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Abstract

Mathematics textbooks typically include word problems or story problems that require students to develop extended written responses. Yet, the answers to these prompts can vary so widely that preservice and inservice teachers must be prepared for multiple levels of interpretation of the language used to capture mathematical thinking. Based on an analysis of word problems within two teacher's editions of elementary mathematics textbooks, we describe a series of strategies and tasks to scaffold teachers' understanding of planning for word problems during mathematics instruction. We detail the following components; (1) the use of the Instructional Resource Guide, which assists in the decision-making process to support preservice and inservice teachers as they plan and analyze word problem language aiding in the selection of tasks based on specific objectives or instructional goals; (2) the creation of a consistent instructional sequence for integrated literacy instruction during mathematics instruction.

Keywords

Writing, Mathematics Education, Professional Development, Word problems, Problem Solvers, Instructional Planning

Math word problems - this simple phrase often strikes fear in the hearts of elementary students, especially for those who are not confident in math or for those who do not use written words to think and process mathematical information. Yet, scattered across mathematics textbooks are word problems that require students to construct written responses that potentially help students solidify concepts beyond the computation of digits (Colonneselyn, Armspaugh, LeMay, Evans & Field, 2018) and possibly provide teachers with a *window* into student thinking (Sowder, 2007). However, a window can become a Pandora's box when student answers to a single math prompt can be so varied and unwieldy that the teacher must engage in multiple levels of interpretation and draw upon a confluence of skills (Verschaffen, Schukajlow, Star & Van Dooren, 2020).

These skills include mathematics reasoning, problem solving, along with language and visual analysis (of drawings)—all skills that require transdisciplinary thinking across mathematics and literacy. To mediate these challenges, we provide a breakdown of the typical word problems presented in elementary mathematics teacher editions and suggest a corresponding framework that provides content support and guidance for preservice and inservice teachers as they use word problems to make instructional decisions.

Background Literature

The Mathematics Textbook as Key Instructional Resource

Textbooks have a major influence on content and instruction in the mathematics classroom (Banilower, Smith, Weiss, Malzahn, Campbell & Weiss, 2013). Major publishing companies typically follow guidelines of the National Council of Teachers of Mathematics (NCTM, 2000) to provide lessons and instructional activities that follow the scope and sequence of the math curriculum while connecting to state standards. Joseph (2012) noted, "As a result, commercially-published materials are used in 85% of classrooms in grades K-5 and 81% of classrooms grades 6-8 (Banilower, Smith, Weiss, Malzahn, Campbell & Weiss, 2013, p. 91)." Additionally, in other reports such as the Center for Education Policy Research (CEPR) from Harvard University (2019), noted that teachers reported covering 82% of mathematics textbook chapters over the course of a school year (p. 15). These findings suggest that the influence of the textbook could potentially impact students' opportunities to learn and achievement levels.

Mathematical Word Problems

Writing to communicate mathematically has many advantages for

conceptual understanding (Casa, et. al., 2016; Pugalee, 2005). For quite some time, the NCTM Principles and Standards for School Mathematics (PSSM) have explicitly called for multiple forms of communication (including writing) and researchers have suggested that writing in math increases students' understanding (PSSM 2000; Fortescue, 1994). For example, in a math intervention study, Cohen, Miller, Casa & Firmender (2015) found that when students engaged in explicit conversations and wrote about their reasoning on an ongoing basis, they demonstrated an increased ability to provide reasoning and use math vocabulary in their oral language and written products in comparison to control groups.

To encourage extended forms of communication, writing prompts are used for different communicative purposes—to explore, inform, argue, and create (Colonneselyn, Armspaugh, LeMay, Evans & Field, 2018). According to Sowder (2007), using writing as a formative assessment provides a window into student reasoning and justifications. Moreover, this can assist in planning for next steps of instruction by identifying student levels of understanding from their written processes. To this end, the range of mathematical writing can span from students by listing steps in a solution, to students writing elaborate justifications for *why* an answer is correct. These writing prompts are commonly known as word problems, story problems, problem solvers, higher order thinking problems, or extensions in math textbooks. However, the reading of these prompts (or what we refer to as "word problems" throughout this paper), requires students to pay attention to every symbol and word in the problem with consideration to the genre of the task encountered (Sherman & Gabriel, 2017).

