Journal of Mathematics and Science Teacher
2026, 6(1), em096
e-ISSN: 2752-6054
https://www.mathsciteacher.com/

MODESTUM

Review Article **OPEN ACCESS**

A scoping review of the structures of semantic word problems

Jamaal Rashad Young [1*], Julia E. Calabrese [2], Leyang Xu [1], Kristian Edosomwan [3]

[1] Texas A&M University, College Station, TX, USA
[2] University of Texas at Arlington, Arlington, TX, USA
[3] University of Houston, Houston, TX, USA
***Corresponding Author:** jamaal.young@tamu.edu

Citation: Young, J. R., Calabrese, J. E., Xu, L., & Edosomwan, K. (2026). A scoping review of the structures of semantic word problems. *Journal of Mathematics and Science Teacher, 6*(1), em096. https://doi.org/10.29333/mathsciteacher/17814

ARTICLE INFO

Received: 18 Jul. 2025

Accepted: 10 Dec. 2025

ABSTRACT

Word problem-solving is central to mathematics education, yet the instructional role of semantic structures remains underexplored. These linguistic and conceptual features are common in assessments but inconsistently addressed in teaching. This study utilized a recognized scoping review framework from health and educational research to analyze 26 peer-reviewed articles, selected from an initial pool of 274 identified through Google Scholar. Studies were screened for relevance and coded using an a priori protocol. Most focused on elementary students, particularly those with learning disabilities, and used quantitative methods with solution accuracy as the primary outcome. Findings reveal strong connections between semantic structure and problem difficulty, student success, language proficiency, and intervention outcomes. Textbook analyses showed limited and uneven exposure to varied problem structures. Thematic synthesis identified seven key contributions, including strategy use, classification, and linguistic clarity. The review emphasizes the need for linguistically responsive instruction, greater semantic diversity in curricula, and further research into how semantic structures shape cognitive and instructional processes.

Keywords: word problems, interventions, cognitive load theory, elementary, systematic review

INTRODUCTION

Problem-solving and specifically word problem-solving are invaluable tools to the teaching and learning of mathematics as evidenced by policy, curricula, and research trends in mathematics education. There is however a consistent lack of clarity and commonality related to the instructional scope, utility, and pedagogical purpose of examining the structures of semantic word problems. Given that word problems represent the most enduring assessment mechanism used in mathematics education, there is promising potential for using the structures of semantic word problems to improve word problem instruction and student achievement. The opportunity to leverage the potential of structures of semantic word problems has yet to be realized despite the fact that word problems have become ubiquitous in mathematics classrooms and curricula. Word problems are currently used in major national and international assessments such as the national assessment of educational progress as well as the PISA. In addition to supporting mathematics literacy and problem-solving skills, word problems also support the early development of the next generation of STEM professionals (McDonald, 2016; Wan et al., 2021). Given the centrality of word problems in mathematics learning and assessment, this study seeks to characterize the volume and scope of research concerning structures of semantic word problems to inform more educative research and praxis. In this study, the structures of semantic word problems indicate the linguistic and conceptual elements embedded in problem design that influence students' problem-solving skills and understanding of the contexts (Jitendra, 2019; Riley et al., 1983), employing in various terms such as *word problem structures* and *semantic structure* which describe the single concept. We combined all the terms as structures of semantic word problems to ensure consistency and clarity in this paper.

Word problems remain an essential part of the mathematics education curriculum. Verschaffel et al. (2000) define word problems as verbal descriptions of problem situations that pose one or more questions that can be answered by applying specific mathematical processes to the available numerical data. There is some contention as to what constitutes a true "word problem" however, data from numerous studies, national, and international assessments all confirm that students struggle with mathematical tasks that are presented as word problems regardless of their authenticity (Goulet-Lyle et al., 2020; Pongsakdi et al., 2020). Nonetheless, here we operationally define word problems as any mathematical task embedded in a verbal description that solicits a solution. This simplification is warranted because in the present study we are focusing on word problem schema or the structures of semantic word problems which are most often present in studies focused on lower elementary problems that tend not to meet the definition proffered by cognitive psychologists. Yet, these initial word problems continue to challenge the mathematics proficiency of early learners often reducing their mathematics self-efficacy, attitudes, and ultimately their mathematics identity. Unfortunately, these early negative experiences with word problems can have enduring effects on mathematics interest and success.

With the mathematics education research literature there has been a longstanding emphasis on assessing students' word problem-solving skills over time (Powell et al., 2022). Aside from the use of word problems on state, national, and international assessments, word problems also support the development of students' overall mathematical knowledge and skills. This includes the use of both standard and non-standard word problems. Hence, understanding student misconceptions and common errors have policy as well as practical implications.

The use of the structures of semantic word problems is rationalized as an opportunity to improve the efficiency and efficacy of word problem instruction. Using the structures of semantic word problems has the potential to efficiently assess student errors by pinpointing specific word problem challenges for students or instructional inconsistencies (Fuchs et al., 2021; Jitendra, 2019). The structures of semantic word problems can also serve as mechanisms to diversify instructional and assessment practices that support differentiation. When integrated into more traditional approaches to word problem instruction it is possible to develop classroom differentiation strategies based on word problem categories and subcategories. Hence, established word problem teaching strategies and practices can be complemented through the integration of the structures of semantic word problems. Although several rationales for the use of the structures of semantic word problems exist, what remains absent is a characterization of the scope of empirical evidence related to teachers' use of semantic problem structures and the effectiveness of these strategies.

In addition to the aforementioned instructional affordances, the use of semantic word problems is also rationalized relative to the facilitation of early success in mathematics and the mathematics identity development of the next generation. Word problem understanding and the lack thereof is connected to mathematics anxiety, a lack of persistence in mathematics, and mathematics avoidance behaviors. To this end, there is a great deal of research available to guide the development of curricula and mathematics instructional material that leverages the structures of semantic word problems. However, the characterization of this research remains largely underdeveloped. Thus, in this study, lenses in structures of semantic word problems can be found with detailed explanation and the purpose of this study will be illustrated in the later sections.

The purpose of this systematic review is to characterize the structures of semantic word problems research in mathematics in order to map the scope and structure by identifying salient trends and possible gaps in the current research. To meet this challenge, we will conduct a scoping review to examine the volume, nature, and characteristics of word problem structure studies published between the years 1980-2020. The review procedures for the present study follow the scoping review methodological framework (see Arksey & O'Malley, 2005). This method was selected over other systematic review traditions because our focus here is to characterize the literature to inform future instructional practice and inquiry. Although scoping reviews emerged from the medical research tradition, scoping reviews of the educational research literature are becoming more common. The research questions (RQs) that will guide our scoping review are:

RQ1. How are structures of semantic word problems examined in mathematics educational research?

RQ2. How do these studies examine the effects of exposure to the structures of semantic word problems learning outcomes?

The remainder of the present discussion is structured as follows. First, we present the theoretical framework–cognitive load theory (CLT), which provides the theoretical grounding for the present study. Then, we review the relevant prior systematic reviews and meta-analyses to generate an umbrella review of the major characteristics and themes present in the literature. Third, we present the scoping review methods, which include all steps presented in Arksey and O'Malley's (2005) framework. The results generated from this process are then presented followed by a discussion of the key findings and implications for research and teaching mathematics word problems using the structures of semantic word problems. We conclude with a summary of the study and a call to actions for researchers and mathematics educational stakeholders.

THEORETICAL FRAMEWORK

The theoretical framework is important to provide a theoretical foundation for the study. The current study is based on the theoretical framework–CLT, which explains the complex dynamics of cognitive processing involved in solving mathematics word problems. CLT emphasizes the intricate interaction between sensory, working, and long-term memory. In education, CLT acts as a guiding principle to avoid cognitive overload, allowing learners to strategically manage the amount of information they process, which is critical to their early and consistent success at solving word problems. Cognitive overload describes a situation in which intrinsic, extraneous, and germane loads overwhelm the learner (Westby, 2018). The phenomenon of cognitive overload can be described as a situation where "productive struggle" becomes unproductive (Young et al., 2024).

