The Effects on Mathematics Performance of Personalizing Word Problems to Students' Interests

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ABSTRACT

Audra Eileen Kosh: The Effects on Mathematics Performance of Personalizing Word Problems to Students' Interests
(Under the direction of Dr. Gregory J. Cizek)

This study explored student performance on topic-personalized word problems (TPWPs) in middle school mathematics whereby the context of a word problem was customized to students' self-selected interests (i.e., sports; movies, music, and television; animals; travel; and science and technology). Using a within-subjects research design, 343 rising eighth-graders answered approximately 6,000 word problems – half of which were TPWPs and half of which were generic word problems – in the context of a free, online summer mathematics skills retention program for students. Research questions focused on whether TPWPs triggered students' situational interest and how accuracy and speed of word problem responses differed between TPWPs and matched generic word problems. After controlling for the mathematics content of the items (i.e., rates and ratios, integer operations, and equations and inequalities), reading demand of the item stem, and students' perceived mathematics ability level, results of multilevel modeling indicated that students were more likely to rate TPWPs as interesting as compared to generic word problems and that students were more likely to answer items correctly when rating items as interesting. However, no evidence was found that students were more likely to answer TPWPs correctly after controlling for interest ratings. Results suggested that TPWPs triggered students' situational interest and that student interest relates to student performance indicators.

To all of my teachers, in all of their many forms.

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Chapter 1: Introduction

Introduction

The *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000) presents a set of mathematical process standards, one of which calls for students to "recognize and apply mathematics in contexts outside of mathematics" (p. 64). One way that curricular materials require students to apply mathematical concepts to real-life contexts is through word problems. Word problems are defined as text that describes a situation whereby the student must infer mathematical relationships in order to answer a question (Verschaffel, Greer, & Corte, 2000). In addition to providing students with real-life scenarios, word problems are a beneficial instructional tool because they can increase students' motivation in mathematics by: 1) exemplifying how mathematics is relevant in real-life, 2) providing a means to assess students based on their ability to solve various problems applicable to real-life career tracks, 3) developing students' general problem-solving abilities both within and beyond mathematics, and 4) developing students' mathematical knowledge at a conceptual level (Verschaffel, Greer, & Corte, 2000).

Despite the benefits of using word problems in mathematical curricular materials, word problems create an ongoing challenge for students. In fact, in a survey of over 700 Algebra I teachers, respondents indicated that trouble with word problems was the greatest struggle students face for Algebra preparedness, more so than manipulating variables, fluency with fractions, decimals, negative numbers, and over a dozen other mathematical skills (Hoffer, Venkataraman, Hedberg, & Shagle, 2007). Moreover, several studies have shown how students fail to make sense of word problems and consequently provide answers to absurd, illogical problems such as “There are 26 sheep and 10 goats on a ship. How old is the captain?” (Verschaffel, Greer, & Corte, 2000, p. 4). In this example word problem, over half of the first- and second-graders in the study’s sample added the numbers in the problem, answering that the captain was 36 years old. This example shows that students learn and routinely apply the rules of school mathematics, often without considering the context of the problem and how the context informs the solution strategy; one such rule is that problems have one single correct answer, usually obtained by adding, subtracting, multiplying, or dividing the numbers in the problem (Verschaffel, Greer, & Corte, 2000).

One reason why many students struggle with word problems may be that word problems often are not personally relevant to students, potentially resulting in low desire to solve the problem and difficulty with making sense of the solution strategy due to the problem’s irrelevance. As in the example cited above with goats and sheep on a ship, it is doubtful that many elementary school students find themselves in a situation whereby they need to either know the captain’s age or count how many animals are on a ship.

An obvious solution to enhancing word problem relevance would be to provide each student with meaningful, real-life word problems so that all students have the opportunity to see the relevance of mathematics to their unique lives. However, a challenging aspect of providing students with meaningful, relevant problems is that a context which is relatable and interesting for one student may not have the same effect for another student because students have diverse backgrounds, cultures, experiences, prior knowledge, and interests, even within students of a single classroom.

In contrast to providing students with personally-relevant word problems and because general curriculum and assessment materials typically need to target a wide range of diverse students, word problems found in instructional materials often include generic contexts in order to increase the likelihood that all students understand the context of the problem. Similarly, mathematics word problems included on large-scale achievement tests such as those mandated at end-of-course or end-of-year for accountability purposes typically go through a sensitivity review process to ensure that the words and context of the problem do not favor or disadvantage any subgroup of students (e.g., English language learners, students of high- or low-socioeconomic status). Thus, as a result of the need to ensure that all students can interpret a word problem's context equivalently, word problems in learning materials often use generic contexts designed to apply to all students. For example, Pythagorean theorem problems frequently include a ladder leaning against a wall; area and perimeter problems often use garden plots or kitchen floors; and quadratic function problems often use throwing balls or other projectiles.

The generic context of word problems is problematic for two reasons. First, when students repeatedly see the same generic problems, students lose a valuable opportunity to learn from contexts that are meaningful in their lives, with the result that students may view mathematics as irrelevant and disconnected from everyday life. Second, because of the repetition in generic word problem contexts, students may eventually learn which mathematical concepts correspond to particular word problem contexts or key words without understanding why a particular mathematical approach is relevant, such as recognizing that a ladder leaning against a wall probably means the problem requires the Pythagorean theorem. This unintentionally changes the instructional purpose and cognitive demand of the problem because the student no longer needs to determine which mathematical concept most appropriately solves a real-life problem. In this way, students learn to game the system and become good at doing school rather than doing mathematics.

To avoid assigning all students generic word problems that fail to connect to students' individual interests, curriculum designers could potentially create separate sets of problems that use different contexts based on different student interests. Although it is possible that students can still learn the common types of contexts associated with particular interest-specific word problems, providing word problems across a range of interest categories and personal preferences can result in a greater variety of mathematical applications and has the added benefit of potentially helping students see how mathematics can be applied in their unique lives according to topics of interest to the student.

The Mechanism of Action: How Interest Affects Learning

In addition to potentially providing a greater variety of mathematical applications and making mathematics relevant for students, providing students' with word problems customized to their interests may also increase student performance in mathematics by capitalizing on several cognitive and behavioral effects that occur when a student's interest is sparked (Hidi, 2006). As defined by Hidi, interest is "a unique motivational variable, as well as a psychological state that occurs during interactions between persons and their objects of interest, and is characterized by increased attention, concentration, and affect" (p. 70). Thus, according to Hidi, interest by definition affects three states that may lead to greater academic performance: heightened interest might serve to increase students' attention to mathematics word problems; it may promote greater concentration on the problem solving task; and it may influence the extent to which the student finds enjoyment in solving mathematics word problems. Moreover, interest has also been found to negatively correlate with cognitive load, meaning that students working on a highly-interesting activity experience reduced cognitive load that improves learning outcomes (Yen, Chen, Lai, & Chuang, 2015; Park, 2015). A full review of empirical research supporting these claims regarding the learning effects associated with interest is provided in Chapter 2.

Hidi and Renninger (2006) posed a model of interest development whereby interest development progresses through four phases: Phase I- triggered situational interest, Phase II - maintained situational interest, Phase III - emerging individual interest, and Phase IV- well-developed individual interest. Phase I, triggered situational interest, "results from short-term changes in affective and cognitive processing" as manifested through modifications to the environment that spark personal relevance, surprising information, or other means (Hidi & Renninger, 2006, p. 114). In Phase II, maintained situational interest, the situational interest triggered in Phase I persists over a period of time, for example by providing a meaningful activity that a student desires to fully complete. Phase III, emerging individual interest, is when a student begins to see value in and associate positive feelings with a particular content area; students in Phase III may reengage with activities within the content area without the need for triggered or maintained situational interest. Finally, Phase IV, well-developed individual interest, extends Phase III by characterizing students that will actively seek to reengage with content and opt to choose a particular activity when given a choice of other activities. Figure 1 shows the four phases of interest development and the cognitive and behavioral characteristics associated with each phase; again, a full review of literature regarding characteristics associated with interest follows in Chapter 2.

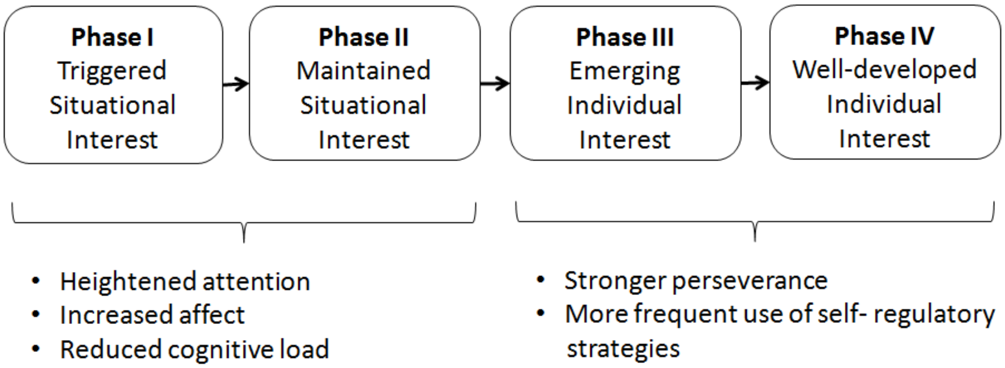

Phase I
Triggered Situational Interest
Phase II
Maintained Situational Interest
Phase III
Emerging Individual Interest
Phase IV
Well-developed Individual Interest
• Heightened attention
• Increased affect
• Reduced cognitive load
• Stronger perseverance
• More frequent use of self- regulatory strategies

Figure 1. The four-phase model of interest development and associated outcomes.