Academic Vocabulary/Mathematical Symbols

The amount of academic vocabulary within a mathematics word problem may increase the complexity of comprehending the problem, impacting the student solution process (Joseph, 2012; Kozdras, Joseph, & Schneider, 2015). For example, in order to write mathematically, the understanding of academic vocabulary is fundamental towards conceptual understanding. Academic vocabulary such as domain specific words, or what Beck, McKeown & Kucan, (2013) refer to as Tier 3 words, are more challenging concepts and require explicit instruction (e.g., hypotenuse, rhombus, addend, sum, etc.). Furthermore, students also need explicit instruction in understanding how to interpret signs and symbols (e.g., +, -, x, etc.) to words, and these words to their corresponding processes in order to fully comprehend the problem (Thompson, Kersaint, Richards, Hunsader, & Rubenstein, 2008; Baumann & Graves, 2010; Beck, McKeown, Kucan, 2013). In thinking about developing students' mathematical literacy, this academic vocabulary needs to be addressed with appropriate scaffolds in place to support conceptual understanding.

Genres of Writing Prompts

In addition, special attention must also be given to the forms of writing elicited by the word problem. In mathematics, a word problem can be classified into four different types of *prompts.* These writing prompts in mathematics can be classified as 1) process 2) content 3) narrative, and/or 4) affective in description (Baxter et al., 2001; Dougherty, 1996; Shield and Galbraith, 1998; Urquhart, 2009). A *process* prompt is a word problem that would require students to explain the process they encounter when solving the problem such as a strategy for a solution, or to reflect as to why they used the steps or the specific strategy communicated to solve the word problem (Dougherty, 1996; Urquhart, 2009). Dougherty (1996) notes the following as a process prompt, "*The most important part of solving this problem is...*" (p. 2). Following, if the word problem has the affordance of mathematics relationships and/or content then it can be classified as a *content* prompt (Urquhart, 2009). Urquhart (2009) notes a content problem example as the following, "*Define parallel in your own words"* (p.7). These content prompts provide student with the opportunity of explaining, relationships, comparing and contrasting, or defining a specific concept. Next, a *narrative* prompt is a word problem that requires a student to demonstrate an understanding of mathematics concepts aligned to imaginary or real-world application. These types of mathematical *narratives* are often complemented with mathematics children's literature (Joseph, 2018; Russo & Russo, 2017, Schneider, 2016; TESS-India, nd). The Teacher Education through School-based Support ("TESS-India," n.d.) note a *narrative* prompt as the following, "*Use your imagination to create a story around the given problem of 4 + 7. (Sample response: A girl was playing 'Snakes and Ladders' with her brother ...)"* (p.4). The final genre of mathematics writing prompts would be classified as *affective.* This type of prompt would require the student to write a response utilizing some type of affect or feeling/opinion about a specific mathematics concept or topic. (Baxter et al., 2001; Williams & Brian, 2000; Shield & Galbraith, 1998). Williams and Brian, (2000), note the following as an affective prompt, "*Explain how you organize your math notebook. How does your notebook help you?"* (p.133).

Challenges of Constructed Responses

Given the complexity of responses required from the four types of mathematical writing prompts, and the specialized word knowledge and language needed to respond to a mathematical prompt, it is clear that all constructed responses are not created equally and successful student responses to these written prompts require a deep understanding of concepts, a sophistication with language, and the expansion of thought (Vygotsky, 1978). Similarly, the complexity of responses and ranges of writing ability require teachers to have an understanding of several instructional components: 1) deep knowledge of mathematics, 2) intuitive understanding of students' mathematics concept development, and 3) knowledge of writing development for teaching and learning (Burns, 2004; Martin,

Polly, McGee, Wang, Lambert & Pugalee, 2015; 2019).