Applying CLT to word problem-solving can reveal the inherent challenges students face as they navigate the translation between concrete and abstract information. Beyond procedural knowledge, proficiency in word problem-solving necessitates the cultivation of context-decoding skills. The semantic variations in word problems further compound these challenges, with research indicating distinct struggles across problem categories. Central to the present study are textbooks because they can delineate the curriculum by significantly influencing student exposure to content. Recognizing the relationship between textbooks and academic performance, the present study explores the content and organization of word problem types across three widely adopted textbooks. By scrutinizing the prioritization of specific word problem types within these educational resources, the research aims to unravel the subtle, yet impactful role textbooks play in shaping students' mathematical experiences and how cognitive load considerations are at play.

There are unique cognitive load considerations in the design of word problems. Specifically, cognitive load can be divided into three types: intrinsic, extraneous, and germane (Orru & Longo, 2019). There is an intrinsic load associated with processing information, regardless of the manner in which it is presented. The intrinsic load remains constant regardless of the extraneous and germane loads (Sweller, 2010). The extraneous load refers to the style in which information is presented and the ease with which it is processed by a particular learner and varies from person to person (Khalaf et al., 2025). Germane load refers to the amount of effort required to process information into schemas through the application of memory and intelligence. As a result, germane load is how new information is processed into long-term memory. Distinguishing between intrinsic, extraneous, and germane load, is imperative to develop word problems as mathematics educators work to circumvent cognitive overload. Formulating robust learning objectives, assessing prior knowledge, and judiciously incorporating visual and auditory elements are pedagogical strategies that are essential components in effective course design, that are often guided by the content presented in textbooks.

The intricacies of cognitive load considerations in word problem instruction remain a challenge for mathematics teachers. Here, we contend that applying the tenets of CLT to reduce the complexities inherent in word problem-solving, should be the primary role of textbooks in the mathematics classroom as it relates to word problem instruction. Thus, using CLT as a framework, we contend that the variation of the structures of semantic word problems should be minimal as all textbook authors should structure the representation of mathematics word problems in textbooks to reduce the cognitive load of learners. Through the lens of the CLT framework, the present study seeks to explore the structures of semantic word problems across different mathematics textbooks, as there are profound implications for learners' cognitive processes, as noted in mathematics education research on word problem teaching and learning. Before our study, a review of the previous literature will be summarized in the following section, providing a comprehensive overview of primary synthesis and findings in the field.

LITERATURE REVIEW

Mathematics education, particularly word problem-solving, has received significant attention in recent years. Researchers have studied various aspects of instruction, intervention, and cognitive processes. In this literature review, we will synthesize findings from multiple studies that contribute to a deeper understanding of the structures of semantic word problems and their impact on students, especially those with learning disabilities (LD) or moderate and severe disabilities (MSD) as this has been the focus of several prior syntheses.

We begin with a review of prior syntheses examining the structures of semantic word problems as supports for special populations of learners. Shin et al. (2020) conducted a meta-analysis of single-case designs that examined the effects of word problem instruction for students with LD across grade 1 through grade 12. They found that the most significant effects were observed in interventions that met adherence, dosage, and regularity criteria, emphasizing the importance of implementation fidelity. This study highlights the importance of adherence to intervention protocols and the need to ensure that interventions are implemented as intended. In a similar meta-analysis, Kong et al. (2021) examine 18 randomized control group studies focused on word problem-solving interventions for elementary-aged students with LD or at risk for LD. They found that these interventions had a substantial positive effect (i.e., effect size of 1.08). The study emphasized the importance of providing evidence-based instruction in general classroom settings before using small-group interventions. This study provides evidence for the effectiveness of targeted interventions for students with LD or those at risk for LD. In systematic reviews related to mathematics word problems and students with LDs, Clausen et al. (2021) and Cook et al. (2019) focused on schema-based instruction (SBI) and modified schema-based instruction, respectively, as strategies for teaching mathematical word problem-solving. Both studies emphasized the potential efficacy of these approaches for students with LD and MSD but emphasized the need for more research, collaboration, and standardized training. These studies highlight the potential benefits of schema-based instruction for students with LD and MSD. Although there is a notable focus on special populations, other systematic reviews are more general in nature.

For instance, Lin (2021) conducted a comprehensive survey of literature on word problem-solving in mathematics education, covering various themes and highlighting debates on problem comprehension, solution strategies, cognitive and metacognitive skills, and the impact of teaching environments. Lin (2020) emphasizes the ongoing need for interdisciplinary research, contributing to theory, research methodology, and educational practice. Lin (2020) highlights the importance of interdisciplinary research and collaboration to advance the field of mathematics education. While Verschaffel et al. (2020) delved into the cognitive and academic skills contributing to elementary school students' abilities to solve mathematics word problems. Their meta-analytic structural equation modeling approach identified language comprehension, working memory, attention, mathematics vocabulary, and mathematics computation as unique predictors of word-problem-solving. The study suggested a framework for future research, considering different formats, populations, and grade levels. This study provides insights into the cognitive and academic skills necessary for students to solve mathematics word problems. Finally, the bibliometric analysis conducted by Suseelan et al. (2022) provided a panoramic view of research in mathematics problem-solving in elementary education from 1969 to 2021. The review emphasized the evolving research landscape and the need for ongoing studies to advance the field. This study highlights the importance of continued research to advance the field of mathematics education.

In recent years, with the emergence of Generative AI and other advanced technologies, solving word problems in mathematics has had a significant impact on traditional methods for students at various levels. Wardat et al. (2023) mentioned that Shakarian et al. (2023) found that ChatGPT significantly changed the way of learning mathematical word problems. Shakarian et al.'s (2023) article specifically indicated that ChatGPT can be solve word problems by providing a "step-by-step derivation". Additionally, Liu et al. (2025) introduced a system, called ChatGPT-MPS, which supports mathematics problem-solving based on ChatGPT. This system aims to help elementary students develop mathematical word problem-solving strategies and a deeper conceptual understanding in various aspects. This study demonstrated the benefits of personalized generative AI for LD students and indirectly helped them develop a comprehensive semantic understanding of word problems. Kim et al. (2022) created an advanced technology called computer-assisted instruction that effectively improved students with LD in solving word problems, including problem structure representation techniques. Mandal and Naskar's (2021) article also develops an educational software application, named AMWPS, to solve arithmetic mathematical word problems, thereby increasing the efficiency of learning and tutoring students. This software features a single equation with a single operation to enhance word problem-solving skills through interactive computer tutoring.

Overall, these studies provide comprehensive insights into word problem-solving in mathematics education. Despite the progress made in identifying effective interventions and predictors, significant gaps still exist. The literature highlights the need for more methodologically sound studies, collaborations with practitioners, and the development of research-based metacognitive scaffolds. Tailored interventions for different age groups and exploration of diverse cognitive and academic skills are crucial for advancing the field. A scoping review is necessary to consolidate existing knowledge, identify gaps, and pave the way for future research addressing the multifaceted challenges in the structures of semantic word problems within mathematics education. Given these persistent gaps and the multifaceted challenges in understanding the structures of semantic word problems, this scoping review was designed to systematically map the existing literature, thereby informing future instructional practices and inquiries.

METHOD

To facilitate a broad scoping, an exhaustive search of the Google Scholar electronic database was conducted using the following keyword combinations: word problem AND structure (n = 99); word problem AND schema (n = 81); and word problem AND strategy (n = 94). This approach aimed at casting a wide net to ensure inclusivity. The preference for Google Scholar over traditional databases was a deliberate choice to mitigate potential exclusions based on subscription and publisher agreements. This search process resulted in an initial pool of 274 studies. After removing duplicates, a final pool of possible studies for inclusion was identified (n = 79). After the initial search process, the 79 publications selected for consideration were screened using the following inclusion criteria and protocol. To address the identified need for a comprehensive characterization of the structures of semantic word problems research, a rigorous scoping review methodology was employed, as detailed in the following sections.