Fittingly to the topic of the present study, Hidi (2006) provided an example of the difference between individual and situational interest in the context of mathematics word problems:

> When we talk about a student who has an individual interest in mathematics and therefore is looking for ways in which he could solve word problems, we conceptualize his/her interest as a predisposition. However, another student who does not have an interest in mathematics may also find the world problem interesting, and thus experience the psychological state of interest triggered by the situation. (p. 73)

The interest development phase that corresponds to receiving word problems aligned to specific contexts, further referred to as *topic-personalized word problems* (TPWPs), will depend on characteristics of the student and the mathematics activity. However, interest-specific word problems most likely correspond to Phases I and II of interest development (i.e., triggered situational interest and sustained situational interest) due to the way the interest-specific word problems make relatively minor modifications to typical word problems in order to make the problems personally relevant. Correspondingly, the mechanism by which TPWPs may result in higher student performance is the increased affect and attention along with reduced cognitive load characteristic of triggered and sustained situational interest. It should be noted, though, that the triggered and sustained situational interest sparked by TPWPs could progress to further stages of interest development for students within mathematics; for example, if a student experienced positive feelings and academic success with a TPWP activity, those feelings could carry into positive feelings about mathematics holistically as a content area, beyond merely the feelings experienced during a TPWP activity. These further-developed phases of interest could then also capitalize on the benefits of enhanced persistence and use of self-regulatory strategies.

Purpose and Research Questions

The purpose of this study was to compare middle school students' performance on TPWPs to performance on matched generic word problems and to explore the possible mechanism by which such word problems may result in increased student performance. The research questions were:

RQ1: Are rising eighth-graders more likely to rate TPWPs as interesting as compared to matched generic word problems?

RQ2: Are rising eighth-graders more likely to answer TPWPs correctly as compared to matched generic word problems, and how do students' interest ratings of problems relate to the likelihood of answering the problem correctly?

RQ3: Do rising eighth-graders spend more or less time solving a TPWP as compared to a matched generic problem, and how does amount of time solving each type of problem relate to mathematical accuracy?

For RQ1, I hypothesized that students would rate TPWPs as more interesting than matched generic word problems due to the aforementioned cognitive and behavioral benefits of sparking students' situational interest. For the same reasons, I hypothesized for RQ2 that students would be more likely to answer a TPWP correctly as compared to a matched generic problem and that favorable ratings of problems – either personalized or generic – would correlate with the likelihood of answering the problem correctly. I posed RQ3 as an exploratory question with no directional hypothesis. Although research on assessment shows that the time spent responding to items generally negatively correlates with the item's difficulty (i.e., students solve items faster when the items are easier; Daniel & Embretson, 2010), Hidi and Ainley's (2008) findings of increased persistence on interest-targeted tasks provides support for the idea that students would spend more time on TPWPs due to showing greater persistence, and thus have longer response times for TPWPs.

To answer the three research questions, I administered both TPWPs and generic word problems to students and compared performance on both sets of problems in terms of accuracy and speed, and I also collected item-level data regarding students' interest in each word problem. In subsequent chapters of this dissertation, I provide a more comprehensive literature review; I describe the specific data sources and data collection methods used for this study; I present the analytic approaches used and results of the analyses; and I provide conclusions and implications of the findings.

Summary

In this study, I seek to inform middle school mathematics teaching and learning by investigating whether or not students perform better when answering TPWPs as compared to generic word problems. Due to the positive behavioral and cognitive outcomes associated with sparking students' interests, it is possible that students will perform better when receiving word problems aligned to their interests. In addition to potentially raising student achievement in mathematics, providing students with personalized word problems also has the potential to overturn perceptions held by some students that mathematics is boring or irrelevant (Brown, Brown, & Bibby, 2008).

If results show that TPWPs are indeed easier for students, then that supports the use of topic personalization as a valuable instructional strategy for students. And, with the growing availability of computers in schools and students' homes (Lauman, 2000), computer-based learning environments could programmatically design unique sets of word problems for students based on their interests. The potential for this technology expands as complimentary work on automatic item generation seeks to use natural language processing to produce large banks of word problems (Deane & Sheehan, 2003).

On the other hand, if results do not show that personalized problems are easier for students, then it would be valuable to learn that now before resources are spent developing learning interventions based on TPWPs. It takes substantially more time by curriculum experts, technology designers, and programmers to create multiple activities that can vary based on student ability or interest; thus, if TPWPs are not indeed easier for students than generic word problems, then there is arguably no need for educational technology designers and item writers to continue investing time to develop TPWPs. Instead, resources could be diverted from creating personalized problems to implementing alternative strategies to support student learning in computer-based learning environments, such as identifying error patterns in student responses in order to provide real-time feedback to students (O'Rourke, Andersen, Gulwani, & Popovic, 2015).

Chapter 2: Literature Review

Four main bodies of literature provide background for this study. The first body of literature summarizes empirical research regarding how interest affects student performance and motivation within the domain of reading. The second body of literatures focuses on prior research on the effectiveness of personalized word problems as an instructional strategy or student motivator in mathematics. The third body of literature covers the mechanism by which interest leads to desirable student outcomes (i.e., learning, achievement, engagement, and motivation). Finally, the fourth section of literature consists of features of mathematics tasks that affect the cognitive complexity of a task, which is important to this study in order to understand how varying features of a mathematics problem can change the way students interact with the problem.

The Domain of Reading: How Interest Affects Learning

Although topic-personalization in the field of mathematics word problems is relatively new, researchers have long studied the effects of allowing students to choose instructional materials that best match their interests in other content areas, particularly reading. The idea is that, when given a choice about which text to read, students will select texts that are more interesting and relevant to them, which in turns leads to the aforementioned benefits of triggering situational interest and leading to sustained individual interest. The effect of choice on student motivation and achievement within the domain of reading has shown that providing students with a choice of which text to read positively affects both motivation and reading comprehension. In a meta-analysis, Guthrie and

Humenick (2004) computed 46 effect sizes of experimental and quasi-experimental studies that granted students a choice of texts and found average effect sizes of .95 and 1.2 for student choice on motivation and reading comprehension, respectively.

In many of the studies included in Guthrie and Humenick's (2004) review, motivation was operationalized as the number of minutes students chose to read beyond the required reading period when given a choice of other activities. For example, McLoyd (1979) asked second- and third-graders to rank books in order from first-choice to last-choice and then assigned half of the participants to read 250 words from their first-choice book and the other half to read 250 words from their last-choice book. After students read 250 words, they were given 10 minutes of free-time to either continue reading, play Scrabble, do crossword puzzles, or do a math game. McLoyd's results showed that students in the high-interest condition (i.e., students that read their first-choice book) spent statistically significantly more time reading than students in the low-interest condition, suggesting that students had greater motivation to read when engaging with texts they found interesting. Similar studies have since replicated McLoyd's findings: for example, Flowerday, Schraw, and Stevens (2004) found that undergraduate students' situational interest in a text positively affected their attitude toward completing a reading and writing task about the text.

In addition to the effect of choice on motivation to read, studies show that allowing students to choose a text impacts achievement indicators. In a study of 84 third-graders tasked with locating information in an expository text, Reynolds and Symons (2001) found that students located answers to a four-question test statistically significantly faster when given the option to choose the topic out of four possible topics as compared to students in a control group that were assigned a text, even after controlling for prior knowledge and level of interest in the topic. Students in the choice condition also answered more questions correctly than students in the no-choice condition, though this difference was not statistically significant. Thus, allowing students to choose instructional materials based on their interests – as the current study will do in the field of mathematics word problems – appears to be a promising instructional strategy.

Personalization of Mathematics Word Problems

Continuing beyond reading to mathematics, another body of research examines how student achievement, engagement, and motivation are affected by personalization of mathematics word problems. As mentioned in the previous chapter, TPWPs modify the context of the word problem based on a students' self-selected interest. Another type of word problem, which I name *incidentally-personalized word problems* (IPWPs) merely changes surface-level features of the problem (i.e., names of people, places, or favorite things) without changing the context of the problem. For example, in an IPWP, the phrasing "A teacher gave her class 12 cans of soda to share…" would be replaced with "Ms. Jones gave her class 12 cans of Dr. Pepper…" where Ms. Jones is the name of the student's teacher and Dr. Pepper is the student's favorite soda. This type of personalization is different from the TPWPs proposed for this study because topic personalization requires giving students different contexts based on their interests. Nevertheless, the literature on IPWPs provides insight to inform this study.

Research on incidental personalization of word problems. Research on IPWPs has largely occurred in two historical waves based on technology available at the time. Prior to widespread computer use in classrooms and web-based learning environments, researchers administered surveys to students and then manually modified word problems to create personalized word problems. The problems were then distributed several days later through paper and pencil testing. A major limitation of this wave of research is that personalizing word problems without the aid of computers is extremely time consuming. Later, as computer-based learning technologies proliferated, technology aided real-time creation of personalized word problems based on information the student entered to the computer. Research from the latter wave is relatively recent. Hence, there are fewer studies from the second wave of research, but they tend to have larger sample sizes of both students and problems due to increased efficiency in creating IPWPs.

