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EMPIRICAL ARTICLE

CHILD DEVELOPMENT

Exploring academic and cognitive skills impacting retention and acquisition of word-problem knowledge gained during or after intervention

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Abstract
In the present study, we investigated the impact of a word-problem intervention in retention and acquisition of knowledge after the intervention ended. We based analyses upon Grade 4 students experiencing mathematics difficulty (average age at pretest = 8.77) who received one of two variants of a word-problem intervention (with [n = 111] vs. without [n = 110] embedded pre-algebraic reasoning instruction) and students within a business-as-usual condition (BaU [n = 127]) separately. Findings revealed that students who received the intervention not only tended to retain less, but they also showed more active knowledge acquisition after the intervention ended. Furthermore, word-problem intervention altered the contributions of some prior knowledge and skills on both retention and acquisition.

Based on randomized controlled trials (RCT) that aim to determine the most effective ways to optimize students' academic outcomes, some researchers are able to conduct follow-up testing to assess the persistence of intervention effects (e.g., Dyson et al., 2020; Powell et al., 2022). Yet, follow-up testing of such significant intervention effects often fades over time, indicating the need for a deeper understanding of the key factors supporting such persistence (e.g., Bailey et al., 2020; Kang et al., 2019). Fadeout is a pattern where the initial effect of an intervention for students who received the intervention diminished after the end of the intervention relative to the students not receiving the intervention (i.e., a control condition), often because control students catch up to students who participated in intervention (Kang et al., 2019). Fadeout may also be attributed to students forgetting some of the knowledge they learned during intervention. In contrast, persistence refers to a pattern in which the initial intervention effect for participating students relative to control students maintained beyond the end of intervention. A common finding is that the intervention group slows down their growth in the posttreatment period, and control students catch up (Bailey et al., 2020).

After an intervention ceases, students in intervention and control may experience differential rates of learning, and this may be based on the knowledge and skills gained during the intervention or after the intervention (Powell et al., 2022). Another reason for differential rates of learning post intervention may be key student-level skills that impact their responsiveness to intervention, such as students' pre-intervention academic knowledge (e.g., Fuchs et al., 2019; Powell et al., 2017). Given that previous skills serve as the foundation for later mathematics learning, the efficacy of interventions may vary as a function of these initial skills (Bailey et al., 2020; Fuchs et al., 2019). In addition to pre-intervention academic knowledge, students' cognitive capacity may also impact students' responsiveness to intervention (Powell et al., 2017).

Currently, little is known regarding factors that may impact persistence of intervention effects, which in this study we will refer to as *retention* (i.e., answering an item correctly at posttest and answering the same item correctly at follow-up testing) or *acquisition* of knowledge after intervention (i.e., answering an item incorrect at posttest but answering the same item

Abbreviations: BaU, business-as-usual; MD, mathematics difficulty; PM, Pirate Math; PMEQ, Pirate Math Equation Quest; RCT, randomized controlled trials; WPS, word-problem solving.

correctly at follow-up testing). Given that students with pre-intervention academic and cognitive advantages demonstrate more rapid gains in mathematical achievement than peers without the same advantages (Geary et al., 2017; Lin & Powell, 2023), how pre-intervention skills impact the retention of knowledge gained through intervention and acquisition of knowledge after intervention is worth exploring. In this study, we included a relatively comprehensive set of pre-intervention academic and cognitive skills. We explored their contributions in the retention and acquisition of word-problem knowledge that students gained during and after intervention to inform intervention advancement.

In this introduction, we explain the necessity of exploring skills that may support the retention and acquisition of knowledge. Then, we present the academic and cognitive skills of interest in this study and discuss how they relates to solving word problems. Finally, we discuss theoretical and practical importance of the present study.

Exploring factors facilitating retention and acquisition

Numerous factors before, during, and after an intervention may affect retention. On one hand, retention of intervention knowledge may be challenging—although intervention students may learn more than they would otherwise, it is plausible that they may subsequently forget more. Likewise, subsequent post-intervention instruction in the classroom may hinder the retention of intervention materials because newly learned information creates a potential for competition with preexisting information stored in memory (Bjork, 2011). Conversely, it is possible that students do not forget the information they learned in an intervention, particularly if the intervention's content is aligned with the material taught in the classroom.

Similarly, numerous factors may affect acquisition of knowledge after the intervention ceases. One factor may be transfer, which is the capacity to take skills learned in one context and apply them in a novel context (Klahr & Chen, 2011). Another factor that may affect acquisition might be related to the natural progression of learning. As outlined in mathematics standards (e.g., National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and emphasized in longitudinal studies of mathematics, easier mathematics knowledge is essential for more complex mathematics knowledge (Lin & Powell, 2022). The constant practice opportunities in mathematics materials and classroom instruction may allow students within intervention conditions to link their knowledge gained during the intervention to what is taught in classrooms. Therefore, intervention may improve students' relevant prior knowledge and thus better equip them for future knowledge acquisition in classroom instruction.

Our current understanding of factors that support the retention or acquisition of knowledge after participation in academic interventions is limited. First, although previous studies have investigated factors that facilitate learning in a natural progression (e.g., Lin, 2021; Spencer et al., 2020), it is unclear how intervention may impact their predicting paths. Second, intervention research has investigated pre-intervention academic and cognitive skills that affect the acquisition of knowledge during interventions (e.g., Fuchs et al., 2019; Powell et al., 2017). However, it remains unclear how these skills continue to affect knowledge acquisition after the intervention has ended.

Word-problem intervention and relevant academic and cognitive skills

In this study, we based our analyses on a word-problem intervention implemented in Grade 3 (Powell et al., 2021) that measured follow-up effects in Grade 4 (Powell et al., 2022). Powell et al.'s (2021) RCT investigated whether word-problem intervention with or without an embedded pre-algebraic reasoning component improved the word-problem performance of third-grade students with mathematics difficulty (MD) when compared to students in a business-as-usual (BaU) condition. With an eye on persistence of effects, Powell et al. (2022) assessed participating students 6–12 months later in fourth grade. Their findings revealed a significant advantage at immediate posttest in Grade 3 for students who participated in the word-problem interventions compared to students in the control. However, this advantage became almost insignificant at follow-up testing in Grade 4. This difference in effects at posttest and follow-up suggests it is crucial to investigate factors that may or may not facilitate the persistence of the word-problem intervention effects.