Study Selection

The process of study inclusion and exclusion involved a process of criteria-based screening and evaluation (Arksey & O'Malley, 2005). After the initial search process, the 79 publications selected for consideration were screened using the following inclusion criteria and protocol. The first criterion was that the article needed to be published within 40 years of the review (1980-2020). Only one article was published prior to 1980 and was therefore removed. The next criterion was that the article needed to be in English. All articles met this criterion. Next, the articles needed to be published in peer-reviewed journals and contain original research. Any article that did not contain a study or was not published in a peer-reviewed journal was also removed (n = 24), including published proceedings. This left 54 articles. The final criterion was focus. Specifically, to further narrow the selection, we examined the focus of the literature presented as well as the study itself. Any article that did not place strong emphasis on *word problems* or *semantic structure* was removed, eliminating another 28 publications. The screening process involved evaluation based on these criteria, ensuring that selected articles were peer-reviewed and contained original research. Exclusion of articles lacking a strong emphasis on *word problems* or *semantic structure* further refined the pool. At the end of the selection process, there were 26 articles remaining for analysis. **Figure 1** presents the entire search, retrieval, and review process.

Charting the Data

Upon identifying eligible studies, an a priori data retrieval protocol facilitated the charting process. A Google Form, with predefined elements, ensured consistency in data collection. The use of this form allowed for assessing interrater agreement, adding a layer of reliability to the charting process. Each study was individually coded, considering articles with multiple studies. Common elements of the data collection instrument included author(s), title and publication information, sample description, research classification, methods and procedures, outcome measures, and educational contributions. It is important to note that each study was coded individually. Several articles contained more than one study (e.g., Xin, 2007), in which case the appropriate number of Google Forms were submitted to account for each study present (i.e., there are more Google form responses than included articles in the analysis). Upon completion of the data collection process, we downloaded all of the Google Form responses into a Microsoft Excel spreadsheet to analyze the dataset.

Collating and Summarizing

The included studies in the present scoping review were collated and summarized in several ways. First, articles were sorted by sample type. Multiple articles contained more than one sample, either to compare across groups or to present more than one study. In these instances, the articles were represented the appropriate number of times to represent each sample. To provide deeper insight into the sample types, each study was categorized by how the sample was analyzed such as in a multiple group comparison or as a whole group with non-sample-related comparison. Next the articles were sorted by research classification and methods or procedures.

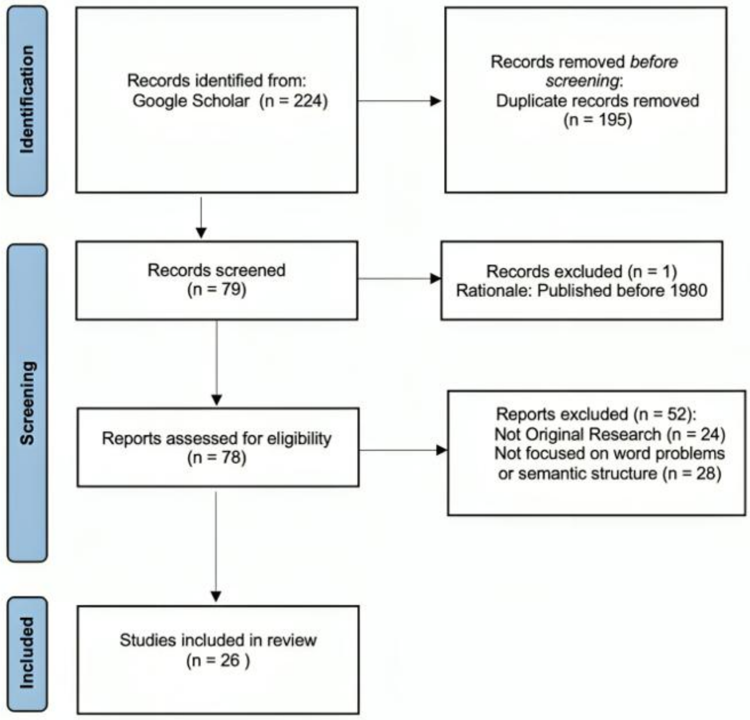

Figure 1. PRISMA diagram of search, retrieval, and review process (Source: Authors' own elaboration)

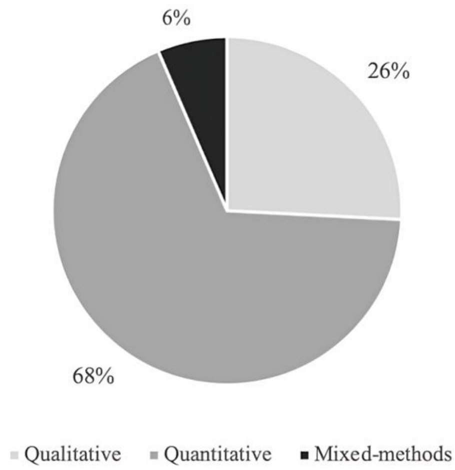

Figure 2. Research approaches (Source: Authors' own elaboration)

Similar to the analysis by sample, any article containing more than one method or procedure was accounted for more than once to represent each study it contained (see **Figure 2**). To compare the different outcome measures, we first coded for common themes to simplify the data. For example, many articles measured some facets of solution correctness, such as percent accuracy (e.g., Alghamdi et al., 2020) or simply number of correct answers (e.g., De Corte et al., 1990). If an outcome measure was unique, it existed as its own theme. After all of the outcome measures were as condensed as possible, we created a matrix to represent each of the articles. Some articles had more than one outcome measure, and all outcome measures for that article were represented in the same row. Finally, articles were sorted by educational contributions. We grouped the articles by similar contributions. For example, De Corte et al. (1990) and Boonen et al. (2016) both detailed a relationship between word problem semantics and children's success in solving them.

To maintain credibility, the collation and summarization process involved careful categorization of articles based on sample types, research classification, methods, procedures, and educational contributions. This systematic approach ensured that each aspect of the studies was appropriately represented, acknowledging instances where articles contained multiple samples or methods. Based on the information retrieved from the studies, the following educational contribution categories were developed: word problem classification, number sentence writing categorization of solution strategy, outside factors' impacts on problem-solving, semantics' impacts on problem-solving, intervention/student support, and numbers' impact on problem-solving.

The outcome measures were condensed into common themes, enhancing the clarity and comparability of the data. The development of a matrix for each article's outcome measures further facilitated the analysis. Educational contributions were meticulously categorized, providing a structured overview of recurring themes and insights. We then quantified the responses

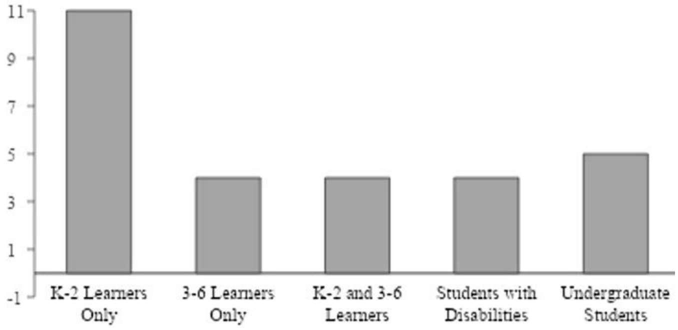

Figure 3. Sample types by age/grade level (Source: Authors' own elaboration)

Table 1. Comparisons by sample type

Analysis type	Frequency (N)
Single group analysis	12
Multiple group comparison	16
Textbook analysis	4

Table 2. Data collection methods

Method	Frequency (N)
Observation	1
Interviews	9
Single test	11
Two tests	2
Pre-post test	4
Textbook analysis	4

within each category to compare frequencies of recurring responses as well as find common themes between the selected articles. Quantification within each educational contribution category allowed for a quantitative analysis, enabling the comparison of frequencies and identification of common themes across selected articles. This process added a layer of validity, grounding the scoping review in empirical observations, which ensured a robust and systematic collection and analysis of the literature. The findings will be presented in the next section, generated from this comprehensive process, which highlights key trends and characteristics of word problem structure research.