Results from both phases of research indicated positive effects of incidental personalization on student motivation and mixed effects on student achievement. In one of the earliest studies on IPWPs, Anand and Ross (1987) randomly assigned fifth- and sixth-graders to receive instructional materials consisting of either problems with generic contexts (e.g., “There are 3 objects. Each one is cut in one-half. In all, how many pieces would there be?”) or matched personalized word problems whereby the students’ favorite things and friends’ names were substituted into the problem. Results showed that students receiving IPWPs did statistically significantly better on a posttest and also had a more positive attitude toward math after completing the unit as compared to the control group.

Several other studies have since replicated these findings by using one of two common research designs. In the within-subjects approach, researchers have compared student performance on assessments consisting of both IPWPs and generic word problems. In the between-subjects design, as was the case in Anand and Ross’s (1987) study, researchers randomly assign students to receive either personalized or generic instructional materials and then both groups complete a common posttest to assess achievement and/or an instrument to measure engagement in mathematics or attitude toward mathematics. Across both types of research design, results have shown positive effects of IPWPs on student achievement and engagement across diverse samples, such as Norwegian students of ages 12 to15 studying probability (Høgheim & Reber, 2015), fourth-grade Taiwanese students solving two-step word problems (Ku & Sullivan, 2002), American sixth-, seventh-, and eighth-graders solving two-step word problems (Ku, Harter, Liu, Thompson, & Cheng, 2007), and American fifth-graders solving fraction addition and subtraction problems (Davis-Dorsey, Ross, & Morrison, 1991). In a slightly different study regarding personalized elements (e.g., using the student's name as the game piece avatar, substituting names of the student's favorite places into the game context) in the context of a computer game about order of operations for fourth- and fifth-graders, Cordova and Lepper (1996) found that students were more interested in playing the game after school and also attempted more challenging problems when they received the personalized version of the computer game.

In contrast to studies that found positive effects for IPWPs, other studies have found no statistically significant differences when giving students IPWPs. In a sample of American third-graders solving a variety of mixed word problems representing different mathematical content, Bates and Wiest (2004) found that students performed equally as well on IPWPs and generic word problems when administering a test consisting of both types of problems. Additionally, although Davis-Dorsey, Ross, and Morrison (1991) found positive effects for incidental personalization in fifth-graders, the same study included a sample of second-graders for which personalization had no statistically significant effects on achievement. In yet another study, Cakir and Simsek (2010) found that seventh-graders in Turkey did not show any greater achievement outcomes after receiving incidentally-personalized instructional materials as compared to a control group.

The mixed results regarding the effectiveness of using incidental personalization to increase student achievement and engagement raise questions about why some research has encouraging, positive results whereas other studies have found no effects. A potential reason for the discrepancy in results is the variability in how researchers define a personalized word problem and the extent to which students may have found personalized word problems interesting. In one study that did not find positive effects for personalization, a teacher had students fill out an interest form including the question "Name one thing you buy at your favorite store" and then substituted that response into a word problem template from a textbook (Bates & Wiest, 2004, p. 25). The resulting personalized problem was "Suppose 30 bottles of glue are shared equally among 6 classes. How many bottles of glue would each class get?" which was personalized for a student responding with "glue" (p. 25). I argue that this problem represents little, if any, personalization – unless this child was particularly fascinated by bottles of glue – which could explain why the authors found no differences on IPWPs with respect to student interest, understanding, or achievement.

Research on topic personalization of word problems. All of the aforementioned research on personalization used IPWPs where a student's favorite things or friends' names were substituted into problem templates as opposed to TPWPs that change the context of the problem based on the student's interests. Research on TPWPs is far less common than research on IPWPs, likely because it takes much more time to write unique word problem contexts based on students' interests rather than merely programmatically swapping out single words within a word problem template.

Early research on TPWPs is largely dominated by the work of Walkington (2013) who conducted a quasi-experimental study that randomly assigned Algebra 1 students to receive topic-personalized or non-personalized word problems over the course of a unit about linear functions and independent variables in a cognitive tutoring system. In the study, students receiving TPWPs performed statistically significantly better on achievement indicators (e.g., accuracy of responses and rate of progression through the computer-based curriculum) both during the experimental unit and during a follow-up unit wherein both the control and treatment group received the same problems four units later in the school year. In other words, students who received the personalization treatment early on continued to outperform the control group even after personalization was removed.

A substantial critique of Walkington's (2013) study relates to the design of the personalized and non-personalized problems. She provided the following example of a word problem used in the control group: "An experimental liquid (LOT#XLHS-240) is being tested to determine its behavior under extremely low temperatures. Its current temperature is 35 degrees Celsius and is slowly being lowered by two and one-half degrees per hour…" (p. 939). As related to the research design, the control group problems are troubling because the context of this problem, which regards an experimental liquid, represents a context with which students in her study (i.e., mostly ninth- and tenth-graders) probably do not normally interact. This is because, first, high-school students normally are not in a setting of experimentally testing liquids; second, the units are Celsius, which is not the dominant measurement system in the United States; and third, the meaning of the identification number of the liquid in the problem (i.e., LOT#XLHS-240) may have been unclear and confusing to students.

Now, consider two personalized word problems from Walkington's (2013) study. The first example was personalized to the interest category of food: "A new soda at McDonald's is being tested to determine its behavior under extremely low temperatures. Its current temperature is 35 degrees Fahrenheit and is slowly being lowered by two and one-half degrees per hour…" (p. 939). The second example was personalized to the interest category of stores: "The Dippin' Dots store at the mall uses extremely low temperatures to freeze its ice cream into tiny balls. Right now, the temperature of a batch of chocolate Dippin' Dots ice cream is 35 degrees Fahrenheit and is slowly being lowered by two and one-half degrees per hour..." (p. 939). There are several concerns related to these problems. First, both problems are actually about food (i.e., one about soda and the other about ice cream), even though the second problem was supposedly targeted to students with an interest in stores. Second, the contexts of both problems represent ideas familiar to high-school students (i.e., McDonald's, the mall, temperature units in Fahrenheit) whereas the control problem represented an unfamiliar context. Thus, Walkington's study has potentially confounded the effect of personalization and merely situating problems in relevant contexts without personalization, thereby failing to provide clear evidence to either refute or support the effect of topic-personalization on student learning.

In another study on TPWPs, Walkington, Petrosino, and Sherman (2013) found that some high-school students performed statistically significantly better on TPWPs as compared to generic word problems. Interestingly, however, personalization had negative effects for high-ability students. As the authors speculated, personalization potentially acted as a distraction for high-ability students that over-complicated the problem contexts by including additional mathematical considerations relevant to real-life but irrelevant to the intended context of the problem. Nevertheless, personalization was an effective instructional strategy for lower-ability students. Their study, however, included only 24 students that solved word problems in only three different contexts.

Finally, in an effort to reduce the time demands of constructing TPWPs, Walkington and Bernacki (2015) conducted another study whereby students wrote their own algebra problems utilizing contexts relevant to the students' lives. The authors found that students rated mathematics as more relevant to their lives after writing their own problems, but they also found that problem writing was challenging for some students. For example, students would write problems that did not represent the intended content, had no question, or were not mathematically accurate.

How Interest and Choice Mediate Motivation, Learning, and Achievement Outcomes

One of the earliest pieces of scholarly work on interest and learning was John Dewey's (1913) book, *Interest and Effort in Education*. Dewey asserted that interest and effort are inherently intertwined, meaning exertions of effort are always motivated by an underlying interest. According to Dewey,

> It is psychologically impossible to call forth any activity without some interest. The theory of effort simply substitutes one interest for another. It substitutes the impure interest of fear of the teacher or hope of future reward for pure interest in the material presented. (p. 2)

Dewey's perspective on the strong relationship between interest and effort, and likewise the relationship between both interest and effort to learning, set the groundwork for a body of research in psychology and education about the psychological or behavioral mechanisms by which interest may lead to learning.

Dewey (1913) distinguished between direct and indirect interest, which are largely equivalent to extrinsic and intrinsic motivation, respectively. In modern literature, where modern is relative to Dewey's 1913 writings, researchers commonly distinguish between situational interest and individual interest, as was described in Chapter 1 with the four-phase model of interest development (Hidi & Renninger, 2006). On the one hand, individual interest, also known as personal interest and similar to what Dewey called direct interest, is "characterized by intrinsic desire to understand a particular topic that persists over time" (Schraw & Lehman, 2001, p. 24). On the other hand, situational interest, which is similar to what Dewey called indirect interest, is "transitory, environmentally activated, and context-specific" (Schraw & Lehman, 2001, p. 24).

Cognitive and behavioral outcomes associated with interest. Because situational interest is attached to features of the environment whereas individual interest is attached to characteristics of the student, it is arguably easier for educators to manipulate situational interest than it is to manipulate individual interest. Correspondingly, the context of this study (i.e., providing students with word problems aligned to their interest) is one means of manipulating situational interest, and researchers have documented several cognitive and behavioral outcomes associated with triggering situational interest; these include reducing cognitive load, heightening attention and concentration, and raising affect and hence persistence.