In this study, we focused on academic knowledge and cognitive skills, as measured at pretest, that may have affected retention and acquisition of knowledge from posttest to follow-up testing. *Academic knowledge* refers to students' prior knowledge before engaging in the intervention. Pre-intervention academic knowledge is important for the retention and acquisition of knowledge after intervention because it provides a foundation for building knowledge (Simonsmeier et al., 2022). It becomes easier to acquire new knowledge when a student already has some prior knowledge in the subject matter because the student can relate new information to what they already know (Simonsmeier et al., 2022). And students can also retrieve and apply newly learned information more effectively over time, which thereby facilitates retention. *Cognitive skills* are important for the retention of knowledge gained through intervention because they are the mental processes that allow individuals to acquire, understand, and use information (Cattell, 1987; Van Der Maas et al., 2006). When students have strong cognitive skills, they are better able to process and integrate new information, which can enhance the retention and acquisition of knowledge after intervention. By understanding the relative roles of pre-intervention academic and cognitive skills, we can design and adapt interventions accordingly.

Academic knowledge

Prior work provides the basis for hypothesizing pre-algebra and reading skills are crucial for problem representation, whereas arithmetic skills are essential for problem solution (Kintsch & Greeno, 1985). With respect to pre-algebra, we involved two measures of equation solving, one with standard (e.g., equations with the equal sign in its standard position, second-to-last in an equation) and nonstandard (e.g., equations with the equal sign in a nonstandard position) equations and one with only nonstandard addition equations. We included both of these measures because students often use equations to represent the mathematical relations between different variables presented in word problems. Transforming problem narratives into algebraic equations remains a key source of error in word-problem solving (Geary et al., 2008). Also, in the category of pre-algebra, we administered a measure of equal-sign understanding because students must have a relational understanding of the equal sign in order to accurately solve different types of standard and nonstandard equations (Powell et al., 2020).

For reading skills, we considered decoding (i.e., word reading accuracy) because decoding is essential for extracting the necessary information and interpreting the language used in word problems (Fuchs et al., 2015). We also used a measure of reading fluency because such capacity allows students to read and comprehend the problem statement quickly and accurately (Lin & Powell, 2022). According to the Simple View of Reading (Gough & Tunmer, 1986), students' comprehension of word problems is largely constrained by word reading accuracy and fluency. In addition, we administered a measure of vocabulary because understanding and recognizing vocabulary terms is important for accurately interpreting the problem. Finally, we included a measure of reading comprehension because understanding problem statements is a form of reading comprehension (Björn et al., 2016; Fuchs et al., 2015).

Regarding arithmetic skills, we included single-digit addition and subtraction to gauge a student's ability to rapidly and precisely recall math facts. Such capacity is essential for performing arithmetic operations within word problem-solving and freeing up mental resources to concentrate on other aspects of problem solving (Fuchs et al., 2006). In addition to single-digit operations, we included double-digit addition and subtraction due to their significance in solving word problems that involve larger numbers and multiple steps. Proficiency in manipulating numbers enhances understanding of numerical relations, which is crucial for accurately solving word problems (Gilbert & Fuchs, 2017; Lin, 2021). Finally, we used a measure of numeration because such foundational knowledge forms the basis for more advanced mathematical reasoning and problem solving. Strong understanding of numeration enables students to flexibly apply mathematical concepts to real-world situations (Geary et al., 2013).

Cognitive skills

Regarding cognitive skills, we included verbal and nonverbal reasoning. Even though prior research has highlighted the unique impact of nonverbal reasoning on solving word problems (e.g., Fuchs et al., 2015; Lin, 2021; Spencer et al., 2020), we involved verbal reasoning because it yielded unique impact on reading comprehension above and beyond the effect of nonverbal reasoning (Lakin & Lohman, 2011). Given that word-problem solving is a form of reading comprehension (Fuchs et al., 2015), we included verbal and nonverbal reasoning to investigate their relative impacts. In addition to reasoning, we explored the roles played by executive functions: working memory and switching. Working memory is crucial for solving word problems because it enables students to hold and manipulate relevant information in mind, selectively attend to relevant information, and use problem-solving strategies effectively (Lee et al.,2009). Switching may be necessary for the representation of problems (Lee et al., 2009). For example, students need to possess the skills to invert and comprehend the equivalence between "x more than y is z" and "x fewer than z is y" semantically. These abilities to invert and assess the veracity of diverse propositions are postulated to be closely linked with the capacity to switch between various mental representations.

Theoretical and practical importance

Theoretically, this study can deepen our understanding of knowledge acquisition after receiving intervention by comparing it to the natural progression of learning. The effects of an intensive academic intervention on the relation between prior knowledge and subsequent knowledge acquisition remain unclear. The present study's findings could shed light on the retention and acquisition of knowledge after the end of intervention by comparing the predictors of these processes between intervention and control students. Suppose the intervention group shows a significant difference from the control group in the impact of initial skills on subsequent mathematics performance. In that case, this finding will highlight the importance of intensive academic interventions as they can modify the cumulative nature of mathematics knowledge. Conversely, if there is no significant difference in the predictors that facilitate retention and acquisition of knowledge between the intervention and control groups, it would suggest that intervention has no or minimal impact on students' natural knowledge progression.

Exploring skills impacting the retention and acquisition of word-problem knowledge gained during or after the intervention is critical for intervention purposes. The present word-problem intervention involved instructional activities focused on building foundational academic knowledge for setting up and solving word problems (e.g., fluency practice with addition and subtraction mathematics facts). However, the relative roles of these skills in supporting the retention and acquisition of skills acquired through intervention are unclear. Given that the word-problem intervention targeted several academic knowledge (e.g., mathematics fact fluency, pre-algebraic reasoning), disentangling their relative contributions is critical. Suppose the retention of word-problem knowledge mainly depends on a few foundational academic knowledge, such as single-digit addition and subtraction or pre-algebra. We may need to adjust the instructional time within the intervention for these activities. If, however, some cognitive skills (e.g., nonverbal reasoning) demonstrate more or unique impacts on the retention of word-problem knowledge, we should consider those factors while designing interventions for students with MD. In sum, investigating factors that facilitate the acquisition of knowledge after participating in an academic intervention is crucial for advancing our understanding of how students learn math and how intervention can be optimized.

Purpose and research questions

The present study represents an important advance in the intervention literature. On the one hand, we explored pretest knowledge and skills essential for retention or acquisition of word-problem knowledge during and after intervention, to date, no study has investigated such a question. Although previous studies have clarified the relative contributions of academic and cognitive skills in solving word problems in natural progression (e.g., Lin, 2021; Singer et al., 2018) or in students' responsiveness to intervention (e.g., Fuchs et al., 2019; Powell et al., 2017), it is unclear if intensive intervention would impact their relative impacts on the retention and acquisition of word-problem knowledge. By comparing the unique skills facilitating retention and acquisition of knowledge during and after intervention between intervention and control conditions, we would learn the impacts of intervention on retention and acquisition of knowledge, respectively. Additionally, the present study provides further insight into whether the embedded pre-algebraic reasoning component in a word-problem intervention affects the retention and acquisition of word-problem knowledge compared to the students in a word-problem intervention alone condition.