RESULTS

Sample Types

Analysis of the various samples showed that the research on word-problem structure tends to be heavily focused in the elementary setting. The large majority of the studies took place within the K-6 grade levels (see **Figure 3**). Furthermore, some of the studies with students with disabilities also took place in a primarily elementary setting, but as the focus of the studies were not on this age specification, it was not counted in the overall frequency by sample. The studies with students with disabilities also contained a variety in their sampling, ranging from specific labeling such as students with hearing impairment (Frostad & Ahlberg, 1999), mental retardation (Jaspers & Van Lieshout, 1994), and mathematics-specific LD (Alghamdi et al., 2020; García et al., 2006) to general labeling (Xin, 2007).

To further explore the sample types, studies were classified by the utilization of the sample as either a multiple-group comparison or single-group analysis (see **Table 1**). Textbook analyses were labeled as such and not included as either of the aforementioned types. While multiple-group comparisons were the most frequent type of study, single-group comparisons were also very common. In the single-group analyses, the typical format consisted of comparing students' performance on various types of the structures of semantic word problems (e.g., Carey, 1991), so while the sample itself was single-group, there was still a comparison embedded within the study as a whole.

Research Design

A large portion of the articles utilized quantitative measures for analyzing the data (see **Figure 2**). The special data collection processes and frequency of each step in this study are via observation, interviews, single test, two tests, pre-post test, and textbook analysis (see **Table 2**). The most common data collection methods were interviews (e.g., García et al., 2006) and single test (e.g., Rabinowitz & Wooley, 1995). In the instance of interviews, students were typically asked to solve word problems but were able to verbally explain or justify their strategy and final solution. However, in single, multiple, and pre posttest design, the students answered questions with some form of written response (paper or computerized) with no opportunity for verbal support. One study (Savard & Polotskaia, 2017) utilized classroom observations to report students' progress with solving problems. The final type of study included textbook analyses. In these studies, the researchers analyzed various texts to determine frequencies

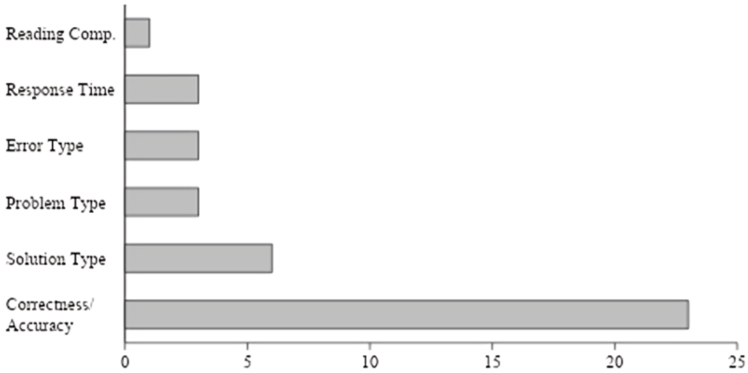

Figure 4. Frequency of outcomes measured (Source: Authors' own elaboration)

Table 3. Outcomes measured by study

Study	C/A	ST	PT	ET	RT	RC
Alghamdi et al. (2020)	X					
Bernardo (1999)	X					
Boonen et al. (2016)	X					X
Carey (1991)	X					
Carpenter et al. (1983)	X	X				
Cummins (1991)	X			X		
De Corte and Verschaffel (1985)	X	X				
De Corte and Verschaffel (1987)	X	X				
De Corte et al. (1990)	X				X	
Frostad and Ahlberg (1999)	X					
García et al. (2006)	X					
Gvozdic and Sander (2020)	X	X				
Jaspers and Van Lieshout (1994)	X					
Kouba (1989)		X				
Lean et al. (1990)	X			X		
Lewis (1989)	X	X				
Rabinowitz and Wooley (1995)	X			X	X	
Savard and Polotskaia (2017)	X					
Schumacher and Fuchs (2012)	X					
Secada (1991)	X					
Sumarwati et al. (2020)			X			
Thevenot and Oakhill (2006)	X				X	
Tyumeneva et al. (2018)			X			
Vicente et al. (2027)	X					
Willis and Fuson (1988)	X					
Xin (2007)	X		X			

Note. C/A: Correctness/accuracy; ST: Solution type; PT: Problem type; ET: Error type; RT: Response time; & RC: Reading comprehension

of various characteristics of word problems, including the structures of semantic word problems (Sumarwati et al., 2020; Xin, 2007) and word choice (Tyumeneva et al., 2018).

Outcomes Measured

Across the different studies, several variables were examined, often multiple within a single study. The quantitative articles included measures such as correctness of the solution to a word problem (e.g., Alghamdi et al., 2020), length of time taken to respond to a question (e.g., De Corte et al., 1990), and reading comprehension scores (Boonen et al., 2016). The qualitative studies coded data such a students' strategies for solving a word problem (e.g., Secada, 1991), what types of errors students made in solving word problems (e.g., Lean et al., 1990), and semantics of problems either posed by students (Tyumeneva et al., 2018) or presented in a textbook (Sumarwati et al., 2020). The most commonly measured outcome was solution correctness or accuracy (see **Figure 4**). In fact, every quantitative study measured this outcome. This took place in a variety of contexts, such as total number of correct solutions (De Corte et al., 1990), correctness sorted by the Riley et al. (1983) semantic classifications (Carey, 1991) and comparing performance before and after rewording of word problems (Bernardo, 1999).

Several studies measured more than one outcome and outcomes in the study are completely measured (see **Table 3**). For example, Cummins (1991), Lewis (1989), and Rabinowitz and Wooley (1995) examined incorrect solutions and classified the errors that the participants made.

Educational Contributions

While all of the articles had a common foundation in word problem structure, their contributions are many. Some articles contained multiple key findings as they contained more than one study or measured more than one outcome. The most common theme in the selected studies was the connection between language and the structures of semantic word problems and problem-solving. For example, the structures of semantic word problems can influence the degree of difficulty of a word problem (Frostad & Ahlberg, 1999; Lean et al., 1990; Rabinowitz & Wooley, 1995; Thevenot & Oakhill, 2006), what strategies a student may use to approach the solution (De Corte & Verschaffel, 1987), and how long it takes them to solve it (De Corte et al., 1990; Rabinowitz & Wooley, 1995). Specifically, many studies showed a strong relationship between the location of the unknown variable and students' solution success or problem difficulty (García et al., 2006; Kouba, 1989; Vicente et al., 2007).

Additionally, there exists a relationship between native language or language proficiency and the ability to solve word problems in that language (Bernardo, 1999; Secada, 1991). In general, semantic and linguistic elements are believed to be tied to overall problem-solving success (Boonen et al., 2016). The key findings from all selected studies are analyzed (see **Table 4**).