Reduced cognitive load. One documented benefit of triggering situational interest, as related to promoting effective learning, is the reduction of cognitive load (Park, 2015). Cognitive load, defined as "a construct representing the load that performing a particular task imposes on the cognitive system”, can limit learning when the cognitive load of an activity interferes with the students’ ability to process all of the necessary information (Sweller, van Merrienboer, & Paas, 1998, p. 266). Cognitive load can be classified as intrinsic, extraneous, or germane cognitive load. *Intrinsic cognitive load* is load due to the difficulty of the learning material, such as solving multistep mathematical problems versus single-step computations, and can be quantified by the number of concepts or procedures a learner must simultaneously process (Debue & van de Leemput, 2014; Sweller, van Merrienboer, & Paas, 1998). *Extraneous cognitive load* is load caused by poor instructional design, such as providing a student with word problems with multi-syllable names from unfamiliar ethnicities that are difficult to pronounce. Finally, *germane cognitive load* is load experienced by learners when processing intended learning goals into long-term memory and schemas, such as making sense of a mathematical model that promotes conceptual understanding rather than performing an algorithm without understanding the rational for why the algorithm works. Accordingly, effective instructional designs should seek to reduce extraneous cognitive load and increase germane cognitive load (Sweller, van Merrienboer, & Paas, 1998). Related to germane cognitive load is the idea of generative cognitive processing, which is when a student actively engages in activities of high germane cognitive load (DeLeeuw & Mayer, 2008). If a student experiences lack of interest, however, the student may experience generative underutilization, which is when a student is capable of learning but does not exert the necessary effort to accomplish the learning goal (Park, 2015).

Although research on the effects of situational interest on cognitive load is minimal at this time, one study found a statistically significant negative correlation between situational interest and perceived cognitive load, meaning students reported lower cognitive load when expressing higher interest (Park, 2015). In a study of 127 undergraduates in a computer literacy course, Park measured participants' situational interest with Likert scales such as "I was completely caught up in what I was studying" and likewise measured participants' perceived cognitive load with an instrument asking participants to rate the amount of mental effort expended on the learning task (p. 222). Park found a negative correlation (r_{xy} = -.417, p<.001) between perceived cognitive load and reported situational interest, implying that triggering situational interest may have increased generative cognitive processing through the mechanism of reducing cognitive load.

Taking a different methodological approach in the context of reading interesting versus non-interesting literary passages, McDaniel, Waddil, Finstad, and Bourg (2000) asked students to react to an audible tone that occurred throughout a students' reading of a passage. The student was told to press the spacebar key on a computer as soon as hearing the tone, and the authors used reaction time to the tone as an indicator of cognitive resources spent on reading the passage, with the idea that a faster reaction time is indicative of spending fewer cognitive resources on reading the passage. The authors found that participants reacted faster to the tones when reading interesting texts, which they claimed supported the idea that interesting texts required fewer cognitive resources while reading.

Heightened attention and concentration. Although the theoretical literature supports the conclusion that interest promotes heightened attention and concentration (Hidi & Ainley, 2008), competing explanations exist based on results from empirical studies about exactly how interest relates to attention and concentration. From one perspective, increased interest leading to heightened attention may result in students spending longer time on interesting tasks because students feel motivated to work on the task longer. In a study where participants read sentences of varying degrees of interest, Anderson (1982) found that fourth-graders read interesting texts slower than non-interesting texts.

Alternatively, a student experiencing greater concentration due to peaked interest may be able to process instructional materials faster, thus resulting in spending less time on an interesting task as compared to a similar task that the student did not find interesting. In the context of personalized mathematics word problems, Walkington (2015) found that students in a treatment group answering TPWPs spent less time both reading and solving the personalized problems as compared to students in a control group solving comparable non-personalized word problems. Walkington concluded that interest-targeted word problems increased students' attention and engagement, as demonstrated by faster response times.

Greater positive affect leading to greater persistence. Yet another benefit of interest is persistence, where a student continues to work on a task despite possibly encountering struggles while working on the task; the relationship between interest and persistence has been found to be mediated by affect. In a study by Ainley, Hidi, and Berndorff (2002), the authors concluded that higher positive affect (i.e., associating positive feelings with a task) was the mechanism by which interest led to greater persistence. In their study, 117 Australian eighth-graders read four texts about different topics. For each text, students rated their topic interest in the text, and affect was measured by students' selection of which emotion they felt after reading the text (e.g., bored or interested) and how strongly students felt the emotion. The authors also collected data on persistence based on how many sections of the text the student read. After considering a variety of structural equation models, the authors found that "the strongest model linking topic interest and learning suggested that topic interest was related to affective response, affect was then related to persistence with the text, and persistence was related to learning" (p. 558). These findings suggest that students who experienced more positive emotions with the text also read more of the text, and reading more of the text was related to greater learning outcomes as measured by a reading comprehension score.

Supporting students' progressions to higher phases of interest. The likelihood that interest-targeted activities will trigger the aforementioned benefits of reduced cognitive load, increased attention and concentration, positive affect leading to persistence, and of use of self-regulatory behaviors corresponds to a student's phase of interest development. Reduced cognitive load, positive affect, and heightened attention are mostly seen in Phase I and II of the four-phase model of interest development (i.e., triggered and sustained situational interest; Hidi & Renninger, 2006; Hidi, Renninger, & Krapp, 2004), whereas persistence and use of self-regulatory strategies are mostly seen in Phases III and IV (i.e., emerging and well-maintained individual interest; Hidi & Ainley, 2008). One psychological mechanism in Phases I or II can evolve into another psychological mechanism in Phases III or IV, as is the case with positive affect in Phases I and II leading to persistence in Phases III and IV.

Despite the benefits associated with each phase of interest development, many students do not exhibit Phase III or Phase IV levels of individual interest. However, it is possible to help students progress in their interest development in order to reach the higher phases of interest and thus receive the positive benefits of those phases such as the use of self-regulatory strategies. As recommended by Renninger and Hidi (2002) based on the results of a case study showing how environmental factors triggered the situational interest of a seventh-grader working on a science project, "support for students' attention to and achievement in working with less well-developed interest might usefully include multiple instances of triggered situational interest and the inclusion of individual interest (e.g., opportunities to work with friends)" (p. 189). In other words, for students that do not have a well-developed interest in a particular task or content domain, educators can help support development of such interest by providing multiple opportunities for triggered interest events, as could possibly be the case in providing students with TPWPs.

When attempting to move students to higher phases of interest development, one instructional method is to provide students with choices related to learning activities, with the assumption that students will choose materials that they find interesting. However, certain conditions must be met in order for choice to intrinsically motivate students. Katz and Assor (2007) proposed a conceptual framework consisting of three components to describe exactly when choice benefits motivation and learning. First, the choices must relate to students' interests. For example, a student may not care to choose which numbers should occur in a mathematics worksheet but may care about which country he or she will study for a geography assignment. Second, the number of choices must be constrained, as too many choices can cause frustration. Last, choice should only be used if culturally-appropriate. For example, in some cultures, choosing differently from others in a group might be a sign of rebellious, unacceptable behavior, whereas in other cultures – especially Western cultures – choice may present an opportunity to express individuality.

Features that Affect the Level of Challenge of Mathematics Word Problems

For the final section of this chapter, I review research about features of mathematics tasks that affect the difficulty or cognitive complexity of word problems; research in this area is critical in order to inform the research design which, as I will describe fully in Chapter 3, used matched pairs of personalized and generic word problems that were matched based on features predicted to affect the problem's difficulty.

Researchers have investigated student performance on word problems or matched symbol problems in school environments where mathematics tasks are typically fabricated to align to a learning objective. In these studies, researchers typically express the level of challenge of a mathematics problem through either item difficulty or cognitive complexity. Item difficulty is a psychometric characteristic of a problem administered as a question on a test, either represented by the percentage of examinees answering the problem correctly or derived from an item response theory model. In either case, the difficulty of an item is a quantitative index based on examinee item response data. Relatedly, the cognitive demand or cognitive complexity of a task refers to the "cognitive processes in which students actually engage as they go about working on the task" (Stein, Grover, & Henningsen, 1996, p. 461), and is often expressed according to a taxonomy of increasingly complex levels such as Boston and Smith's (2009) rubric for classifying the cognitive demand of a mathematics task.

Regarding research on word problems in school contexts, Nathan and Koedinger (2000) pointed out that teachers and researchers have a "symbol precedence model of development algebraic reasoning" (p. 168), meaning they believe that students first learn how to solve symbolic equations and then learn to solve story problems (i.e., word problems) by using a strategy whereby the story context is translated into an equation and then solved. The symbol-precedent view is corroborated in textbook design as well: in nine out of ten textbooks analyzed by Nathan, Long, and Alibali (2002), equations were presented prior to story problems. Moreover, the authors pointed out that story problems are often presented toward the end of chapters as challenge problems.

The symbol-precedence view of mathematical development has been challenged, however. In a study of high-school students, Koedinger and Nathan (2004) tested student performance on three different types of problems matched for mathematical structure and varied by presentation format: 1) story problems (e.g., a question about a waiter making tips and an hourly rate), 2) word equations (e.g., Starting with $81.90, I subtract $66 and then divide by 6. What number do I get?), and 3) symbolic equations (e.g., Solve for x: (81.90-66)/6 = x). Students performed statistically significantly better on story problems and word equations as compared to symbolic equations, but there were no statistically significant differences on performance between story problems and word equations. The authors concluded that presenting problems verbally as opposed to symbolically is the key determinant of difficulty rather than the situational context.