Furthermore, teachers must also understand how to facilitate close reading (Fisher & Frey, 2012) whereby complex text can be read multiple times with annotating, questions, and prompting for further understanding. Additionally, teachers should be prepared to develop their content knowledge in order to interpret children's responses (Sipe, 2008). In other words, students may answer problems in a variety of ways, using alternative language and novel phrasing in order to describe their thinking.

Methods

Textbook Prompt Analysis: Minimal Support and Missed Opportunities

To determine the type of instructional support preservice and inservice teachers may need, we built on the first author's (Christine) analysis of the teacher editions of two fourth-grade level math series (*enVision MATH* and *Everyday Mathematics)* (See Joseph, 2012 for details). By analyzing 100% of the lettered or number exercises in the two student editions and corresponding teachers' editions and resources, Christine documented the type of teacher edition support teachers received regarding mathematics word problem instruction:

1. **No Student Sample or Teacher Support**: The teacher edition provided *no* student sample of a response or directions of support for the word problem.
2. **Written Directions:** The word problem included *some* form of directions of support for the teacher. However, there was *no* student sample response.
3. **Student Sample Problem with Correct Response:** These word problems had only *one* student sample provided. There were no other directions of support for the word problem.
4. **Student Sample with Correct Response and Teacher Support:** The prompts included a form of support for writing *along with* a student sample of the response. These written directions included a brief description in the form of instructional notes.

The majority of prompts (90%) in the two teacher editions required students to construct responses to questions that could be interpreted in multiple ways. Although the students could answer in numerous ways, the teacher editions provided limited support for the teacher to provide instruction for various responses. Specifically, the teacher editions were lacking in the area of direction of support in how to teach, select or assign word problems to match learning goals and objectives. Additionally, the teacher editions did not provide instructional suggestions based on the word problem even thought a sample response may have been provided. As a result, the limited instructional

scaffolding for mathematical writing in the teacher edition indicated a key opportunity for professional development and support.

Given that we understood the range and types of writing prompts used across two major mathematics textbooks, we also recognized the need for additional professional development regarding mathematics writing prompts. Specifically, 1) selecting mathematics writing prompts for instruction; and 2) supports needed regarding the use of mathematics writing prompts for instruction.

Determining Interest and Usage

To determine how teachers used mathematics writing prompts and what barriers existed regarding the use of mathematics writing prompts for instruction, we focused on inservice teachers (n=35) in a Title 1 school in which 83% of the student population (n=689) were economically disadvantaged and 31% of the students were dual language learners. Christine, a district math coach at the time, met with the teachers during collaborative planning sessions in Professional Learning Communities (PLC's). These teachers represented Grades 1-5 and the PLC's were held once a week for 16 weeks.

Initial discussions focused on the school's selected math series and teacher edition (*Go Math* by Houghton Mifflin). The teachers worked together to locate, identify, and categorize mathematical writing prompts in order to gain a sense of the information these prompts could yield. Throughout the PLC meetings, Christine recorded anecdotal notes to summarize the following findings. The teachers identified four categories regarding their use of writing prompts: (1) as a formative assessment measure, (2) as a vehicle for teaching and uncovering skills/strategies, (3) as a discourse method for communicating mathematically, and (4) as a tool for the facilitation of real-world mathematics.

Across the grade level teams, the teachers stated that they valued mathematical writing prompts as an important component during mathematics instruction. Moreover, intermediate grade level teachers emphasized the extensive amount of writing prompts on high-stakes assessments in mathematics and the impact these assessments have on teaching and learning. Approximately 75% of the teachers stated they consistently used mathematical word problems in a formative matter to confirm strategies and assess their students' learning of the mathematics. The teachers also expressed a need for support in planning for word problem instruction. Specifically, they wanted to know *when* and *how* to use mathematical word problems during their instructional time with students.