Table 4. Key findings from selected studies

Reference	Study purpose	Sample	Design	Problem focus	Key findings	Implications
Alghamdi et al. (2020)	Evaluate effectiveness of schema-based instruction for solving multiplicative word problems in students with mathematics disabilities.	N = 3 5th grade students with LD	Single-case multiple-probe design	Multiplicative word problems	Improved accuracy and use of diagrams; strong effect sizes (tau-U = 1.0).	Schema-based instruction supports visual modeling and strategy use for students with LD.
Bernardo (1999)	Examine how native language and problem wording affect bilingual students' problem-solving success.	N = 283 grade 2, Filipino-English bilingual students	2×2×2×3 factorial experimental design	Change, combine, compare types	Native language and explicit relationships improved success rates.	Reword problems and teach in students' native language to improve comprehension.
Boonen et al. (2016)	Explore impact of semantic-linguistic complexity on word problem-solving in RME context.	N = 80 Dutch 6th rade students	Experimental 2×2×2 design with ANOVA	Compare problems (consistent/inconsistent language)	Reading comprehension was key to solving semantically complex problems.	Teach reading strategies that align with semantic structures in math problems.
Carey (1991)	Investigate first grader's flexibility in writing number sentences for word problems.	N = 64 1st grade students	Mixed methods with interviews and assessments	Addition and subtraction word problems	Flexibility varies with number size and problem structure.	Encourage multiple representations and sentence forms to develop structural understanding.
Carpenter et al. (1983)	Examine how early instruction affects strategy choice and sentence writing.	N = 43 1st grade students	Pre/post-test design with curriculum intervention	Addition and subtraction word problems	Instruction reduced strategy variation and shifted focus from modeling to operations.	Balance instruction between semantic understanding and procedural skills.
Cummins (1991)	Explore linguistic vs. conceptual sources of error in interpreting arithmetic problems.	N = 35 1st grade students	Two experimental tasks with qualitative analysis	Addition and subtraction with comparative terms	Linguistic misinterpretations (e.g., altogether) caused more errors than conceptual gaps.	Clarify relational terms and use visuals to support comprehension.
De Corte and Verschaffel (1987)	Propose a descriptive theory of children's word problem-solving strategies.	Belgian elementary students	Multiple case studies with problem-solving tasks	Change, combine, compare, equalize	Strategies align with semantic structures; unfamiliar structures cause rigid strategy use.	Teach flexibility with varied semantic structures and unknown positions.
De Corte and Verschaffel (1987)	Study how semantic structure affects 1st grade strategy development.	N = 30 Belgian 1st grade students	Longitudinal interviews	Addition and subtraction	Strategy use developed over time, influenced by structure and position of unknown.	Early exposure to varied structures supports representational flexibility.
De Corte et al. (1990)	Investigate how semantic complexity affects children's strategies and accuracy in subtraction problem-solving.	N = 60 2nd and 4th grade students from Flemish schools	Cross-sectional experimental design with structured interviews	Subtraction word problems with simple and complex semantic structures	Simple-structured problems led to better performance; older students used more abstract strategies.	Instruction should scaffold both semantic understanding and representational flexibility across grades.
Frostad and Ahlberg (1999)	Explore how children with hearing impairments interpret and solve subtraction word problems.	N = 32 hearing-impaired students (ages 6 through 10) in Norway	Mixed methods with computer-based problem-solving and interviews	Subtraction problems: change 2, 4, 6 types	Students struggled more with change 6; semantic complexity influenced performance and interpretation.	Visual modeling and semantic scaffolding are critical for students solving arithmetic word problems.

Table 4 (Continued). Key findings from selected studies

Reference	Study purpose	Sample	Design	Problem focus	Key findings	Implications
Garcia et al. (2006)	Compare problem difficulty classification in students with and without arithmetic LD.	N = 148 Spanish students, aged 7 through 9 (N = 104 LD, N = 44 typical)	Quantitative comparative study using facet theory	Addition or subtraction problems varying by structure, unknown position, and operation	Unknown position had more impact on difficulty than operation; LD students struggled most with noncanonical formats.	Instruction should prioritize problem structures and unknown positions to support LD learners.
Gvozdic and Sander (2020)	Assess effectiveness of semantic recoding instruction in improving flexible strategy use.	N = 208 French 1st grade students (ACE vs. BAU classrooms)	Experimental design with between-group comparison	Additive and subtractive problems with varying semantic structure	ACE students showed higher performance and more adaptive strategy use, especially on high-cost problems.	Semantic analysis training improves flexibility and efficiency in solving arithmetic word problems.
Jaspers and Van Lieshout (1994)	Evaluate a CAI program to teach text analysis and modeling of word problems to students with mild intellectual disability.	N = 5 educable mentally retarded children (ages 8 to 12)	Single-subject multiple baseline design	10 semantic types (change, combine, compare) with irrelevant info	Modest improvement in semantic steps; complex instruction may have overwhelmed cognitive resources.	Instruction must balance semantic demands with simplicity; CAI tools should scaffold, not overload learners.
Kouba (1989)	Examine children's strategies for solving multiplication and division word problems involving grouping and matching structures.	N = 128 students (grades 1-3) from Midwestern US school	Descriptive interviews with problem-solving tasks	Multiplication and division (grouping and matching)	Children used varied strategies; structure and unknown position influenced method choice.	Expose students to diverse semantic forms; scaffold transition from concrete to abstract strategies.
Lean et al. (1990)	Investigate linguistic and pedagogical factors affecting children's understanding of arithmetic word problems across two countries.	N = 2,493 children (Australia and Papua New Guinea, K-6)	Cross-sectional comparative quantitative study	Change, combine, compare problems	Relational language (e.g., 'more/less') led to misinterpretations; compare problems were hardest.	Teach semantic analysis of relational terms; align problem structure with language instruction.
Lewis (1989)	Test whether diagram training improves students' representation and accuracy on compare word problems.	N = 96 undergraduate students with initial errors on compare problems	Randomized control trial (diagram, statement, control groups)	Compare problems with consistent and inconsistent language	Diagram training improved accuracy and transfer; statement-only group underperformed.	Support integration of visual and verbal strategies to enhance comprehension.
Rabinowitz and Wooley (1995)	Determine whether comprehension and computation compete for attentional resources in solving word problems.	Experiment 1: N = 77 adults; experiment 2: N = 59 6th graders	Two experiments testing processing time and error types on semantic structures	Addition/subtraction; separate vs. join; problem size	Comprehension and computation occurred serially; separate-type problems caused more errors.	Teach problem structure distinctly from computational practice; scaffold strategies for separate types.
Savard and Polotskaia (2017)	Develop and test open-ended word problems to promote relational reasoning among elementary students.	N = 216 experimental and N = 196 control students in Quebec	Design-based research; qualitative and comparative outcome evaluation	Additive and multiplicative problems framed around real-world relationships	Experimental students improved in strategy flexibility and complex problem-solving.	Use open-ended tasks that foster mathematical relationship understanding; scaffold problem re-framing.
Schumacher and Fuchs (2012)	Determine whether understanding relational terminology mediates the effect of intervention on compare word problem performance.	N = 275 2nd grade students at risk for mathematics difficulty in the USA	Randomized controlled trial	Compare word problems with relational terms (e.g., more than, less than)	SBI + language intervention group outperformed SBI-only and control groups. Relational term understanding mediated gains.	Embedding language instruction into schema-based interventions enhances performance on relational word problems.
Willis and Fuson (1988)	Assess whether schematic drawing training improves second grader's solution of word problems with complex structures.	N = 43 2nd grade students in Illinois (high and average math ability)	Pre-post design with intervention group	Addition or subtraction word problems across multiple semantic types	Increased use of correct strategies and drawings; improvement in solving problems requiring addition for subtractive semantic structures.	Schematic drawings support flexibility and comprehension; they should be integrated into instruction across semantic types.

Table 4 (Continued). Key findings from selected studies

Reference	Study purpose	Sample	Design	Problem focus	Key findings	Implications
Sumarwati et al. (2020)	Improve students' word problem-solving abilities and teachers' practices in problem design via collaborative action research.	N = 3 4th grade teachers and their students from 6 rural Indonesian schools	Collaborative action research, 3 cycles; mixed methods	Thematic and linguistically simplified word problems	Student performance and engagement improved with clearer narratives; test scores rose to 91.75%.	Use familiar themes and simple language in word problems; co-design fosters reflective teaching and improved student outcomes.
Thevenot and Oakhill (2006)	Explore working memory's role in solving dynamic vs. static multi-step word problems in adults.	N = 42 undergraduates (21 high-span, 21 low-span)	Experimental design with operand recognition tasks	Static vs. dynamic arithmetic problems (e.g., sequential vs. simultaneous info)	Dynamic problems supported sequential strategy use and lower cognitive load; WMC influenced approach.	Problem design can ease working memory demands; consider order and representation when teaching multi-step problems.
Tyumeneva et al. (2018)	Examine semantic alignment in Russian math textbooks and students' reasoning across whole-number and rational number problems.	Russian textbooks (grades 4-7), N = 141 university students	Cross-national comparative; 2 textbook analyses + 2 experiments	Semantic alignment: operations with object symmetry and number types	Students aligned symmetric objects with addition, asymmetric with division; alignment seen despite inconsistent textbook cues.	Intuitive semantic alignment influences reasoning; explicit instruction may build more flexible heuristic use.
Vicente et al. (2007)	Investigate how situational vs. conceptual rewording affects word problem-solving accuracy and classification.	N = 152 5th and 6th grade students in Spain	Experimental design: original vs. situationally vs. conceptually reworded problems	Change, Combine, Compare problems	Conceptual rewording improved accuracy and structure classification; situational rewording had no effect.	Rewriting problems to clarify mathematical structure supports comprehension, especially for struggling students.
Xin et al. (2007)	Evaluate Chinese students' performance on realistic arithmetic word problems and effect of instructional guidance.	Study 1: N = 202 students; Study 2: N = 60 (Beijing, China)	Two-part mixed-method study with instructional intervention	Standard vs. realistic arithmetic word problems	Students defaulted to computation over real-world reasoning; process-oriented instruction improved reflective thinking.	Teachers must model real-life considerations; process-oriented prompts enhance realistic problem-solving.