A curiosity in Koedinger and Nathan’s (2004) study was that student success in story problems and word equations was linked to the use of informal strategies such as guess-and-check or unwinding (i.e., working backwards from the answer), but such strategies may not be effective for more complex algebra problems. To test the hypothesis that there is a trade-off between problem presentation and complexity, Koedinger, Alibali, and Nathan (2008) conducted a follow-up study with more complicated problems tested on college students. The 2008 study included double-reference problems where an unknown quantity is used twice in the matched symbolic equation. For example, the problem “Roseanne just paid $38.24 for new jeans. She got them at a 15% discount. What was the original price?” translates to the equation $x – 0.15x = 38.24$ where the variable occurs twice (p. 370). As expected, because these double-reference problems devalue informal strategies, results showed that students performed better on symbolic equations than story problems.

Enright, Morley, and Sheehan (2002) conducted a study similar to those of Koedinger and Nathan (2004, 2008) that examined the impact of particular story and equation problem features on difficulty. The authors systematically varied characteristics of two sets of algebraic word problems related to rates and probability in a sample of Graduate Record Examination (GRE) examinees. For the rate problems, they varied whether the item included variables or numbers, the context of the problem (i.e., cost or distance), and the level of complexity of the constraints in the problem. The factor that impacted difficulty the most was the presence of variables as opposed to numbers. Interestingly, the authors found that the effect of context depended on whether or not variables were required: for rate problems without variables, a cost context (e.g., prices with dollar signs to calculate a unit rate) made the item statistically significantly easier than a distance context (e.g., miles per hour). But, for items with variables, there was no statistically significant difference between cost and distance rate problems. Similar to Nathan and Koedinger's results, these results indicate that context matters less for more mathematically complex problems such as problems using variables as opposed to numbers.

For the probability problems in Enright and colleagues' (2002) study, the authors also varied whether the item was phrased as a problem about probability (i.e., What is the probability of…) or percentage (i.e., Which percentage of…) and whether the context was a real-life scenario or an abstract number context (e.g., An integer is chosen at random from…). The authors also varied the complexity of counting when describing the sample space in a probability item (e.g., integer between 200 and 399 versus integer beginning with the digits 2 or 3 and ending with the digits 8 or 9). Results showed that complexity of counting had the greatest impact on item difficulty and that items phrased as probability questions were more difficult than items phrased as percentage questions. Real-life versus abstract context had no statistically significant differences in item difficulty.

Additional studies of word problems further demonstrate how minor semantic changes affect difficulty, particularly through the use of keywords that signal students to use certain operations or strategies. Martin and Bassok (2005) defined translation cues as "standardized phrases and keywords that are highly correlated with correct solutions" which allow students to go directly from words to solution strategies with little need to interpret the context of the word problem (p. 471). For example, students identify *altogether* to mean addition, *difference* to mean subtraction, and *times* to mean multiplication.

Translation cue strategies can backfire when a mismatch exists between the translation cue and solution strategy. For example, in the statement "There are six times as many students (S) as professors (P)", 37 percent of undergraduate engineering students incorrectly translated this sentence to the corresponding expression, with the response 6S=P accounting for 68 percent of the incorrect answers (Clement, 1982, p. 17). This type of error, known as a reversal error, commonly occurs when the student tries to directly translate the keywords in the statement to the expression without making sense of the relationship between quantities. Another example of how semantics can complicate mathematics is the commonly-cited bat and ball problem (i.e., A bat and a ball cost $1.10. The bat costs one dollar more than the ball. How much does the ball cost?), for which over 50 % of students at elite universities responded with the incorrect answer of ten cents (Kahneman, 2011).

To further investigate how students use word cues, Martin and Bassok (2005) conducted a study to test their hypothesis that story problems also have semantic cues in addition to translation cues that affect which strategies students use and the likelihood of a correct response. They hypothesized that certain objects (e.g., blue marbles and red marbles) represent symmetrical relationships usually modeled by addition or subtraction whereas other objects (e.g., apples and baskets or chairs and tables) represent asymmetrical relationships associated with multiplication and division. Problems have semantic alignment when the symmetrical or asymmetrical relationship between the words in the problem matches the correct solution strategy (Bassok, Chase, & Martin, 1998). Martin and Bassok (2005) presented seventh-graders, ninth-graders, eleventh-graders, and college students with different types of problems that varied in their semantic alignment and whether students were asked to provide a numerical answer or write an expression or equation. As hypothesized, semantic alignment affected whether students answered story problems correctly; more students answered correctly to semantically aligned problems, as expected. However, semantic alignment had no effect on expression or equation writing tasks. Also, although students performed better on problems with semantic alignment, this effect was stronger for younger students and diminished as age increased. These results imply that word cues matter less for higher-ability students answering more complex questions, probably because the mathematical complexity of the problem trumps context cues.

Koedinger, Alibali, and Nathan (2008) conducted similar research on word problem phrasing with high-school and college algebra students. The authors tested for difficulty differences between story-implicit problems expressed with everyday language of mathematical operations (e.g., gave away, kept) and story-explicit problems that utilized mathematics terminology (e.g., subtracted, added). They found no statistically significant differences between performance on story-implicit versus story-explicit problems. However, this result is likely due to the age of the participants. It is possible that younger students are still developing understanding of mathematical terminology, as was the case in the aforementioned lower-elementary and middle school examples, whereas high-school and college students already have this foundational knowledge.

A synthesis of the above research on mathematics word problems reveals that the role of context as a predictor of item difficulty cannot be summarized with a simple answer about when context makes a problem more or less difficult. Instead, the context of a problem interacts with other features of the problem and the student, with evidence supporting the idea of a tradeoff between word problem context, mathematical complexity of the problem, and the age and ability of the student. Research findings indicate that context affects lower-level students more so than students completing higher-level mathematics.

Summary

In this chapter, I reviewed four bodies of literature that informed the work of this dissertation. First, I presented evidence from the field of reading across pre-school through college contexts to support the idea that motivation, learning, and achievement outcomes increase when students read texts that they self-select as interesting to them. Second, I reviewed research with mixed effects for using incidentally-personalized word problems, and I presented the only two known studies claiming to use TPWPs, each of which had substantial limitations. Third, I summarized literature about the cognitive processes that mediate the relationship between interest and learning.   Fourth, I reviewed features of mathematics word problems that affect the difficulty of those problems, including subtle differences in problem phrasing, vocabulary, and context.

To summarize the research most similar to the present study, research on personalized word problems shows encouraging results in some cases but no statistically significant differences as compared to generic word problems in other cases. I assert that a reason for the discrepancy in results is due to the different ways in which authors have operationalized both personalized and control problems, with differences due to incidentally-personalized versus topic-personalized word problems and due to control problems situated in either familiar or abstract contexts. Students' perceptions of these personalized problems as interesting or not could explain differences in the studies' results. In my study, I will focus on TPWPs. Currently, the only available research in this area is Walkington's (2013) study that used minimal context changes to personalized word problems and Walkington, Petrosino, and Sherman's (2013) study with a limited sample size. Additionally, previous studies typically make the assumption that personalized word problems are interesting to students; I do not make this assumption and instead collect data at the problem level about which word problems students find interesting and how students' ratings of word problem interest influence student performance.

Chapter 3: Method

Using a within-subjects design whereby participants completed both TPWPs and generic word problems, I compared students' interest ratings, accuracy of responses, and speed of responses of TPWPs to those of generic word problems. A description of the data collection procedures, participants, instrument design, data preparation methods, and analyses methods follows.

Procedures and Participants

Data collection for this study occurred within the context of a free online summer program designed to prevent summer learning loss in mathematics. The summer program, known as the Summer Math Challenge (SMC), was offered by MetaMetrics® to rising second- through eighth-graders during six weeks of June and July, 2016. The SMC focused on different learning standards each week as aligned to The Quantile® Framework for Mathematics, a scale measuring task and concept difficulty that consists of approximately 550 Quantile Skills and Concepts (QSCs) reflecting the mathematical content students learn in grades K-12 (MetaMetrics, Inc., 2011). The online program included instructional resources, games, quizzes, and interactive activities for students to complete at home each week. Participation was voluntary, and parents learned about the SMC through announcements made to educational leaders at the state-, district-, or school-level. Participants from the 2015 SMC were automatically enrolled in the 2016 SMC but could opt-out if desired. Access to a computer with internet over the summer was required for participation in both the summer program and the research study. Although students could access SMC resources at any time during the summer or academic school year, data collection for this study was permitted between June 16, 2016 and July 29, 2016, the official six week duration of the SMC. Any students completing the data collection instrument after July 29, 2016 were excluded from data analyses in order to facilitate timely completion of data analyses.

Data for this study focused on rising eighth-graders enrolled in the SMC. Grade level was reported by the individual that enrolled the student in the SMC, which could have been an educator, parent, other care giver, or the student himself/herself. In total there were 334 students across 34 states included in data analysis. Figure 2 shows the geographic distribution of students in the study, where the number in the state is the number of students in the sample from that state. North Carolina had the most participants – roughly one-third of the total sample – likely because the creators of the SMC were based in North Carolina. Of the 334 students, 40 (12.0%) were reported to find math at grade level difficult; 147 (44.0%) were reported to find math at grade level about average; 146 (43.7%) were reported to find math at grade level easy; and one participant did not provide a response for ability level. Similarly to grade level, these perceptions of mathematics ability were self-reported at the time of SMC enrollment by whoever enrolled the student in the SMC. Individuals enrolling students in the SMC also had the option to provide the student’s Quantile measure (i.e., a quantitative mathematics ability measure) upon enrollment to the SMC. Not all students receive a Quantile measure or know where to access this information; in fact, only 27 students provided a Quantile measure, thus not warranting any additional consideration in analyses. No data were collected on gender, race, English language status, or any other demographic variables.