We incorporated a comprehensive range of knowledge and skills in the model considering that solving word problem is a complex process that engages various conceptually distinct and related academic and cognitive skills. It is essential to examine these skills individually but also in a coordinated manner. The use of elastic net regression, a variable selection method, allowed us to explore and identify skills that uniquely facilitate retention and acquisition of knowledge from this comprehensive set. For example, we included two operations within arithmetic (i.e., addition and subtraction). We also distinguished single-digit and double-digit problems that students may adopt distinct strategies to solve (e.g., memory-based retrieval with single-digit problems versus algorithms for double-digit problems; Caviola et al., 2018).

In this study, we investigated three research questions. First, will the efficacy of the intervention disappear after the intervention ceases one year later? If so, to what extent will intervention and BaU students differ in the retention and acquisition of knowledge during and after intervention? Second, which academic and cognitive skills support the retention and acquisition of word-problem knowledge gained during and after intervention? Third, does the pre-algebraic reasoning component of a word-problem intervention impact the retention and acquisition of word-problem knowledge?

METHOD

In the word-problem intervention study, which evaluated the efficacy of word-problem intervention with and without an embedded pre-algebraic reasoning component, we recruited three cohorts of third-grade students experiencing MD for three consecutive years from a large urban school district in the Southwest of the U.S. Cohort 1 participated during the 2016–2017 school year. We randomly assigned students experiencing MD to 1 of 3 conditions, blocking by classroom teachers: PMEQ (Pirate Math Equation Quest; i.e., word-problem intervention with embedded pre-algebraic reasoning), PM-alone (Pirate Math alone; i.e., word-problem intervention without pre-algebraic reasoning), and a control group (BaU; i.e., no word-problem intervention from research team).

For pretesting, our sample sizes included 450 students across the three cohorts with 155 PMEQ students, 131 PM-alone students, and 164 BaU students. We completed posttesting at third grade with 415 students across the three cohorts, with 122 students within condition. In their fourth-grade year, we completed follow-up testing with 111 students within the PMEQ condition, 110

PM-alone students, and 127 BaU students. Thus, the sample included 348 students with complete data on the posttest and follow-up variables used in the analysis. We gather data on three occasions. The first is the pretest, which takes place in September/October of Grade 3. The second is the posttest, which takes place in March and April of Grade 3. The third is the follow-up, which takes place from October to March of Grade 4. An overall attrition rate of 16.1% combined with a differential attrition rate of 7.9% (PM-alone vs. PMEQ), 9.8% (PM-alone vs. BaU), and 1.8% (PMEQ vs. BaU) represents a tolerable threat of bias under optimistic assumptions set by What Works Clearinghouse (2017).

We worked with three cohorts of third graders, ages 8.08–10.08 years at pretest (M = 8.77, SD = 0.47). We used *Single-Digit Word Problems* to screen students with MD (Jordan & Hanich, 2000). Students with MD were determined if they answered seven or fewer items correctly (out of 14) and considered eligible for this study. This cut-off score of seven indicated performance at or below the 25th percentile. In 2021, the school district reported 55% of students as Hispanic, 30.1% as White, 6.6% as Black, and 8.3% as belonging to another racial or ethnic category. In the district, 31.2% of students qualified as English learners, and 13.3% received special education services. Overall, 51.9% of students in the school district qualified as economically disadvantaged. Table 1 presents the demographics for the analyzed sample.

Word-problem intervention

For a detailed description of the two variations of the word-problem intervention, see Powell et al. (2021). In this section, we provide a brief overview. Each session in both word-problem intervention conditions included five activities: (1) Math Fact Flashcards, (2) Equation Quest or Pirate Crunch, (3) Buccaneer Problems, (4) Shipshape Sorting, and (5) Jolly Roger Review. Only one activity (i.e., Equation Quest or Pirate Crunch) differed for students in the two intervention conditions. Students in the two variants of word-problem intervention attended 45–51 individual sessions (30 min each) in which students learned about the additive word-problem schemas (i.e., Total, Difference, Change) and how to build up and solve word problems utilizing schema knowledge. Students in PMEQ practiced understanding the equal sign as relational and solving standard (e.g., 2 + _ = 5) and nonstandard (e.g., 5 = 8 − _ or 7 + _ = 6 + 5) equations for 2–5 min each session. Instead, students in PM-alone completed 2 to 4 min of review activities each session on telling time, money, geometry, perimeter, area, place value, and fractions.

TABLE 1 Demographics by condition.

	PM-alone (*n* = 110) %	PMEQ (*n* = 111) %	Control (*n* = 127) %
Demographics			
Female	58.18	53.85	57.48
Race			
Black	10.91	10.58	14.17
White	10.00	5.77	3.15
Hispanic/Latino	72.73	74.04	68.50
Other	6.36	9.61	13.65
English learner	61.11	62.73	55.91
SPED education	11.82	10.58	12.60

Note: Demographics were only available for 343 students involved in the analysis. And five students with complete posttest and follow-up had missing demographic information.

Abbreviations: PM, Pirate Math; PMEQ, Pirate Math Equation Quest.

Measures

At pretest, we assessed students' word-problem solving, arithmetic competencies, pre-algebraic knowledge, reading competencies, and cognitive competencies. At posttest and follow-up testing, we assessed students' word-problem solving.

Pre-intervention arithmetic predictors

Single-digit addition and subtraction

We measured single-digit addition with *Addition Fact Fluency* (Fuchs et al., 2003), which comprised 25 addition fact problems with sums from 0 to 18. Single-Digit Subtraction, measured with *Subtraction Fact Fluency* (Fuchs et al., 2003), comprises 25 subtraction fact problems with minuends from 0 to 18. Each subtest lasted 1 min. The score was the number of correct answers. For this sample, Cronbach's alpha was .87 for single-digit addition and .84 for single-digit subtraction.

Double-digit addition and subtraction

Students completed two-digit by two-digit addition and subtraction problems with and without regrouping in *Double-Digit Addition* and *Double-Digit Subtraction* (Fuchs et al., 2003). Students had 3 min to complete 20 problems on each subtest. Cronbach's alpha was .92 for double-digit addition and .80 for double-digit subtraction.

Numeration

We administered the Numeration subtest of the *Key Math-3 Diagnostic Assessment* (Connolly, 2007). It measured mathematics foundational skills related to whole and rational numbers, such as counting, arithmetic, and place value. As reported by Connolly (2007), split-half reliability ranges from .97 to .99.