Since so many factors can play into the difficulty or solution success rate of a word problem, it is encouraging to know that one of the other common themes in the research is the existence of interventions to assist students in solving word problems. Multiple researchers examined the impact of various approaches to increasing students' ability to solve word problems (Alghamdi et al., 2020; Carpenter et al., 1983; Gvozdic & Sander, 2020; Jaspers & Van Lieshout, 1994; Savard & Polotskaia, 2017; Lewis, 1989; Willis & Fuson, 1988). Unfortunately, there may be some approaches that do not work universally for all problem types (Willis & Fuson, 1988), but the research is encouraging in that it includes interventions for multiple demographics, including students with disabilities (Jaspers & Van Lieshout, 1994).

Though these key findings could be classified into only seven themes with two largely relating to word problem structure (see **Figure 5**), the breadth of information provided is so fast that one would be remiss to not further divulge into the individual contributions. Although the comprehensive analysis of the selected studies has revealed clear trends in sample types, research designs, measured outcomes, and educational contributions, providing an enhanced empirical foundation for understanding the landscape of semantic word problem research structure, it is important to acknowledge the limitations of this scoping review, which will be discussed in the subsequent section, providing the way for a deeper exploration of their implications.

DISCUSSION

The present scoping review aimed to examine the research conducted in mathematics related to the structures of semantic word problems. The study aimed to identify gaps and trends in the scope and structure of this research. The review analyzed studies between 1980 and 2020 to gain insights into how the structures of semantic word problems are examined and their impact on learning outcomes. After applying strict inclusion criteria, the scoping review process selected 26 articles for analysis. These studies focused on diverse topics, including schema-based instruction, language proficiency, and intervention strategies. By selecting a contemporary timeframe (1980-2020), the study aimed to provide a current perspective on the structures of semantic word problems research in mathematics education. The discussion will address the RQs, highlight key findings, and offer recommendations and implications for teaching and learning word problems in mathematics.

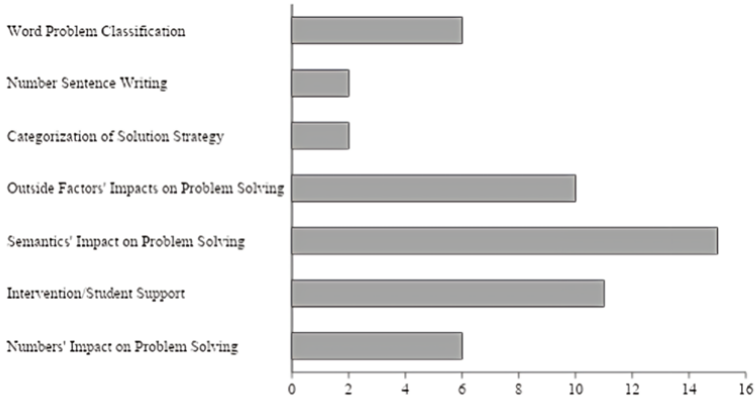

Figure 5. Educational contributions by study (Source: Authors' own elaboration)

RQ1. How Are the Structures of Semantic Word Problems Examined in Mathematics Educational Research?

The review focused on the structures of semantic word problems within elementary education, particularly in grades K-6. The research encompassed various samples, specifically emphasizing students with LD and diverse demographic groups. Both single-group analyses and multiple-group comparisons were standard, showcasing a balanced exploration of the structures of semantic word problems across different contexts. The educational contributions of the selected studies covered a broad spectrum of themes. Notably, the connection between language and the structures of semantic word problems emerged as a common thread. Studies highlighted the influence of semantic-linguistic elements on problem-solving success, emphasizing the importance of explicit relationships between given and unknown information. Moreover, the review showed the intricate relationship between solution correctness and the structures of semantics in word problems. The positioning of the unknown variable, native language proficiency, and the complexity of the structures of semantic word problems all played significant roles in influencing problem-solving outcomes. The results of the present scoping review align with and extend the findings of prior literature in mathematics education, specifically in the realm of word problem-solving structures. Notably, the contemporary focus on the structures of semantic word problems within elementary education (grade K-grade 6) echoes the broader attention given to word problem-solving in recent years, particularly for students with LD and diverse demographic groups.

RQ2. How Do These Studies Examine the Effects of Exposure to the Structures of Semantic Word Problems on Learning Outcomes?

The research design employed varied methods, with a substantial use of quantitative measures. Studies measured outcomes such as the correctness of solutions, response times, and reading comprehension scores. Quantitative data collection methods, such as interviews and single tests, were prevalent, emphasizing the importance of empirical evidence in understanding the impact of exposure to the structures of semantic word problems on learning outcomes. Additionally, interventions were identified as critical in assisting students with word problem-solving. Various approaches, tailored to different demographics, demonstrated potential for enhancing students' abilities. This finding supports the notion that targeted interventions can address challenges associated with the structures of semantic word problems.

Recommendations and Implications

1. **Tailored interventions:** The emphasis on interventions in the studies highlights the potential for tailored instructional strategies to enhance word problem-solving skills. Educators should explore diverse intervention approaches catering to the specific needs of students, including those with LD.
2. **Language considerations:** The connection between language and the structures of semantic word problems underscores the importance of considering language proficiency in mathematics education. Teachers should be aware of students' linguistic challenges and incorporate language-enhancing strategies into their instruction.
3. **Diversity in problem types:** Recognizing the variety in outcomes measured and the impact of the structures of semantic word problems on different types of word problems, educators should diversify problem types in instructional materials. This approach can help students build a robust problem-solving repertoire.
4. **Early intervention in elementary grades:** Given the prevalence of studies in elementary settings, there is a clear need for early intervention. Mathematics educators should focus on developing strong foundational skills in word problem-solving during the formative years to ensure long-term success.
5. **Research-based curriculum development:** Curriculum developers and educational policymakers should leverage the insights gained from these studies to inform the development of research-based curricula. A focus on incorporating evidence-based strategies and interventions can contribute to improved mathematics education outcomes.

This discussion section emphasized how the structures of semantic word problems are studied in mathematics education and their significant influence on learning outcomes. This section also provides recommendations for future teaching methods and curriculum updates. The conclusion section will bring these insights together, highlight the study's main contribution, and suggest a clear way forward for researchers, educators, and policymakers.

CONCLUSION

As we attempt to unravel the intricacies of mathematics teaching and learning, this scoping review has spotlighted the research surrounding the structures of semantic word problems from 1980 to 2020. The present study aimed to identify gaps and trends and shed light on the impactful connection between s the structures of semantic word problems and learning outcomes. The findings from this scoping review echo beyond the pages of research journals; they resonate in classrooms, influencing the daily interactions between educators and students.

Specifically, the identified connection between language and the structures of semantic word problems calls for heightened awareness among educators. Language proficiency is not only a tool for communication but a gateway to problem-solving success. Teachers are urged to incorporate language-enhancing strategies into their instruction, making mathematics accessible and inclusive. Additionally, recognizing the impact of semantic structures on different types of word problems, the call here is for diversity in instructional materials. By diversifying problem types, educators can empower students to build a robust problem-solving repertoire. This diversity reflects the real-world complexity of mathematical challenges.

Furthermore, the prevalence of studies in elementary settings emphasizes the urgency of early intervention. Mathematics educators are called upon to focus on developing strong foundational skills in word problem-solving during the formative years. Early intervention sets the stage for long-term success in mathematical proficiency. Finally, the insights gleaned from these studies should not reside solely within the realm of research but should permeate curriculum development. A call to action is extended to curriculum developers and educational policymakers to leverage this knowledge to create research-based curricula that leverage prior research to support mathematics word problem instruction. In doing so, the focus should be on evidence-based strategies and interventions, contributing to improved mathematics education outcomes.

