity because some students had participated in word-problem intervention and showed a dramatic increase in scores. In the future, we should collect data from TA students on *Texas Word Problems – Part 1* and *Part 2* to calculate the reliability of the measure with a more heterogeneous sample.

Second, both the measures sampled a limited number of word problems. We selected word problems related to common schemas used in the elementary grades. To sample each schema and the position of the unknown within each schema, students typically had only one opportunity to solve a problem featuring a specific schema with a specific position of the unknown. Therefore, in the future, researchers should administer the same combination of problem (e.g., Difference problem with an unknown greater amount) multiple times to understand consistency of performance.

Third, we identified more Hispanic students and dual-language learners in the category of students with MD than in the TA students category. This is not surprising given the screener for MD was a measure of word-problem solving. We have investigated differences by demographics in other research (e.g., Powell et al., 2020), and within the category of students with MD, we have not identified differences by race or ethnicity. We hypothesized a student's MD superseded other variables. Future research, however, should investigate this to understand the intersection of demographic variables an MD.

Conclusion

Overall, TA students outperformed students with MD on word-problem accuracy. For schemas, TA students and students with MD performed higher on Change and Difference problems than on Total problems. For the position of the unknown, student performance typically aligned with previous research for Change and Total problems (Garcia et al., 2006; Powell et al., 2009), with students often performing higher on problems with the final position unknown than on problems with the first and second position unknown. Alternatively, student performance on Difference problems differed from previous research for the position of the unknown, where both TA students and students with MD performed lowest on problems with the final position unknown. Students with MD performed higher on problems without irrelevant information or charts and graphs than problems with these features. When problems included irrelevant information, charts and graphs, or both, students with MD performed the highest on problems with irrelevant information only.

Not all problems followed the same trends. The inconsistencies in patterns likely occurred due to the unique factors within the word problems work together to influence student performance on each word problem (Pongsakdi et al., 2020). Future research should continue to investigate if the patterns observed are maintained with statistical significance testing to better understand how word-problem factors impact student performance. This will support instruction development in word-problem solving for both TA students and students with MD.

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Table 1

Participant Demographics

	All students (N = 2,841)	TA (n = 2,149)	MD (n = 692)
Sex			
Female	1,016 (35.7%)	720 (33.5%)	269 (38.9%)
Male	961 (33.8%)	712 (33.1%)	249 (36.0%)
Not reported	864 (30.4%)	717 (33.4%)	147 (21.2%)
Race/ethnicity			
Black	203 (7.1%)	142 (6.6%)	61 (8.8%)
Asian	92 (3.2%)	79 (3.7%)	13 (1.9%)
Hispanic	929 (32.7%)	545 (25.4%)	384 (55.5%)
White	566 (19.9%)	525 (24.4%)	41 (5.9%)
Multi-racial	141 (4.9%)	110 (5.1%)	31 (4.5%)
Other	41 (1.4%)	27 (1.3%)	14 (2.0%)
Not reported	869 (30.6%)	721 (33.6%)	148 (21.4%)
Special education			
Not in special education	1,836 (64.6%)	1,369 (63.7%)	467 (67.5%)
Receiving special education	136 (4.8%)	60 (2.8%)	76 (11.0%)
Not reported	869 (30.6%)	720 (33.5%)	149 (21.5%)
Dual-language learners			
Dual-language learner	815 (28.7%)	473 (22.0%)	342 (49.4%)
Not dual-language learner	1,160 (40.8%)	959 (44.6%)	201 (29.0%)
Unreported	866 (30.5%)	717 (33.3%)	149 (21.5%)

Note. MD = mathematics difficulty; TA = typically achieving.