Pre-intervention pre-algebraic predictors

Standard and nonstandard equations

We used *Open Equations* (Powell, 2007) to assess students' ability to solve 30 standard and nonstandard equations. On the measure, 10 equations featured the equal sign in its standard position (e.g., 3+__=8). Students also completed 20 equations in nonstandard formats, which included two identity statements (e.g., __=4), 10 nonstandard equations with an operator symbol on the right side (e.g., 5=9−__), and eight nonstandard equations with operator symbols on both sides (e.g., 9–6=7−__). Apart from the identity statements, 14 equations included addition operator symbols and 14 included subtraction operator symbols. Within the 6-min limit, students completed as many problems as possible. With a maximum score of 30, we scored this measure as the number of correct answers. Cronbach's α was .82.

Nonstandard addition

Nonstandard Addition (Powell, 2015) assessed students' ability to solve 14 open nonstandard equations with operator symbols (i.e., addition sign) on both sides in 3 min. All equations included addition operator symbols. Two problems featured the same numbers on both sides of the equal sign (e.g., 6+2=6+__), two problems used the same numbers but in reverse (e.g., 4+__=2+4), two problems involved grouping of addends (e.g., 2+3+4=2+__), and the remaining eight problems required solving for a missing part without a pattern (e.g., 5+__=3+4). Cronbach's α was .82.

Equal-sign understanding

Equal-Sign Tasks (Matthews & Rittle-Johnson, 2009), assessed students' understanding of the equal sign and equivalence in written format. First, examiners required students to write a definition of the equal sign. Students then determined whether the equal sign was correctly employed in nonstandard, closed equations. Then, students read statements of equivalence and determined whether each statement was always true, sometimes true, or never true. Finally, students viewed a closed equation with addends on both sides, broke the equation into two parts, and described what the equal sign meant in the equation. The highest possible score was 14. Cronbach's α was .60 for this sample.

Pre-intervention reading predictors

Decoding

To assess reading accuracy, we relied on the *Wide Range Achievement Test (WRAT-4) Word Reading* (Wilkinson & Robertson, 2006). *Word Reading* measured letter and word decoding through letter identification and word recognition on 55 items. Total scores reflected the word score plus the letter score. At 10 incorrect consecutive responses of 0, the interventionist terminated the test. Test–retest reliability was .86 (Wilkinson & Robertson, 2006).

Reading fluency

We utilized the *Test of Word Reading Efficiency-Second Edition* (TOWRE-2; Torgesen et al., 2012) for reading fluency. The TOWRE-2 assessed a student's ability to pronounce printed words by accurately reading as many real words printed in vertical lists in 45 s. Reliability coefficients ranged from .87 to above .90 (Torgesen et al., 2012).

Vocabulary

We utilized the *WASI-II Vocabulary* to measure word knowledge and verbal concept formation with three picture items and 22 verbal terms. For the picture items, students named the object presented visually. For the verbal items, students defined words shown visually and orally. Students defined words until the end of the test or until reaching a ceiling of five consecutive erroneous responses. Split-half reliability ranges between .86 and .87 (Zhu, 1999).

Reading comprehension

We used the *Woodcock Johnson-IV* (WJ-IV) *Passage Comprehension* (Schrank et al., 2014). Students read a short passage and identified a missing key word in the passage. Total scores counted correct responses with a ceiling of six consecutive incorrect responses of 0. The test-reliability coefficient was .89 (Schrank et al., 2014).

Pre-intervention cognitive predictors

Nonverbal reasoning

We measured students' nonverbal reasoning using the *Weschler Abbreviated Scale Intelligence-II* (WASI-II) *Matrix Reasoning* subtest (Wechsler, 2011). *Matrix Reasoning* measured nonverbal reasoning using pattern completion, classification, analogy, and serial reasoning tasks. Students viewed an incomplete matrix or series and selected the response from five options that completed the matrix or series. Students completed the visual pattern for 35 items or until reaching a ceiling of four errors over five consecutive items or four consecutive errors. Reliability, as reported by Weschler (2011) is .94.

Verbal reasoning

The *WASI-II Similarities* (Wechsler, 2011) measured students' verbal concept formation and reasoning. For the picture items (items 1–3), students selected the option that shared a common characteristic with the target objects. For the verbal items (items 4–22), students were presented two words that represented common objects or concepts and described how they were similar. Students identified similarities between two words until the end of the test or until reaching a ceiling of 3 consecutive incorrect responses of 0. Split-half reliability coefficients for both subtests met or exceeded .90 (Wechsler, 2011).

Working memory

To assess working memory, we used the *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole, 2001) *Counting Recall* subtest. Counting Recall, like Listening Recall, featured six dual-task items at span levels from 1–6 to 1–9. Students counted a set of 4, 5, 6, or 7 dots, each on a separate card. Following the last card, students recalled the number of dots on each card. Passing 4 items at a level advanced the student to the next level. Each span level raised the number of items to be remembered by one. Three incorrect responses terminated the test. We used the trials correct score. According to the test developer, test–retest reliability was between .91 and .93 (Pickering & Gathercole, 2001).

Switching

We measured switching with the 64-card abbreviated form of the *Wisconsin Card Sorting Test* (WCST; Kongs et al., 2000). During administration, examiners placed four stimulus cards in front of the student. The student was asked to match cards from their deck to the four stimulus cards, and the examiner provided feedback. After a specified number of correct matches, the examiner switched the matching criteria, and the student had to switch and adapt to the new matching strategy. Administration lasted less than 5 min. As reported by Kongs et al. (2000), test–retest reliability is greater than .90.

Posttest in Grade 3 and follow-up in Grade 4 word-problem outcome

We created a composite score called *Word Problems* by combining three word-problem assessments (*Texas Word Problems-Brief*, *Texas Word Problems-Part 1*, and *Texas Word Problems-Part 2*; Powell & Berry, 2015). This composite score included five Total (i.e., putting amounts together), six Difference (i.e., comparing amounts), 11 Change problems (i.e., a set increases or decreases), and three multi-schema problems (i.e., Total and Difference; Total and Change; Difference and Change). Interventionists read each problem aloud to the students and allowed them approximately 1 min to solve the problem and write a response. Interventionists may re-read each problem up to once on student request. We graded these measurements based on the number of correct numerical and label responses, up to a maximum of 52. Cronbach's α was .94 for this composite score.