Implementing a Prompt Selection Tool and an Instructional Sequence

Because the teachers identified a need to know *when* and *how* to use word problems, and the lack of scaffolded support in the teacher editions for writing in mathematics, this cause necessitated the development of the Instructional Resource Guide (See Figure 1). The IRG provided the planning

support needed as a guide for implementing problems solvers within an instructional sequence.

Instructional Resource Guide

The Instructional Resource Guide (IRG, See Figure 1) breaks down the decision-making process to help teachers select prompted tasks based on specific objectives or instructional goals. To use the guide, teachers begin by analyzing the objective of their instruction (to introduce, to review, to instruct, to practice, to intervene, to assess). Placing the *objective* as the focal decision was essential for the teachers to determine the method of instruction to follow. With the objective in place, the teachers could also identify the most relevant prompt to administer and determine the delivery of instruction. While making these decisions, the teacher would also consider student affordances elicited from the prompt. In other words, how might the student answer the task? Did the problem solver require a description, narration, elaboration, or synthesis of mathematics content that would help the teacher provide the proper instructional supports? In analyzing the level of support teachers required, the *Instructional Resource Guide* developed into a tool that teachers used on a daily basis to plan instruction and address these topics.

Instructional Sequence

The IRG supported the teacher's selection of writing tasks within the various components of the mathematics instructional block. In addition, the IRG also led teachers to develop a consistent instructional sequence that corresponded to specific prompt selection. In other words, in selecting a purpose and corresponding writing prompt, the teachers also considered their gradual release of instructional support:

> ***Formative Assessment:*** select a prompt to "gather information about the learning in mathematics to directly improve that learning" (Popham, 2008).
>
> ***Warm up/Review:*** select a prompt relevant to strategies for content previously taught. ***Introduction of content:*** select a prompt for tapping prior knowledge, identifying strategies, and understanding student thinking regarding new content.
>
> ***Practice of content:*** select a prompt to practice skills, concepts, and strategies.
>
> ***Summative assessment:*** Select a prompt to serve as a final judgment on student success and the quality of instruction regarding the mathematics content (Popham, 2008).

By using the guide to select the appropriate *type of prompts* to meet the instructional goal, teachers were able to select the *method of instruction* within the mathematics block to administer the writing prompt.

Initial Results

Across the professional development series offered during PLC meetings in which the teachers implemented an instructional sequence and used the *Instructional Resource Guide*, teachers stated that they increased in the type of word problems used during the mathematics block. Specifically, two fourth grade teachers and one fifth grade teacher reported an increase in their use of writing tasks by selecting warm up/review, introduction of content, practice of content, and during the intervention block as enrichment or remediation. Prior to the PLC meetings, these three teachers only assigned word problems as outlined in the textbook.

Implementation of the Instructional Resource Guide

In the process of tracing the development and introduction of the *Instructional Resource Guide* (IRG) and the corresponding instructional sequence, we engaged in design-based research (Reinking & Bradley, 2008) to examine the instructional modifications necessary to support teacher's implementation of the guide into their classroom instruction. Over the course of 16 weeks, Christine met with each of six inservice teachers during their planning periods, once a week for approximately 40 minutes. During the first meetings, the teachers consulted the mathematics' teacher edition to identify the Chapter or Unit aligned to the standard to be taught. Next, the teachers identified the tasks regarding the learning goal of the instruction. For example, if a teacher wanted to use the task in order to practice working with content or vocabulary then a *warmup/review* task would be selected.

During this selection process, each teacher used the curriculum materials available to select tasks that were aligned to the standards and objective of the lesson. Their conversations centered on the language of the task, and the student affordance (how students may or may not answer).