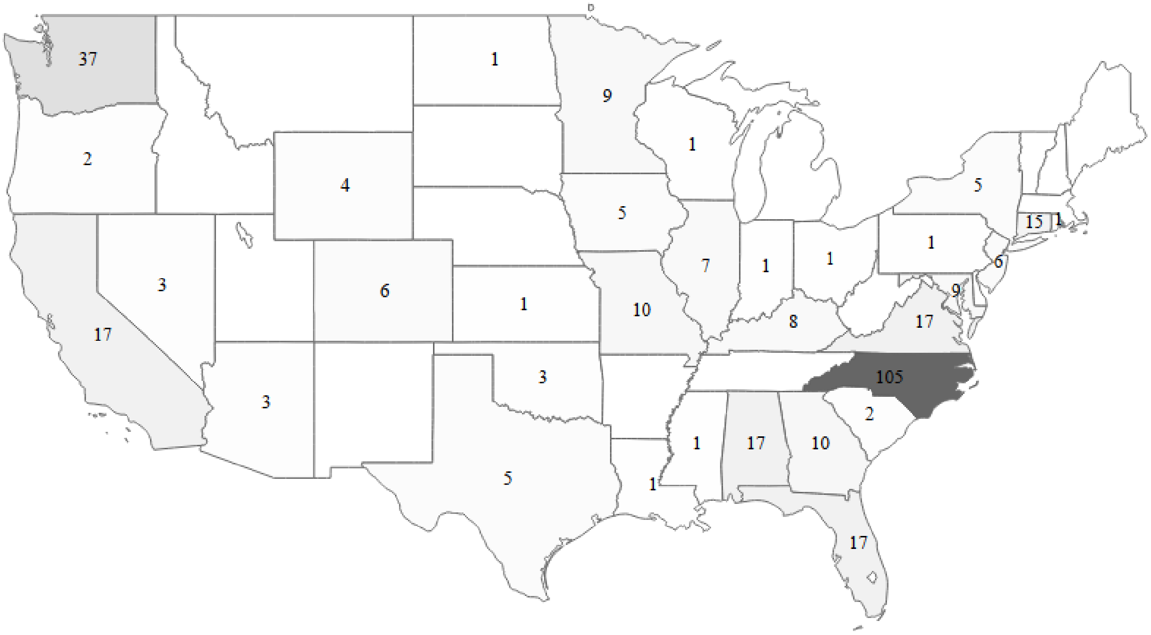


Figure 2. Number of participants in each state. Hawaii is not pictured with one student. Alaska is not pictured with zero students.

In 2016, the SMC concepts for rising eighth-graders included proportional reasoning, operations with rational numbers (including negative numbers, fractions, and decimals), equations and inequalities, and probability. Data collection for this study was conducted during three sessions occurring at weeks one, two, and four of the SMC. These weeks were selected because, historically, participation rates are higher during the earlier weeks of the SMC, thereby allowing for a greater sample of students. Week four was selected instead of week three because the mathematics content of week three (i.e., operations with rational numbers where operands must be mixed with fractions, decimals, and negative numbers) was not conducive to writing word problems across a wide range of contexts. Additionally, week three of the SMC fell during the Independence Day holiday when participation rates were predicted to be low due to holiday-related family activities.

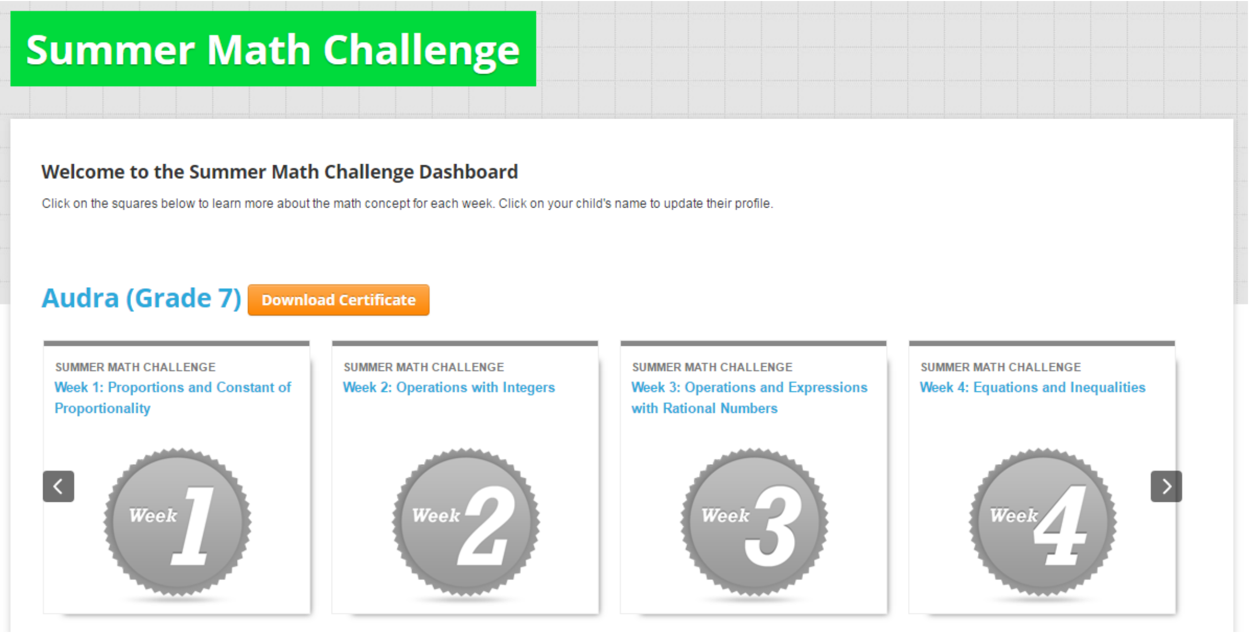
Table 1 displays the mathematics topic for each of the data collection sessions along with the relevant QSCs for that week's topic that were used in data collection. These particular content standards were chosen by a team of three mathematics subject matter experts, including myself, based on the reasoning that the content represented skills typically learned in seventh-grade that are most crucial for success in eighth-grade, as determined by Common Core State Standards for Mathematics (CCSSM) documents that outline the major concepts taught in seventh- and eighth-grade mathematics courses (National Governors Association for Best Practices & Council of Chief State School Officers, 2010).

Table 1

Quantile Skills and Concepts in Each Data Collection Session

Data collection session	Topic	Quantile skills and concepts
1	Proportions and constant of proportionality	• Calculate unit rates in number and word problems, including comparison of unit rates. • Calculate unit rates of ratios that include fractions to make comparisons in number and word problems.
2	Operations with integers	• Model or compute with integers using addition or subtraction in number and word problems. • Model or compute with integers using multiplication or division in number and word problems.
3	Equations and inequalities	• Solve two-step linear equations and inequalities and graph solutions of the inequalities on a number line. • Solve linear equations using the associative, commutative, distributive, and equality properties and justify the steps used. • Write a linear equation or inequality to represent a given number or word problem; solve.

Data for the study were collected via three similar Qualtrics instruments embedded as links in the SMC website and sent in emails to participating SMC families. Qualtrics is a web-based data collection tool commonly used for administering surveys but which can also be adapted for educational testing. In the SMC, families logged on to the website in order to access daily instructional materials targeted to the student's grade level and self-selected ability level (i.e., below grade level, at grade level, above grade level). Figure 3 and Figure 4 show a screenshot of a sample grade seven SMC dashboard where families clicked on the respective week and then saw the instructional resources for that week. The text used for the study on the dashboard, which mirrored the text used in email notification of activities, appears in Appendix A. If a SMC account had more than one child assigned to grade seven in the SMC (e.g., a family with twins in the same grade or an educator enrolling a full class in the SMC), then clicking the Qualtrics link triggered a screen posing the question “Which child is doing the activity?”. The user could then click on the name of the child in order to ensure proper identification of participants.



Summer Math Challenge

Welcome to the Summer Math Challenge Dashboard

Click on the squares below to learn more about the math concept for each week. Click on your child's name to update their profile.