Data analysis

Operationalization of outcome variables

In the current study, we operationalized *retention* as answering an item correctly at the immediate posttest and answering the same item correctly at the follow-up testing. We calculated a retention rate from posttest to follow-up by dividing the total number of items retained at follow-up by the total number of correct items at posttest. We multiplied the retention rate by 100% and used the percentage of retention as the outcome variable for ease of interpretation. We used the formula in Equation (1) to calculate the percentage of retention items. Please see Table 2 for the descriptive of retention number and percentage for each condition.

$$\text{Percentage of Retention} = \frac{\text{Follow} - \text{Up Correct}}{\text{Posttest Correct}} \times 100\,\%. \tag{1}$$

We operationalized *acquisition* as answering an item incorrectly at posttest but acquiring the skills to answer correctly at follow-up. We calculated the acquisition of learning from posttest to follow-up by

TABLE 2 Performance by condition.

	PM-alone (n=110)		PMEQ (n=111)		Control (n=127)	
	M	SD	M	SD	M	SD
WPS pretest	7.49	6.59	7.63	5.53	7.95	6.44
WPS posttest	25.87	10.31	27.32	9.25	12.76	7.89
WPS follow-up	15.85	8.97	17.83	10.03	14.28	9.27
Retention number	9.73	7.53	11.19	8.30	7.10	6.23
Retention %	38.76	23.38	40.50	22.90	56.32	24.54
Acquisition number	6.13	3.84	6.64	4.05	7.16	5.89
Acquisition %	25.76	15.30	29.45	18.22	19.55	17.07

Abbreviations: Acquisition number, the total number of acquired items at follow-up testing, that were not answered correctly at posttest; Acquisition r%, the percentage of acquisition of word-problem items; PM, Pirate Math; PMEQ, Pirate Math Equation Quest; Retention %, the percentage of retention of word-problem items; Retention number, the total number of items retained at follow-up testing; WPS, word-problem solving.

dividing the total number of acquired items at follow-up by the posttest incorrect items (i.e., posttest total items − posttest correct items). As shown in the formula in Equation (2), we multiplied the acquisition rate by 100% and used the percentage of acquisition as the outcome variable. See Table 2 for a descriptive of the number of acquisition items and acquisition percentage for each condition.

$$\text{Percentage of Acquisition} = \frac{\text{Acquisition Number at Follow} - \text{Up}}{\text{Posttest Incorrect}} \times 100\%. \quad (2)$$

Elastic net regression

In this study, we used elastic net regression, which solves the following conditional minimization problem

$$\underbrace{\min_{\gamma,\beta,\beta_0} \frac{1}{N}\sum_{i=1}^{N}\left(y_i - \beta_0 - \gamma^T x_i - \beta^T z_i\right)^2}_{\text{mean square error}} + \underbrace{\lambda\left[(1-\alpha)\|\beta,\gamma\|_2^2/2 + \alpha\|\beta,\gamma\|_1\right]}_{\text{elastic net penalty}},$$
$$\text{s.t.} \quad \gamma \neq 0$$

where N is the total sample size, y denoted outcome, x denoted predictor variable of interest, z denoted control variables, γ denoted coefficients of x, and β denoted coefficients of z. There were two tuning parameters in this problem: λ and α. The tuning parameter λ controlled the overall strength of the penalty. α bridged the gap between lasso regression ($\alpha=1$, the default) and ridge regression (α = 0). Elastic net shrank coefficient estimates and selected predictors from a large predictor set using a combination of lasso and ridge regression penalties. We determined the best tuning parameters for the penalized regression (λ and α) using 10-fold cross-validation. We used the R software package's *glmnet* library to carry out the investigations (Friedman et al., 2021).

To explore factors impacting the retention and acquisition of word-problem knowledge beyond the intervention period (i.e., from posttest to follow-up), we conducted elastic regression by including pre-intervention arithmetic, pre-algebra, reading, and cognitive as predictors and percentage of retention and acquisition as the outcomes for students within the intervention (PM-alone vs. PMEQ) and BaU conditions, separately. Within the analysis for intervention students, we included intervention conditions (i.e., PMEQ vs. PM-alone) as a predictor for the percentages of retention and acquisition to investigate whether the pre-algebraic reasoning component of the word-problem intervention impacted the retention and acquisition of word-problem knowledge post intervention. In the analysis, the PM-alone condition served as the reference group. We would like to note interpreting the elastic net regression coefficient estimates is the same as interpreting ordinary least squares regression coefficients.

RESULTS

We present the results in three subsections. First, we report descriptive statistics and comparisons between intervention conditions on relevant outcomes. Second, we describe the findings from elastic net regression for students within the intervention and control conditions. Third, we summarize our findings to address each research question.

Means, standard deviations, and comparisons among conditions

Table 2 displays the means and standard deviations for word-problem solving (pretest, posttest, follow-up), numbers of retained and acquired items, and percentages of retention and acquisition of word-problem knowledge for each condition.

Table 3 displays the effect sizes for each comparison between intervention conditions, which are presented in standard deviation units. On the word-problem posttest, students in PMEQ (ES = 1.70) and PM-alone (ES = 1.44) outperformed students in the BaU condition. At follow-up testing, only students in PMEQ outperformed BaU students (ES = 0.37). Regarding retention rate, BaU students demonstrated a higher retention rate than those in PMEQ (ES = 0.66) and PM-alone (ES = 0.73) conditions. Please note, however, that the BaU students scored significantly lower at posttest than students in PMEQ or PM-alone; therefore, the retention rate requires careful interpretation. Regarding the acquisition of word-problem knowledge beyond the intervention timeframe,

TABLE 3 Effect sizes as a function of intervention status.

	Contrasts		
	Control versus		PM-alone
Variable	PM-alone	PMEQ	PMEQ
WPS pretest	0.07	0.05	−0.02
WPS posttest	−1.44***	−1.70***	−0.15
WPS follow-up	−0.17	−0.37*	−0.21
Retention number	−0.38*	−0.56***	−0.18
Retention %	0.73***	0.66***	−0.08
Acquisition number	0.20	0.10	−0.13
Acquisition %	−0.38*	−0.56***	−0.22

*p< .05; ***p<.001.

Abbreviations: Acquisition %, the percentage of acquisition of word-problem items; Acquisition number, the total number of acquisition items at follow-up testing, that were not answered correctly at posttest; PM, Pirate Math; PMEQ, Pirate Math Equation Quest; Retention %, the percentage of retention of word-problem items; Retention number, the total number of items retained at follow-up testing; WPS, word-problem solving.

BaU students demonstrated a lower acquisition rate of learning than students in PMEQ (ES = −0.56) and PM-alone (ES = −0.38).

Description of factors impacting the retention and acquisition of word-problem knowledge

In this section, we present our findings from elastic net regression for students within the intervention and control conditions separately.