In conclusion, the present scoping review guides educators, researchers, and policymakers toward a more nuanced understanding of the intricate dance between the structures of semantic word problems and successful learning outcomes. We believe that this examination of the structures of semantic word problems in elementary education was more than an academic pursuit–it is a key to unlocking effective teaching methodologies and fostering student success with mathematics word problems.

Limitation

While the scoping review employed a comprehensive methodology to gather and analyze relevant literature on the structures of semantic word problems in mathematics education, certain limitations need to be acknowledged to provide a transparent understanding of the study's scope and potential implications. First, the reliance on Google Scholar as the primary electronic database might introduce a bias in the selection of studies. Google Scholar, although inclusive, may not cover all relevant scholarly literature, potentially omitting articles from databases with stricter subscription and publisher agreement models. This could result in overlooking valuable contributions to the field. Second, the inclusion criterion specifying peer-reviewed journals and original research might inadvertently exclude valuable insights published in other formats, such as conference proceedings. This may lead to an underrepresentation of certain perspectives and findings that contribute to the overarching understanding of the structures of semantic word problems. However, the decision was made impartially due to the fact that many of the duplicates eliminated were conference proceedings, dissertations, or master's theses of peer-reviewed published works. Finally, several articles contained more than one study, introducing complexity in data retrieval. While efforts were made to account for each study individually, this multiplicity might pose challenges in synthesizing and comparing findings across studies. Recognizing these limitations is crucial for interpreting the findings and ensuring that the scoping review's outcomes are viewed through a nuanced lens. Future research endeavors should strive to address these limitations, extending the breadth and depth of our understanding of the structures of semantic word problems in mathematics education.

Author contributions: JRY: conceptualization, methodology, supervision, writing - original draft, writing - review & editing; **JEC:** data curation, formal analysis, writing – review & editing; **LX:** investigation, visualization, writing – review & editing; **KE:** validation, writing – review & editing. All authors have reviewed and approved the final manuscript.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that the study is a scoping review of publicly available peer-reviewed literature and does not involve human participants, animal subjects, or identifiable personal data. As a result, institutional ethical approval and participant consent were not necessary.

AI statement: The authors stated that the manuscript was written and analyzed without the use of generative AI or AI-based tools.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Alghamdi, A., Jitendra, A. K., & Lein, A. E. (2020). Teaching students with mathematics disabilities to solve multiplication and division word problems: The role of schema-based instruction. *ZDM Mathematics Educatio, 52*, 125-137. https://doi.org/10.1007/s11858-019-01078-0

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19-32. https://doi.org/10.1080/1364557032000119616

Bernardo, A. B. (1999). Overcoming obstacles to understanding and solving word problems in mathematics. *Educational Psychology, 19*(2), 149-163. https://doi.org/10.1080/0144341990190203

Boonen, A. J., de Koning, B. B., Jolles, J., & van der Schoot, M. (2016). Word problem solving in contemporary math education: A plea for reading comprehension skills training. *Frontiers in Psychology, 7*. https://doi.org/10.3389/fpsyg.2016.00191

Carey, D. A. (1991). Number sentences: Linking addition and subtraction word problems and symbols. *Journal for Research in Mathematics Education, 22*(4), 266-280. https://doi.org/10.2307/749272

Carpenter, T. P., Hiebert, J., & Moser, J. M. (1983). The effect of instruction on children's solutions of addition and subtraction word problems. *Educational Studies in Mathematics, 14*(1), 55-72. https://doi.org/10.1007/BF00704702

Clausen, A. M., Tapp, M. C., Pennington, R. C., Spooner, F., & Teasdell, A. (2021). A systematic review of modified schema-based instruction for teaching students with moderate and severe disabilities to solve mathematical word problems. *Research and Practice for Persons with Severe Disabilities*, *46*(2), 94-107. https://doi.org/10.1177/15407969211007561

Cook, S. C., Collins, L. W., Morin, L. L., & Riccomini, P. J. (2019). Schema-based instruction for mathematical word problem solving: An evidence-based review for students with learning disabilities. *Learning Disability Quarterly*, *43*(2), 75-87. https://doi.org/10.1177/0731948718823080

Cummins, D. D. (1991). Children's interpretations of arithmetic word problems. *Cognition and Instruction, 8*(3), 261-289. https://doi.org/10.1207/s1532690xci0803_2

De Corte, E. & Verschaffel, L. (1985). Influence of rewording verbal problems on children's problem representations and solutions. *Journal of Educational Psychology, 77*(4), 50-56. http:// doi.org/10.1037/0022-0663.77.4.460

De Corte, E., & Verschaffel, L. (1987). The effect of semantic structure on first graders' strategiesfor solving addition and subtraction word problems. *Journal for Research in Mathematics Education, 18*(5), 363-381. https://doi.org/10.2307/749085

De Corte, E., Verschaffel, L., & Pauwels, A. (1990). Influence of the semantic structure of word problems on second graders' eye movements. *Journal of Educational Psychology, 82*(2), 359-365. https://doi.org/10.1037/0022-0663.82.2.359

Frostad, P., & Ahlberg, A. (1999). Solving story-based arithmetic problems: Achievement of children with hearing impairment and their interpretation of meaning. *Journal of Deaf Studies and Deaf Education, 4*(4), 283-293. https://doi.org/10.1093/deafed/4.4.283

Fuchs, L. S., Seethaler, P. M., Sterba, S. K., Craddock, C., Fuchs, D., Compton, D. L., Geary, D. C., & Changas, P. (2021). Closing the word-problem achievement gap in first grade: Schema-based word-problem intervention with embedded language comprehension instruction. *Journal of Educational Psychology, 113*(1), 86-103. https://doi.org/10.1037/edu0000467

García, A. I., Jiménez, J. E., & Hess, S. (2006). Solving arithmetic word problems: An analysis of classification as a function of difficulty in children with and without arithmetic LD. *Journal of Learning Disabilities, 39*(3), 270-281. https://doi.org/10.1177/00222194060390030601

Goulet-Lyle, M. P., Voyer, D., & Verschaffel, L. (2020). How does imposing a step-by-step solution method impact students' approach to mathematical word problem solving? *ZDM Mathematics Education, 52*, 139-149. https://doi.org/10.1007/s11858-019-01098-w

Gvozdic, K., & Sander, E. (2020). Learning to be an opportunistic word problem solver: Going beyond informal solving strategies. *ZDM Mathematics Education, 52*, 111-123. https://doi.org/10.1007/s11858-019-01114-z

Jaspers, M. W., & Van Lieshout, E. C. (1994). The evaluation of two computerised instruction programs for arithmetic word-problem solving by educable mentally retarded children. *Learning and Instruction, 4*(3), 193-215. https://doi.org/10.1016/0959-4752(94)90023-X

Jitendra, A. K. (2019). Using schema-based instruction to improve students' mathematical word problem solving performance. In A. Fritz, V. G. Haase, &P. Räsänen (Eds.), *International handbook of mathematical learning difficulties: From the laboratory to the classroom* (pp. 595-609). Springer. https://doi.org/10.1007/978-3-319-97148-3_35

Khalaf, B., Al-Abbas, L., Mahmood, I., & Jaalout, O. (2025). Enhancing translation pedagogy: Exploring learners' cognitive loads using contextual instruction. *Educational Process: International Journal, 17*, Article e2025325. https://doi.org/10.22521/edupij.2025.17.325

Kim, D., Park, K., & Lee, S. (2022). A synthesis of computer-assisted mathematical wordproblem-solving instruction for students with learning disabilities or difficulties. *Remedial and Special Education, 42*(6), 337-350. https://psycnet.apa.org/record/2023-24447-002

Kong, J. E., Yan, C., Serceki, A., & Swanson, H. L. (2021). Word-problem-solving interventions for elementary students with learning disabilities: A selective meta-analysis of the literature. *Learning Disability Quarterly*, *44*(4), 248-260. https://doi.org/10.1177/0731948721994843