Audra (Grade 7)

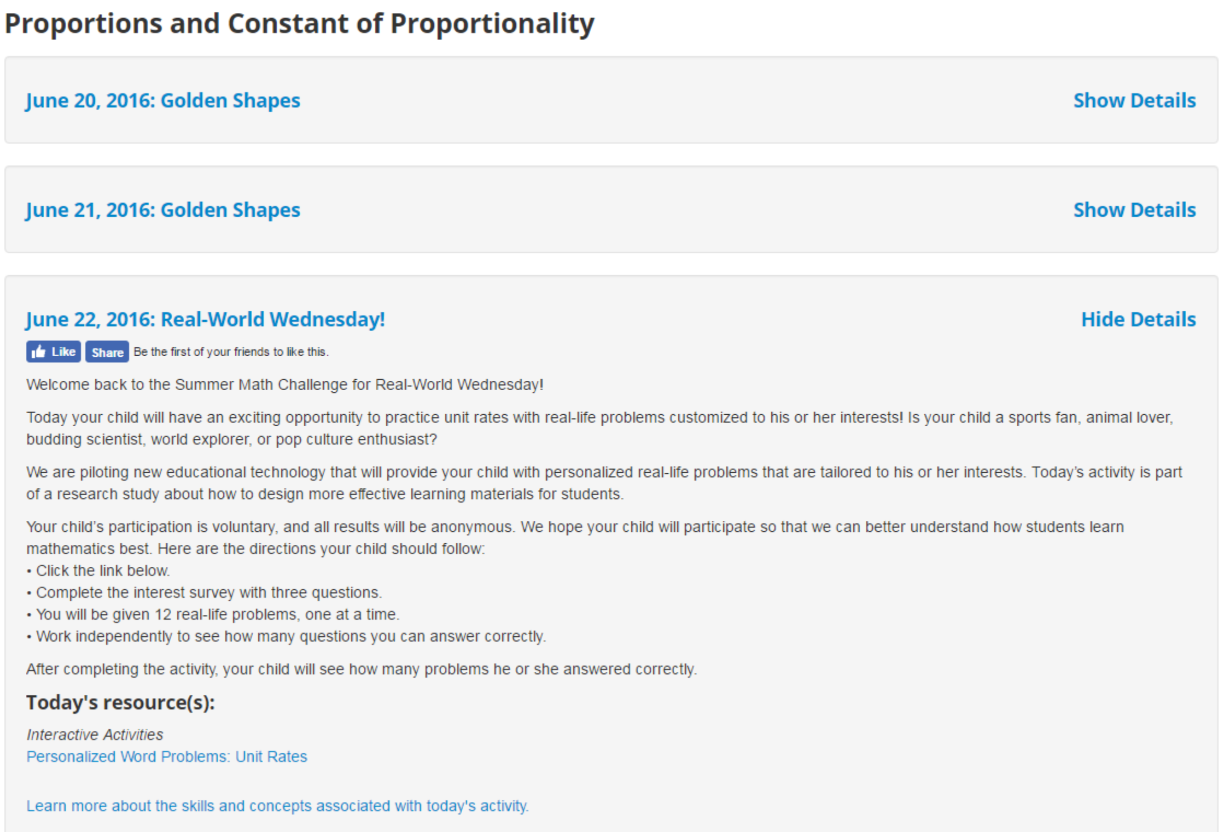
SUMMER MATH CHALLENGE
Week 1: Proportions and Constant of Proportionality

SUMMER MATH CHALLENGE
Week 2: Operations with Integers

SUMMER MATH CHALLENGE
Week 3: Operations and Expressions with Rational Numbers

SUMMER MATH CHALLENGE
Week 4: Equations and Inequalities

Figure 3. Sample dashboard for the SMC.



Proportions and Constant of Proportionality
June 20, 2016: Golden Shapes
Show Details
June 21, 2016: Golden Shapes
Show Details
June 22, 2016: Real-World Wednesday!
Hide Details
Like
Share
Be the first of your friends to like this.

Welcome back to the Summer Math Challenge for Real-World Wednesday!

Today your child will have an exciting opportunity to practice unit rates with real-life problems customized to his or her interests! Is your child a sports fan, animal lover, budding scientist, world explorer, or pop culture enthusiast?

We are piloting new educational technology that will provide your child with personalized real-life problems that are tailored to his or her interests. Today's activity is part of a research study about how to design more effective learning materials for students.

Your child's participation is voluntary, and all results will be anonymous. We hope your child will participate so that we can better understand how students learn mathematics best. Here are the directions your child should follow:

- Click the link below.
- Complete the interest survey with three questions.
- You will be given 12 real-life problems, one at a time.
- Work independently to see how many questions you can answer correctly.

After completing the activity, your child will see how many problems he or she answered correctly.

Today's resource(s):

Interactive Activities
Personalized Word Problems: Unit Rates

Learn more about the skills and concepts associated with today's activity.

Figure 4. Sample introductory text to daily SMC activity.

Development of Student Interest Categories

TPWPs in this study were based on five interest categories: 1) sports, 2) music, television, and movies, 3) travel, 4) animals, and 5) science and technology. The student interest categories were developed by analyzing trends in search history records from EdSphere®, an online reading and writing learning platform. In EdSphere, students type a response to the question "What do you want to read about today?" and EdSphere returns texts related to that topic.

Search history records were obtained for all searches occurring between November 29, 2012 and February 2, 2016. The data set included 1,398,901 search terms from students in first- through twelfth-grade. Because word problems were administered to students transitioning between seventh- and eighth-grade, I analyzed searches from both seventh- and eighth-graders for a total of 336,202 searches. From these 336,202 searches, a simple random sample of 1,000 terms was split into two data sets consisting of 500 terms for initial development of student interest categories (i.e., a training data set) and another 500 terms for cross-validating the categories that emerged from the first 500 terms (i.e., a validation data set).

Search terms were first cleaned to remove non-codable records. First, I identified nonsensical searches of random text (e.g., “jajajajjajajja” and “hnnnnnnnnnn”) and uninformative phrases (e.g., “surprise me”, “all”, or “other”). Second, searches of vague words or abstract concepts were removed, such as “kids”, “sorry”, and “courage”, as these search terms were difficult to use as evidence for a student’s interest. Third, searches related to violence or drugs were removed because of their inappropriateness for developing learning materials for minors. Finally, searches for book genres, book titles, or author names were excluded due to the assumption that students were likely trying to identify a particular book in response to the question “What do you want to read about today?” rather than entering a topic. In the training data set, a total of 60 search terms were removed, meaning 440 search terms remained for analysis.

I applied inductive coding to classify each search term into a category. Inductive coding assumes no pre-existing categories prior to beginning coding, thus allowing categories to emerge from the data as coding progresses. From this analysis, six themes emerged: animals, history, pop culture (i.e., music, movies, and television), sports, science and technology, and travel. These categories were then applied to the validation data set to ensure replicability of codes to data that were not used in category development. In the validation data set, 101 search terms were deemed non-codable for the same reasons described above, resulting in 399 codable search terms. Using the same categories developed from the training data set (i.e., animals, history, pop culture, sports, science and technology, and travel), 327 search terms fit within these categories. Table 2 presents the categories by frequency count and by percentage of the total codable and uncategorized search terms, along with examples of search terms from each category.

Table 2

Frequency of Search Terms in Each Interest Category

Interest category	Frequency	Cumulative frequency	Percentage of all codable terms	Example search terms
History	81	81	20.3%	Revolutionary war, Holocaust, Articles of Confederation, Middle Ages
Sports	72	153	18.0%	soccer, Real Madrid, Babe Ruth, summer olympics
Pop Culture	62	195	15.5%	Star Wars, Sandra Bullock, The Beatles, One Direction
Travel	41	236	10.3%	New York City, Amazon Forest, London, Washington D.C.
Animals	38	274	9.5%	animal sanctuaries, panda, dogs, cheetahs
Science and Technology	33	307	8.3%	nuclear fission, freshwater ecosystems, Japan robotics, erosion
Uncategorized	72	399	18.1%	teen driving, Valentine’s Day, Guinness world records
Total	399	399	100.0%	

Out of the 399 codable search terms, 72 (18.1%) did not fit into any of the six interest categories. These 72 uncategorized terms were further analyzed to check for the possibility of additional categories, but the diversity of the 72 terms was too vast to warrant a seventh category, as the terms were unique phrases such as “teen driving”, “unsolved mysteries”, “Guinness world records”, and “Valentine’s Day”. The closest theme emerging from the 72 uncategorized search terms was video games, but video games only represented seven searches out of the 399 codable searches, which was not high enough to warrant an entirely new interest category. Furthermore, the number of categories was intentionally minimized in order to facilitate writing a feasible number of problems and to not diminish the motivational effects of choice by providing too many options as described by Katz and Assor (2007).