Factors support retention of word-problem knowledge

We included 19 predictors in our model. This included the 16 academic and cognitive variables plus age, gender, and intervention condition (i.e., PMEQ vs. PM-alone). Regarding intervention students, the elastic net regression selected a model including 9 out of the 19 predictors as the best model predicting the retention of word-problem knowledge from posttest to follow-up (hyperparameters: $\alpha = .51$, $\lambda = 1.27$). Table 4 shows selected predictors and their coefficients. Significant predictors of retention were as follows: single-digit addition ($\beta = 0.17$), double-digit subtraction ($\beta = 0.75$), numeration ($\beta = 0.34$), standard and nonstandard equations ($\beta = 0.13$), equal-sign understanding ($\beta = 1.24$), vocabulary ($\beta = -0.23$), reading comprehension ($\beta = -0.28$), nonverbal reasoning ($\beta = 0.40$), verbal reasoning ($\beta = 0.41$).

Regrading students within BaU condition, the elastic net regression selected a model including 3 out of 18 predictors (there is one fewer predictor because we did not include intervention condition in this model) as the best model predicting the retention of word-problem knowledge (hyperparameters: $\alpha = .53$, $\lambda = 4.09$). Significant predictors included numeration ($\beta = 0.97$), nonstandard addition ($\beta = 0.13$), and decoding ($\beta = 0.17$).

Factors support acquisition of word-problem knowledge

Regarding intervention students, the elastic net regression selected a model including 10 out of the 19 predictors as the best model predicting the acquisition of word-problem knowledge from posttest to follow-up (hyperparameters: $\alpha = .29$, $\lambda = 2.44$). Table 4 shows selected predictors and their coefficients. Predictors of students' acquisition of word-problem knowledge were as follows: single-digit addition ($\beta = 0.30$), single-digit subtraction ($\beta = 0.53$), numeration ($\beta = 0.84$), standard and nonstandard equations ($\beta = 0.26$), nonstandard addition ($\beta = 0.61$), equal-sign understanding ($\beta = 0.72$), reading comprehension ($\beta = 0.10$), nonverbal reasoning ($\beta = 0.11$), and verbal reasoning ($\beta = 0.34$), and intervention condition ($\beta = 0.59$).

For the BaU students, the elastic net regression selected a model including 8 out of 18 predictors as the best model (hyperparameters: $\alpha = .37$, $\lambda = 1.33$). Predictors of control students' acquisition of word-problem knowledge were as follows: double-digit subtraction ($\beta = 0.84$), numeration ($\beta = 1.04$), standard and nonstandard equations ($\beta = 0.16$), nonstandard addition ($\beta = 1.75$), equal-sign understanding ($\beta = 0.25$), decoding ($\beta = 0.06$), verbal reasoning ($\beta = 0.36$), and working memory ($\beta = 0.80$).

TABLE 4 Skills supporting retention and acquisition of word-problem knowledge.

	Estimate[a]			
	Retention		Acquisition	
Variable	PM	Control	PM	Control
Constant	22.68	38.77	−1.71	−2.55
Single-digit addition	0.17		0.30	
Single-digit subtraction			0.53	
Double-digit addition				
Double-digit subtraction	0.75			0.84
Numeration	0.34	0.97	0.84	1.04
Standard and nonstandard equations	0.13		0.26	0.16
Nonstandard addition		0.57	0.61	1.75
Equal-sign understanding	1.24		0.72	0.23
Decoding		0.17		0.06
Reading fluency				−0.11
Vocabulary	−0.23			−0.41
Reading comprehension	−0.28		0.10	
Nonverbal reasoning	0.40		0.11	−0.12
Verbal reasoning	0.41		0.34	
Working memory				0.80
Switching				
Age				
Gender				
Intervention condition	0.59	–		–

Note: All coefficients are penalized by the elastic net. Coefficients shrunk to 0 are not displayed.

[a]Penalized beta.

Summary of findings

Concerning our first research question, the efficacy of intervention almost disappeared at follow-up testing. Only students in the PMEQ group significantly outperformed BaU students, with a small to medium effect. Furthermore, we determined that students who received the intervention tended to retain less (i.e., forget more) but exhibited greater knowledge acquisition after the intervention.

To address our second research question concerning skills essential for the retention and acquisition of word-problem knowledge gained through intervention, we differentiated two types of knowledge and skills demonstrating clear patterns: one that was predictive to both intervention and BaU conditions and the other that showed significant predictive effects only among the students within the intervention condition. We interpret the first type as essential for proficiency with word-problem knowledge in general. In contrast, we view the second type as providing unique support for the retention and acquisition of skills gained through intervention. First, the intervention magnified the influence of single-digit addition and subtraction, along with verbal and nonverbal reasoning, on the retention and acquisition of knowledge obtained via the intervention. Secondly, the intervention reduced the impact of working memory on subsequent knowledge acquisition. Finally, regardless of participating in the intervention, numeration and pre-algebra remained crucial.

Regarding our third research question, intervention conditions (PMEQ vs. PM-alone) significantly impacted the retention of word-problem knowledge ($\beta = 0.59$). Students who received word-problem intervention with a pre-algebraic reasoning instruction component (PMEQ) demonstrated greater retention than students who received word-problem intervention alone (PM-alone).

DISCUSSION

The present study aimed to investigate the influence of the intervention on subsequent knowledge acquisition with a word-problem intervention. Similar to prior research, we observed that the effect of the intervention was no longer significant one year later. However, it is worth noting that the intervention improved the knowledge acquisition for students who received it. Furthermore, we observed that the intensive intervention changed the impacts of specific prior knowledge and skills on the retention and acquisition of knowledge after the intervention. In the discussion, we first explain the effects of intervention on students' natural learning progression. Then, we discuss the specific prior knowledge and skills and pre-algebraic reasoning instruction for retaining and acquiring word-problem knowledge after the intervention.

Effects of intensive interventions on the acquisition of subsequent knowledge

Previous research has shown the efficacy of intensive intervention often diminishes at follow-up testing, possibly due to forgetting (Bailey et al., 2020; Kang et al., 2019). Through the differentiation of retention and knowledge acquisition, we determined that students who received the intervention not only tended to retain less (i.e., forget more), but they also showed more active knowledge acquisition after the intervention. We would like to note that even though intervention groups demonstrated a higher acquisition rate than the control group, our current operationalization of knowledge acquisition may still underestimate the impact of interventions on subsequent learning. Given that student who received interventions tended to have more correct answers on posttests than the control group, it became more difficult for them to show evidence of knowledge acquisition. Thus, the detected differences in knowledge acquisition between intervention and control groups are crucial. In addition, with our third research question, our finding revealed that students in the PMEQ group showed a higher likelihood of retaining the acquired knowledge compared to those in the PM-alone group. This finding suggested intensive intervention can modify the knowledge acquisition rate. In sum, fadeout or persistence of intervention effects is a complex process, and we should not attribute such effects to forgetting.