Data Collection

Christine conducted the professional development training for writing in mathematics to K-5 grade level teachers in the following format:

Day 1: Gauge Interest to Determine Differentiated PD. Christine met with each grade level team during their PLC's to discuss the teachers use of word problems. At the beginning of the meeting, presented each team member with a copy of the *Instructional Resource Guide* (Figure 1) to determine if they had any interest in using the tool. The teachers made the following comments regarding their first impressions of the *Instructional Resource Guide*:

> "*I never thought of using word problems in all these different ways and formats. I am excited to begin the unit with a writing task and end with a writing task.*"
>
> *"I might end up skipping a "step" – that way it gives me a goal to incorporate more word problems into planning. This is a huge importance for the literacy integration in mathematics."*

"*This chart provided me with a way to understand where my students are and where to go next with my instruction*"

Given the teachers positive response, Christine asked the teachers to collaboratively select the *type* of instruction they wanted to model. Teachers in grades K, 1, 3 and 4 chose *Practice of Content* (see Figure 1) because these grade level teams were in the middle of an instructional unit. Grade 5 selected an end of unit task to assess student learning. This task was selected as a *Summative Assessment*. The Grade 2 team chose *Formative Assessment* to determine what students knew about the content that was going to be encountered in the upcoming unit.

Day 2: Select Word Problems and Textbook Selection. On Day 2, the grade-level groups reviewed the teacher editions to identify word problems in the textbook that would facilitate a constructed response. Based on the content within the standard, and discussions of misconceptions, the teachers decided to focus on a specific word problem lifted from the textbook per grade level team.

Day 3: Modeling and Student Collaboration. Christine modeled the instructional delivery of the word problem with students. At the end of the lesson, Christine showcased purposeful selections of student work while facilitating collaborative discussions with the students. Christine selected exemplars and highlighted common errors to support conceptual development. During the student collaborative, Christine addressed misconceptions and pointed out efficient strategies in real time. This real time intervention allowed for students to develop a deeper understanding of the content by the type of discourse that began to unfold from the task response. The teachers observed the process.

Day 4: Analyzing Student Responses to Determine Next Steps. Teachers communicated their analysis of student responses. For example, the Grade 2 team discovered, through conversations with students and analysis of student data, that several students had misconceptions regarding academic vocabulary and pictorial representations. The Grade 2 teachers then decided to create tasks that encouraged pictorial representations that were similarly aligned to the textbook word problem. In Grade 5, the teachers decided to build conceptual understanding through additional writing extensions. These writing extensions facilitate building on word problems in the textbook to promote real world application. In addition, these teachers determined that the tasks selected for further practice should include a student response with a visual representation. Furthermore, if the word problem from the textbook aligned to the standard and objective of the instruction but did not provide the opportunity for a written response, the teachers made certain modifications.

- **(Original)** Does the following array model represent the multiplication sentence of 3x2?

- **(Modification)** Does the following array model represent the multiplication sentence of 3x2? Explain your reasoning.

Adding the modification of "Explain your reasoning" extended the prompt by requiring the student to write a solution or provide justification.

Summary. The teachers specifically discussed the value of the IRG and the coaching sequence. They also expressed the need for additional PD focused on mathematics writing instruction and methods for supporting students when modifying textbook word problems to meet student's needs. These recommendations form the next phases of our work as outlined below.

Writing Instruction is Needed in the Mathematics Classroom

The lack of support surrounding word problems in mathematics teacher editions is a clear indication that professional development is necessary and urgent. In support of this matter, the following has been reported by the Partnership for Assessment and Readiness for College and Careers (PARCC), notes:

> "The PARCC (2018) Item Development correspondence:
> Designers of curricula, assessments, and professional development should all attend to the need to connect the mathematical practices to mathematical content in mathematics instruction. Separating the practices from the content is not helpful and is not what the standards require. The practices to do not exist in isolation; the vehicle for engaging in the practices is mathematical content (p. 45)."

As a result, instructional supports for writing in mathematics should be considered. More specifically supports aligned to mathematics strategies, literacy structures, and mathematics processes. These supports should provide teacher with the awareness of how to reflexively move from each element as the process of writing is complex. In addition, writing in the disciplines requires instruction in the specific genres used within the field. In support of these suggestions, Joseph (2012) notes the paradigm shift for support in literacy as stated by Moje, Overby, Tysvaer, & Morris (2008):

> "We need to consider the larger contexts in which strategies are drawn up and the practices that various strategies support. It may be most productive to build Disciplinary literacy instructional programs rather than merely encourage content teachers to employ literacy teaching practices and strategies (p. 96)."