Table 2

Texas Word Problems – Brief

Category	Problem	All students (N = 2,841)		TA (n = 2,149)		MD (n = 692)	
		M	*SD*	*M*	*SD*	*M*	*SD*
Change		0.45	0.32	0.53	0.30	0.18	0.2
Increase: Start	There were some students on the school bus. Then, 19 more students got on the bus. There are now 34 students on the bus. How many students were on the bus to start with?	0.29	0.45	0.37	0.48	0.04	0.2
Increase: End	Alfred drove 59 miles, and then he stopped for gas. Then, Alfred drove 34 more miles before stopping for lunch. How far did Alfred drive?	0.61	0.49	0.71	0.45	0.29	0.4
Decrease: Start	Frances poured cups of lemonade. She sold 38 cups and has 19 cups left. How many cups did Frances pour?	0.29	0.46	0.34	0.48	0.14	0.3
Decrease: Change	Jack had $38, and then he bought a shirt. Now, Jack has $14. How much did the shirt cost?	0.59	0.49	0.71	0.46	0.23	0.4
Difference		0.43	0.35	0.53	0.34	0.15	0.2
Greater	The library has 23 books about dinosaurs. The library has 14 more books about space. How many books about space does the library have?	0.61	0.49	0.69	0.46	0.36	0.4
Lesser	The grocery store has 22 fewer peaches than apples. If the grocery has 74 apples, how many peaches does the store have?	0.46	0.50	0.58	0.49	0.08	0.2
Difference	Mr. Jones delivers packages. He delivered 26 packages on Thursday and 85 packages on Friday. How many more packages did he deliver on Friday?	0.23	0.42	0.30	0.46	0.02	0.1
Total		0.25	0.43	0.32	0.47	0.03	0.1
Part[a]	The farmer has 61 sheep and cows. If 25 of the animals are sheep, how many are cows?	0.25	0.43	0.32	0.47	0.03	0.1

Note. MD = mathematics difficulty; TA = typically achieving.

[a]At screening, there was only 1 Total problem, and it was a Total problem with a part missing. We repeat this data to keep the same formatting betwee

Table 3

Texas Word Problems – Part 1 and Part 2

Categories	Problems	MD (n = 476) *M*	MD (n = 476) *SD*
Change		0.26	0.20
Increase: Start	The temperature in the morning was cool. By the afternoon, the temperature had risen 35 degrees, so it is now 82 degrees outside. What was the temperature in the morning?	0.04	0.19
Increase: Change	This graph shows the number of cookies each student baked on Monday. Then, Thomas baked some more cookies. Now, Thomas has 55 cookies. How many cookies did Thomas bake?	0.02	0.13
Increase: End	Last year, there were 11 trumpet players in the band. This year, 14 new trumpet players and 4 tuba players joined the band. How many trumpet players are in the band now?	0.26	0.44
Decrease: Start	Pam picked some apples at the orchard. She used 19 apples to bake apple pies and has 23 apples left. How many apples did Pam pick?	0.29	0.46
Decrease: Change	Jack brought 78 cookies to school on his birthday. Then, he gave some cookies to his friends. Now, Jack has 23 cookies. How many cookies did Jack give away?	0.48	0.50
Decrease: End	Mr. Luther had 26 pencils in his desk. Then, he gave 12 pencils to 6 of his students. How many pencils does Mr. Luther have now?	0.48	0.50
Difference		0.24	0.23
Greater	Charlie has 24 more baseball cards than football cards. He has 45 football cards. How many baseball cards does Charlie have?	0.47	0.50
Lesser	Abby is 5 years older than her brother. If Abby is 16 years old, how old is her brother?	0.22	0.41
Difference	The graph shows the favorite subject of third-grade students. How many more students chose Math than chose Writing?	0.04	0.19
Total		0.08	0.15
Total	The graph shows the favorite fruit of third-grade students. How many students chose oranges or bananas?	0.10	0.30
Part	The graph shows the prices of items at the department store. A new t-shirt and watch cost $41 in all. How much does a watch cost?	0.01	0.11
Part	Donna and Natasha folded 96 paper cranes. Donna folded 25 paper cranes. How many paper cranes did Natasha fold?	0.18	0.38