Our analysis indicated similarities and disparities in the predictors of retention and acquisition among students who received the intervention and their counterparts in the BaU. Therefore, our findings suggest that interventions can, to some extent, alter the natural progression of knowledge acquisition, enhancing or weakening the contributions of knowledge and skills to subsequent learning. For example, our finding revealed that working memory was crucial for subsequent knowledge acquisition only among BaU students, whereas not crucial for students who received the intervention. In other words, participation in the intervention reduced the impact of working memory in subsequent knowledge acquisition. This finding was in line with previous research that working memory plays an important role in the natural progression of acquiring word-problem knowledge (e.g., Lin & Powell, 2022). More importantly, the finding of the present study revealed that intensive intervention could diminish its impact on subsequent knowledge acquisition. This is particularly important for the education of students with MD considering that a deficit in working memory is a core challenge for such students (Peng & Fuchs, 2016). If participation in an intervention can reduce the significance of certain cognitive skills during the learning progression, then we can provide tailored interventions specifically for students with such cognitive deficits.

Word-problem intervention's impact on prior knowledge and skills

Our findings revealed that specific prior knowledge, such as numeration and pre-algebra, remained consistently critical regardless of whether students participated in the word-problem intervention. This suggests that the intervention did not alter the contributions of this knowledge to subsequent word-problem solving. Secondly, our findings revealed that the intervention did change the impacts of several skills on subsequent word-problem solving. On the one hand, the intervention increased the contributions of single-digit addition and subtraction, as well as verbal and nonverbal reasoning, to the retention and acquisition of word-problem knowledge during and after the intervention. On the other hand, participation in the intervention decreased the contributions of working memory to the acquisition of word-problem knowledge after the intervention. In the following sections, we first discuss knowledge essential for proficiency with word-problem solving in general and then discuss knowledge and skill that were only essential for students who received the intervention.

Knowledge essential for solving word problems in general

Numeration and pre-algebra remained consistently important regardless of whether an intervention had occurred. Given that numeration (measured with *KeyMath3 Numeration*) involves multiple domains (i.e., counting, place value, number magnitude, fractions, decimals, and percentages), a relatively comprehensive mathematics measure may better capture students' overall pre-intervention foundation in arithmetic than a single arithmetic measure focused on one type of arithmetic skill (e.g., single-digit addition). This finding, to some extent, aligns with research investigating students' natural mathematics progression that a comprehensive mathematics assessment may serve as a better predictor for students' subsequent mathematics performance (Lin & Powell, 2022).

Our finding on pre-algebra provided additional support to the importance of pre-algebraic reasoning in solving word problems (e.g., Powell et al., 2020). In other words, whether students received word-problem interventions that included instruction on pre-algebraic reasoning, pre-algebra remained consistently vital for long-term word problem-solving proficiency. Thus, pre-algebra instruction not only matters in intensive word-problem intervention but is also crucial for general classroom instruction. Explicitly teaching students to view the equal sign as a relational symbol and to solve equations with unknowns may not only benefit their classroom performance, but also help them retain and acquire word-problem knowledge that was gained through intervention.

Knowledge and skill uniquely supporting retention and acquisition of word-problem knowledge

Firstly, our findings revealed the unique impacts of single-digit addition and subtraction (i.e., mathematics fact fluency) on the retention and acquisition of word-problem knowledge gained through intervention. According to previous research, acquisition of learning greatly relies on fluent application of foundational knowledge required for completing such acquisition (Salomon & Perkins, 1989). Our research indicated that incorporating fluency training of foundational knowledge in interventions, combined with effective problem-solving strategies, can better leverage the role of mathematics fact fluency in subsequent knowledge acquisition and retention. The present finding supports the notion that intensive word-problem intervention should embed arithmetic fluency training activities.

Nonverbal and verbal reasoning yielded unique impacts on the retention and acquisition of knowledge gained through word-problem intervention. Students with greater initial reasoning capacity demonstrated a greater chance to learn and benefit from the present intervention. According to previous research, reasoning facilitates word-problem solving processes, such as categorizing a word problem as a specific problem type or inferring information not evident in the problem statement (Wang et al., 2016). The present word-problem intervention with embedded word-problem schema instruction and training on crossing out irrelevant information in word-problem prompts facilitate the role of reasoning in building the internal representations of word problems. Considering that reasoning relates to students' capacity to learn the abstractions and principles behind each problem to think more flexibly, students with greater initial reasoning capacity could better understand the structures underlying each word problem and apply what they have learned in new situations (Goddu et al., 2020). Another possibility is that receiving intensive word-problem intervention potentially affects the development of reasoning capacities (Martinez, 2000). The constant engagement of reasoning in performing increasingly complex word problems may serve as a training of reasoning.

On the other hand, participation in the intervention decreased the contributions of working memory to the acquisition of word-problem knowledge after the intervention had ended. One possible explanation of the decreased role of working memory relates to the enhanced role of mathematics fact fluency. That is, fluency with relatively foundational academic knowledge enables students to efficiently allocate cognitive resources (e.g., working memory) to perform more complex problems, such as word-problem solving (Lin, 2021). More flexible application of mathematics facts may reduce the importance of working memory and no longer constitute a limiting factor in solving word problems.

Pre-algebraic reasoning instruction facilitate the acquisition of word-problem knowledge

Finally, students within the PMEQ condition demonstrated a greater chance of knowledge acquisition from posttest to follow-up testing compared to PM-alone students, suggesting embedding the pre-algebraic reasoning component within the word-problem intervention may facilitate the acquisition of knowledge after intervention. More importantly, the higher acquisition rate of the PMEQ condition may have contributed to the significant performance advantage observed at follow-up testing, compared to BaU. This finding suggested that making some small adaptations to interventions may prove beneficial in improving the rate of knowledge acquisition once the intervention has ended.

One plausible explanation for the detected advantage of PMEQ students in acquiring word-problem knowledge is that additional pre-algebraic reasoning instruction facilitates students' understanding of the underlying structure of word problems. Thereby students understand equations used to represent different schemas better. Even though both word-problem intervention conditions provided explicit, scaffolded instruction on how to set up and solve word problems using equations, extra exposure to pre-algebraic reasoning help students gain a better understanding of the equations used to represent schemas (e.g., $P1+P2=T$ for Total schema; $G-L=D$ for Difference schema). It is possible that developing relational understanding of equal sign provides the foundation on which the schema equation is built. After the foundation for the problem schema and its corresponding equation is built, later word-problem learning gained during regular classroom instruction help refine the schema for performing word problems. Schemas practiced during intervention were triggered when students tried to comprehend, understand, or make sense of new word problems—the students tried to fit new word problems into those schemas acquired through intervention.