Additional research is necessary in order to fully implement how teachers can instruction mathematical writing successfully.

A survey published on writing in mathematics suggests that instructional support of writing in mathematics has not changed at all or is growing too slowly to have any observational measurement and that mathematics writing may often be considered less sophisticated in terms of composition (Kosko, 2016). Given the requirements of the NCTM *Principles*

and Standards for School Mathematics (PSSM) (2000) note that the content standards in mathematics are developed through reasoning and proof, problem solving, communication, representation and connections. In thinking about the processes, writing certainly plays a central role. However, current methods of writing instruction, such as the Writer's Workshop or the 6 Traits of Writing instruction (Culham, 2003), may not have a clear alignment to these processes.

Mathematics Instruction is Needed in the Language Arts Classroom

Teachers and researchers in writing have identified common characteristics now widely recognized in traits models: ideas, organization, voice, word choice, sentence fluency, conventions, and presentation (e.g., Culham, 2003). These characteristics, based on the work of Diederich (1974) who sorted stacks of student writing into *good*, *fair,* and *poor* categories, have become essential components in the process of writing, providing students with a common language for writing assessment. Similarly, other researchers have developed scoring assessments and features guides to analyze students' spelling development (e.g., Bear, Invernizzi, Templeton, & Johnston, 2020).

Borrowing concepts and procedures from these models, we are calling for a new look at writing instruction in connection to informal strategies such as when writing is used as a formative tool for assessing understanding and instructional decision making. Elbow and Sorcinelli (2006) noted the difference in low stakes writing as an instructional strategy compared to more formal or high stakes writing (i.e., essays, term papers). With low stakes writing, students are removed from the boundaries of high stakes writing and are able to write freely through many forms such as exploratory or focus questions, free writing in response to a question, summary writing or reflective journals (White, Reichelt, & Woods 2011).

Using the IRG, preservice and inservice teachers can begin to address the appropriate time for writing instruction to occur during mathematics. This planning guide does not address all the areas of writing support that are needed in the mathematics classroom. However, it is the first step in planning for the utilization of how low stakes writing such as mathematics word problems can facilitate high stakes learning such as measurements of ability and conceptual understanding. Teachers and students can begin to build on mathematical concepts through the appropriate objective, method, type and delivery of word problems. This planning process is the beginning of understanding how one field can successfully inform the other.

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Figure 1: Instructional Resource Guide (IRG)

Objective of Instruction.	Method of Instruction	Type of Prompt	Delivery of Instruction (Teacher Led or Supported)	Assessment
To assist in the development of instruction for the **upcoming objective** through the use of student interviews and analysis of student data.	Formative Assessment	Prompt will encompass the upcoming benchmark or standard.	Whole Group Small Group Independent	Formative Rubric Learning Scales (Not graded)
To continue practice in working with content, vocabulary, and strategies of **previous objective**s.	Warm Up/Review	Prompt will be a review of standard previously taught	Whole Group Small Group Independent	Formative or Summative (Grading Optional)
To instruct in the area of content, vocabulary, and strategy development of the **current objective**.	Introduction of Content	Prompt will encompass the **upcoming** benchmark or standard.	Whole Group Small Group	Formative (Rubric Optional/Not graded)
To practice content, vocabulary and application of strategies of **current objective**.	Practice of Content	Prompt will encompass the **current** benchmark	Whole Group Small Group Independent	Formative (Rubric Optional/Not graded)
To assess the mastery of the skills/concepts taught within the **current objective.**	Summative Assessment	Prompt will encompass the benchmark or standard **previously** taught.	Whole Group Small Group Independent	Formative or Summative (Rubric/Graded)