Kouba, V. L. (1989). Children's solution strategies for equivalent set multiplication and division word problems. *Journal for Research in Mathematics Education, 20*(2), 147-158. https://doi.org/10.2307/749279

Lean, G. A., Clements, M. A., & Del Campo, G. (1990). Linguistic and pedagogical factors affecting children's understanding of arithmetic word problems: A comparative study. *Educational Studies in Mathematics, 21*(2), 165-191. https://doi.org/10.1007/BF00304900

Lewis, A. B. (1989). Training students to represent arithmetic word problems. *Journal of Educational Psychology, 81*(4), 521-531. https://doi.org/10.1037/0022-0663.81.4.521

Lin, X. (2021). Investigating the unique predictors of word-problem solving using meta-analytic structural equation modeling. *Educational Psychology Review*, *33*(3), 1097-1124. https://doi.org/10.1007/s10648-020-09554-w

Liu, J., Sun, D., Sun, J., Wang, J., & Yu Philip, L. H. (2025). Designing a generative AI enabledlearning environment for mathematics word problem solving in primary schools: Learning performance, attitudes and interaction. *Computers and Education: Artificial Intelligence, 25*, Article 100438. https://doi.org/10.1016/j.caeai.2025.100438

Mandal, S., & Naskar, S. K. (2021). Classifying and solving arithmetic math word problems–Anintelligent math solver. *IEEE Transactions on Learning Technologies, 14*(1), 28-41. https://doi.org/10.1109/TLT.2021.3057805

McDonald, C. V. (2016). STEM education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International, 27*(4), 530-569. http://hdl.handle.net/10072/380672

Orru, G., & Longo, L. (2019). Direct instruction and its extension with a community of inquiry: A comparison of mental workload, performance, and efficiency. In *Proceedings of the 11th International Conference on Computer Supported Education (CSEDU 2019)* (Vol. 1, pp. 436-444). SCITEPRESS. https://doi.org/10.5220/0007757204360444

Pongsakdi, N., Kajamies, A., Veermans, K., Lertola, K., Vauras, M., & Lehtinen, E. (2020). What makes mathematical word problem solving challenging? Exploring the roles of word problem characteristics, text comprehension, and arithmetic skills. *ZDM Mathematics Education , 52*, 33-44. https://doi.org/10.1007/s11858-019-01118-9

Powell, S. R., Berry, K. A., Fall, A. M., Roberts, G., Barnes, M. A., Fuchs, L. S., Martinez-Lincoln, A., Forsyth, S. R., Vinsonhaler, R. K., Benz, S. A., Zaparolli, B. L., & Lin, X. (2022). Does word-problem performance maintain? Follow-up one year after Implementation of a word-problem intervention. *Journal of Research on Educational Effectiveness, 15*(1), 52-77. https://doi.org/10.1080/19345747.2021.1961332

Rabinowitz, M., & Wooley, K. E. (1995). Much ado about nothing: The relation among computational skill, arithmetic word problem comprehension, and limited attentional resources. *Cognition and Instruction, 13*(1), 51-71. https://doi.org/10.1207/s1532690xci1301_2

Riley, M. S., Greeno, J. G., & Heller, J. I. (1983). Development of children's problem-solving ability in arithmetic. In H. P. Ginsburg (Ed.), *The development of mathematical thinking* (pp. 153-196). Academic Press.

Savard, A., & Polotskaia, E. (2017). Who's wrong? Tasks fostering understanding of mathematical relationships in word problems in elementary students. *ZDM Mathematics Education, 49*, 823-833. https://doi.org/10.1007/s11858-017-0865-5

Schumacher, R. F., & Fuchs, L. S. (2012). Does understanding relational terminology mediate effects of intervention on compare word problems? *Journal of Experimental Child Psychology, 111*(4), 607-628. https://doi.org/10.1016/j.jecp.2011.12.001

Secada, W. G. (1991). Degree of bilingualism and arithmetic problem solving in Hispanic first graders. *The Elementary School Journal, 92*(2), 213-231. https://doi.org/10.1086/461689

Shakarian, P., Koyyalamudi, A., Ngu, N., & Mareedu, L. (2023). *An independent evaluation of ChatGPT on mathematical word problems (MWP)*. arXiv. https://doi.org/10.48550/arXiv.2302.1381

Shin, M., Bryant, D. P., Powell, S. R., Jung, P.-G., Ok, M. W., & Hou, F. (2020). A meta-analysis of single-case research on word-problem instruction for students with learning disabilities. *Remedial and Special Education*, *42*(6), 398-411. https://doi.org/10.1177/0741932520964918

Sumarwati, E. S., Pujosudarmo, S., & Nurkamto, J. The types of word problem discourse structure in mathematics textbook presented in Indonesian for primary school students. *Journal of Education and Practice, 5*(12), 151-162. https://www.researchgate.net/profile/Sumarwati-Sumarwati/publication/341270683_The_Types_of_Word_Problem_Discourse_Structure_in_Mathematics_Textbook_Presented_In_Indonesian_For_Primary_School_Students/links/5eb6b8e44585152169c11d74/The-Types-of-Word-Problem-Discourse-Structure-in-Mathematics-Textbook-Presented-In-Indonesian-For-Primary-School-Students.pdf

Suseelan, M., Chew, C. M., & Chin, H. (2022). Research on mathematics problem solving in elementary education conducted from 1969 to 2021: A bibliometric review. *International Journal of Education in Mathematics, Science, and Technology, 10*(4), Article 10031029. https://doi.org/10.46328/ijemst.2198

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257-285. https://doi.org/10.1016/0364-0213(88)90023-7

Thevenot, C., & Oakhill, J. (2006). Representations and strategies for solving dynamic and static arithmetic word problems: The role of working memory capacities. *European Journal of Cognitive Psychology, 18*(5), 756-775. https://doi.org/10.1080/09541440500412270

Tyumeneva, Y. A., Larina, G., Alexandrova, E., DeWolf, M., Bassok, M., & Holyoak, K. J. (2018). Semantic alignment across whole-number arithmetic and rational numbers: Evidence from a Russian perspective. *Thinking & Reasoning, 24*(2), 198-220. https://doi.org/10.1080/13546783.2017.1374307

Verschaffel, L., Depaepe, F., & Van Dooren, W. (2020). Word problems in mathematics education. In S.Lerman (Ed.), *Encyclopedia of mathematics education* (pp. 908-911). Springer. https://doi.org/10.1007/978-3-030-15789-0_163

Vicente, S., Orrantia, J., & Verschaffel, L. (2007). Influence of situational and conceptual rewording on word problem solving. *British Journal of Educational Psychology, 77*(4), 829-848. https://doi.org/10.1348/000709907X178200

Wan, Z. H., Jiang, Y., & Zhan, Y. (2021). STEM education in early childhood: A review of empirical studies. *Early Education and Development, 32*(7), 940-962. https://doi.org/10.1080/10409289.2020.1814986

Wardat, Y., Tashtoush, M. A., AlAli, R., & Jarrah, A. M. (2023). ChatGPT: A revolutionary toolfor teaching and learning mathematics. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(7), Article em2286. https://doi.org/10.29333/ejmste/13272

Westby, C. (2018). Cognitive Load and Learning. *Word of Mouth*, *29*(4), 8-12. https://doi.org/10.1177/1048395018759556b

Willis, G. B., & Fuson, K. C. (1988). Teaching children to use schematic drawings to solve addition and subtraction word problems. *Journal of Educational Psychology, 80*(2), 192-201. https://doi.org/10.1037/0022-0663.80.2.192

Xin, Y. P. (2007). Word problem solving tasks in textbooks and their relation to student performance. *The Journal of Educational Research, 100*(6), 347-360. https://doi.org/10.3200/JOER.100.6.347-360

Young, J. R., Bevan, D., & Sanders, M. (2024). How productive is the productive struggle? Lessons learned from a scoping review. International *Journal of Education in Mathematics, Science, and Technology, 12*(2), 470-495. https://doi.org/10.46328/ijemst.3364