Another plausible explanation is that pre-algebraic thinking prepares students for the acquisition of learning in general, as evidenced by some recent research showing that relational understanding of equal signs predicts subsequent mathematics learning (Hornburg et al., 2022; Matthews & Fuchs, 2020). According to Hornburg et al. (2022), students may benefit from an early understanding of mathematical equivalence before overly narrow operational patterns (e.g., automatically carry out all of the arithmetic operations, expecting the equal sign and answer blank at the end of math problems) become entrenched. Mastering the abstract equivalence relation in arithmetic problems may help students become accustomed to looking for general principles when encountering new problems, thereby facilitating the acquisition. Additional pre-algebraic reasoning instruction, to some extent, prepares students to transition from the arithmetic learning stage to the pre-algebraic learning stage (Pillay et al., 1998).

Limitations and future research

Before concluding, we note several limitations which could be used to inform future research. First, despite our extensive inclusion of pre-intervention academic and cognitive skills, other pre-intervention academic (e.g., mathematics vocabulary) and cognitive skills (e.g., in-class attentive behavior) may impact retention and acquisition of word-problem knowledge (Lin, 2021; Swanson, 2004). In addition to academic and cognitive skills, other factors, such as whether having a sustaining classroom environment following an intervention (Kang et al., 2019), may also impact. Future research could explore how the extent of alignment between intervention and subsequent classroom instruction affects the retention and acquisition of skills acquired through intervention.

Second, we noted we taught some of the pre-intervention academic knowledge (e.g., single-digit addition, equal-sign understanding) implicitly or explicitly during the intervention. For example, the present word-problem intervention included a 2-min Math Fact Flashcards activity at the start of each lesson. Therefore, we alert readers our findings may not apply to all word-problem interventions. Future word-problem intervention research without a numerical fluency building activity could further explore whether fluency in mathematics fact matters for the retention of knowledge. Third, when operationalizing the concept of retention, we did not consider whether students had correctly answered similar items during the pretest. As a consequence, the knowledge retention observed in our study may include a small proportion of items that students had already learned before the intervention began.

Finally, we did not conduct follow-up testing several times after the immediate posttest. According to Powell et al. (2022), the detection of significant follow-up intervention effects may relate to the time lag between the end of intervention and follow-up testing. Future research may follow up multiple times upon completion of the posttest to understand how time past intervention implementation impacts the unique predictors of retention and acquisition of skills acquired through intervention. Lastly, the reliability of the equal-sign understanding measure of 0.6 might be questionable. Given that other related measures of pre-algebraic understanding (e.g., standard and nonstandard equation) and the intervention contrasts (PM-alone vs. PMEQ) also demonstrated unique impacts on the persistence of intervention effects, our finding provided support for the notion that equal-sign understanding matters for solving word problems.

Implications

Our findings have several implications for theory and practice. Theoretically, our findings recommended viewing the fadeout of intervention effects from a different perspective. Our findings showed intervention enhanced the acquisition rate and that different intervention variants resulted in varying acquisition rates.

Furthermore, intervention may also change the impacts of prior knowledge and cognitive skills on subsequent knowledge acquisition. Therefore, the learning process after the intervention is complex, and we need to consider how interventions affect the impacts of prior knowledge in subsequent learning. Additionally, we would like to note that although intervention students demonstrated a greater acquisition rate than the BaU students, intervention students' lower retention rate of the word-problem knowledge gained through intervention primarily explains the fadeout of intervention effects.

Second, intervention might alter the impacts of prior knowledge and skills on the retention and acquisition of knowledge after intervention ended. By comparing the emerged significant predictors between intervention and control conditions, we differentiated knowledge and skills uniquely facilitating the persistence of intervention effects (e.g., single-digit addition, reasoning) and knowledge crucial for performing word problems across students within intervention and BaU conditions (i.e., numeration, pre-algebra). Such differentiation matters because it helps us understand the fadeout of intervention effects. For example, our finding—reasoning uniquely supported the retention and acquisition of word-problem knowledge gained through intervention—suggested the word-problem intervention may enable students with greater initial reasoning capacity to develop a deeper understanding of word-problem schemas.

Third, our findings indicated while working memory played a crucial role in subsequent knowledge acquisition for BaU students, it was not as important for students who received the intervention. Therefore, we believe this finding adds to the dual-process theory and underscores the need to view it from a more dynamic standpoint (Evans & Stanovich, 2013). That is, after students have accumulated crucial prior knowledge and gained problem-solving strategies through intensive intervention, the importance of working memory in subsequent knowledge acquisition may diminish. Thus, equipping students with word-problem strategies and essential prior knowledge can help in decreasing their dependence on working memory, particularly for those who have a working memory deficit. Furthermore, within skills demonstrating generally support for the retention and acquisition of word-problem knowledge, most are pre-intervention academic knowledge (i.e., single-digit addition, numeration, equal-sign understanding). Considering that academic knowledge are more malleable than cognitive skills, our finding recommended the importance of early intensive intervention focused on academic competencies.

Practically, our findings may serve as a starting point to inform the adaption of previous effective interventions to improve the persistence of intervention effects. To explore how to adapt prior interventions to facilitate persistence of intervention effects, researchers need to identify key competencies to strengthen the instructional design. For example, first off, given that reasoning uniquely facilitated the retention and acquisition of word-problem knowledge gained through intervention, future intervention research may consider enhancing the role of students' reasoning in solving word problems. For example, we could help students create a representation that depicts the relations among the problem parts to teach them to engage their reasoning capacity during word-problem solving (e.g., Krawec et al., 2012). Second, future intervention focused on word-problem solving may embed explicit instruction on pre-algebraic reasoning, such as relational interpretation of equal sign and use of equations to represent different word-problem schemas because pre-algebraic reasoning skills (e.g., equal-sign understanding) supported the retention and acquisition of word-problem knowledge across intervention and control conditions. Third, because we also revealed mathematics fact fluency facilitated the acquisition of word-problem knowledge, future word-problem intervention may embed arithmetic fluency training activities or extend the length of arithmetic fluency training to facilitate such acquisition.

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CONFLICT OF INTEREST STATEMENT

We have no known conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

Data necessary to reproduce analyses are not available, but analysis code is available upon request to the first author.

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