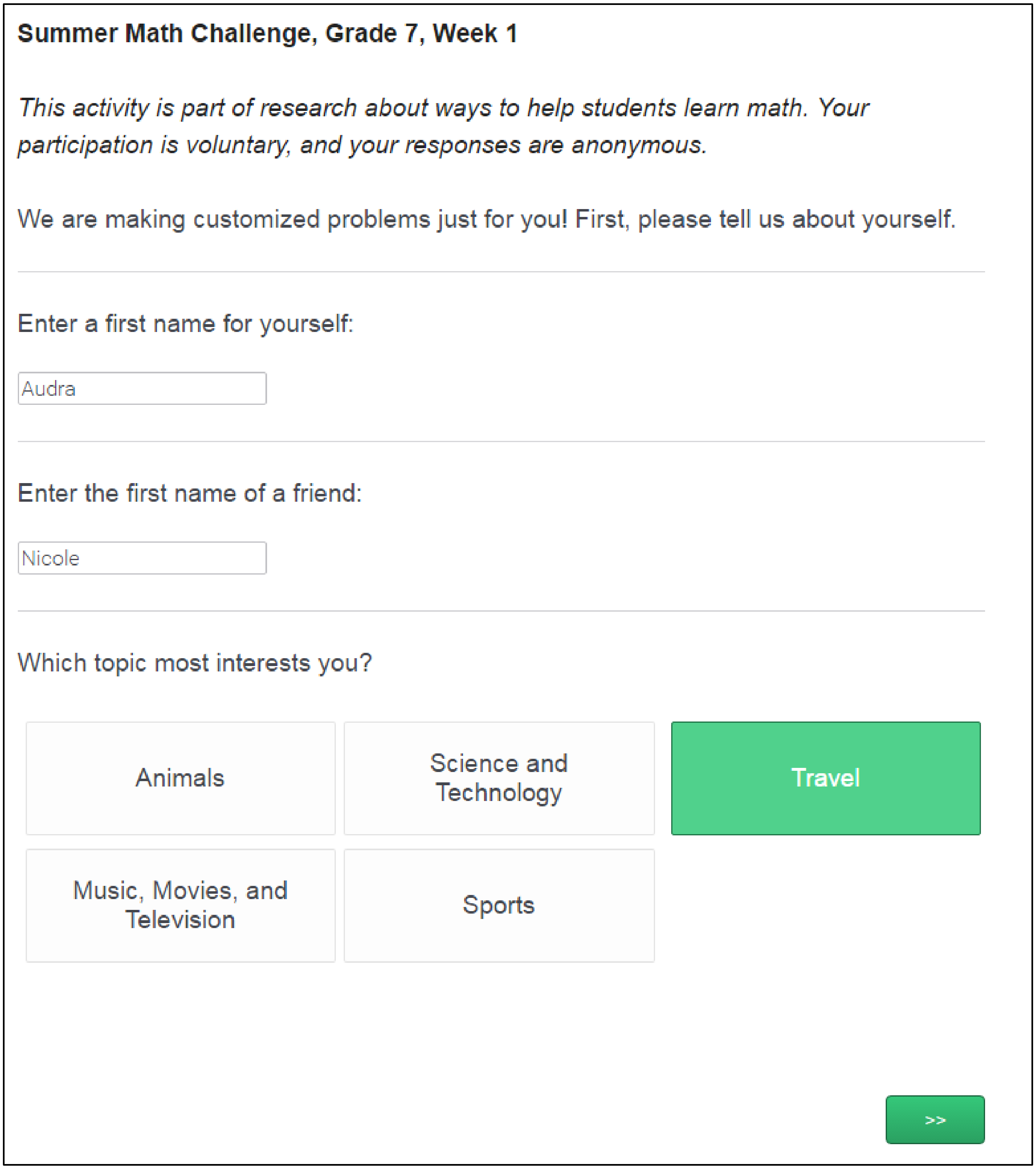
Despite the six categories that emerged from the inductive coding, I removed history as a category due to challenges related to combining history and mathematics in a meaningful yet research-appropriate way. This decision was made after careful consideration and consultation with two history teachers, including one middle school teacher with over ten years of experience teaching eighth-grade American history in addition to another 10 years of experience teaching Algebra 1 and one tenth-grade history teacher with over 25 years of experience. Both teachers gave excellent suggestions for word problems within the realm of the content for this study (i.e., given how far Lewis and Clark traveled over a certain period of time, calculate how many miles they walked per day), however writing problems such as these posed challenges related to the numbers used in the problems and other confounding factors. Specifically, the history problems generally needed to be based on facts in order to represent meaningful scenarios rather than fabricated numbers and contexts, and these numbers could not be uniformly applied to the matched problems in other interest categories. Additionally, writing problems based on history facts introduced a confounding variable of whether the problem contained factual or fictional information, which could have potentially affected results in a way that limited inferences made from data in this study. It was not possible to make all problems factual due to the need to utilize the same numbers across sets of matched problems in order to ensure consistent difficulty of mathematical tasks. To be clear, I do not claim that history and mathematics lack interdisciplinary overlap; rather, for the purpose of this study, it was not possible to write history word problems that preserved the other features of the research design while still achieving meaningful word problems.

After removing history, the five remaining interest categories utilized in this study were: 1) sports, 2) music, television, and movies, 3) travel, 4) animals, and 5) science and technology. This study is the first – to my knowledge – to develop interest categories for word problems based on empirical student data rather than researchers' perceptions of students' interests.

Instrument Development

Students had the opportunity to complete an instrument administered through Qualtrics consisting of 12 word problems – six TPWPs and six generic word problems – once per week for three weeks for a total of 36 problems per student.

Student interest questionnaire. The instrument began with a student interest questionnaire that asked students to select a name for themselves and the name of a friend and then answer "Which topic most interests you?" by selecting either Sports; Music, Movies, and Television; Science and Technology; Travel; or Animals. The interest categories were displayed in random order. Figure 5 shows an example screenshot of the interest questionnaire. For all questions, the instrument incorporated data validation so that the participant would receive an error message if he or she did not provide a response.



Summer Math Challenge, Grade 7, Week 1

This activity is part of research about ways to help students learn math. Your participation is voluntary, and your responses are anonymous.

We are making customized problems just for you! First, please tell us about yourself.

Enter a first name for yourself:

Audra

Enter the first name of a friend:

Nicole

Which topic most interests you?

Animals | Science and Technology | [✓ Travel]

Music, Movies, and Television | Sports

Figure 5. Screenshot of sample student interest questionnaire.

Development of word problems. Following the student interest questionnaire, the instrument used skip logic to route students to an appropriate set of word problems based on the responses to the interest questionnaire. Item development began by identifying psychometrically well-performing selected-response items from a large bank of items previously pretested through various K-12 testing programs. Items were selected as well-performing items, known as exemplar items, based on the criteria that the item's point-biserial correlation was greater than or equal to .2 and the p-value of the item (i.e., the percentage of examinees that answered the item correctly) was between .3 and .7 based on a pretest sample of at least 1,500 seventh-graders. Additionally, the item must have been a word problem that represented the same content standards as the respective week's content in the SMC. In a few cases, new items were written when an exemplar item was not available that fit into the study constraints (e.g., when it was not possible to modify the interest categories). Names included in generic items were modified in some cases in order to minimize the likelihood that a generic word problem included a student's actual name by chance. This was done by changing common names (e.g., John, Ryan) in generic word problems to names more frequently used in generations older than the study population (e.g., Phyllis, Marshall), including the formal salutation for an adult (e.g., Mr. Johnson) or by using culturally-diverse names as is done in typical K-12 item development (e.g., Kianna).

Prior to writing items, I consulted with a former middle school science teacher for content-specific suggestions on how to incorporate science ideas in the mathematics content of the word problems. I also reviewed resources recommended by other teachers that provide ideas for how to integrate mathematics into real-life scenarios, such as the IMAX Educator Guides and the Washington Post Curriculum Guides. Using these ideas and my own experience as both a former eighth-grade middle school mathematics teacher and current mathematics item writer, I then modeled items for the study based on the identified exemplar items, meaning the study items shared characteristics of the exemplar items such as type of mathematical task, cognitive complexity level using Webb's (1997) Depth of Knowledge hierarchy, formatting and styles (e.g., italicizing variables in equations), sentence structure, distractor rationales, number type (e.g., decimals to the tenths place, whole numbers that are multiples of five, etc.), use of visual aids, etc.. All TPWPs were selected-response items with four options in order to replicate the format of the exemplar items.

Each generic item had a matched TPWP. Pairs of matched items had similar features theorized to predict difficulty, such as types of numbers, problem structures, distractor rationales, text complexity of stem, number of words in stem, and formatting of answer choices (e.g., presenting an answer as a single numeric value versus an expression to represent a calculation). Table 3 displays an example of a generic item with a matched TPWP for each interest category, where the place holder *Student Name* was filled with the student's response from the interest questionnaire. The full set of items is available in Appendix B; some items are redacted for test security purposes, since some items may be on current operational test forms. The generic word problem and matched TPWPs represented the same type of mathematical task (i.e., choosing which set of items has the lowest unit rate in the context of money). The problems also shared similar number structures (i.e., the dollar values are two-digit whole numbers to the tenths place and the number of objects in each answer choice is a whole number less than or equal to 20). Lastly, the stems had similar sentence structure between generic word problems and their matched TPWPs.

Table 3

Example Generic and Personalized Word Problems

Problem type	Example item
Generic	Mr. Johnson wants to buy plants for his backyard. Which price for plants is the ***lowest*** unit price? A) $136.00 for 20 plants B) $100.80 for 14 plants C) $72.60 for 11 plants D) $67.50 for 9 plants
Sports	*Student Name* wants to buy soccer trophies for a group of friends. Which price for soccer trophies is the ***lowest*** unit price? A) $138.00 for 20 soccer trophies B) $92.40 for 14 soccer trophies C) $86.40 for 12 soccer trophies D) $61.60 for 8 soccer trophies
Animals	*Student Name* wants to buy dog collars for an animal shelter. Which price for dog collars is the ***lowest*** unit price? A) $138.00 for 20 dog collars B) $92.40 for 14 dog collars C) $86.40 for 12 dog collars D) $61.60 for 8 dog collars
Science and Technology	*Student Name* wants to buy beakers for a science lab. Which price for beakers is the ***lowest*** unit price? A) $138.00 for 20 beakers B) $92.40 for 14 beakers C) $86.40 for 12 beakers D) $61.60 for 8 beakers
Music, Movies, and Television	*Student Name* wants to download music albums. Which price for album downloads is the ***lowest*** unit price? A) $138.00 for 20 albums B) $92.40 for 14 albums C) $86.40 for 12 albums D) $61.60 for 8 albums
Travel	*Student Name* wants to buy tickets for a group of friends to ride cable cars in San Francisco. Which price for tickets is the ***lowest*** unit price? A) $138.00 for 20 tickets B) $92.40 for 14 tickets C) $86.40 for 12 tickets D) $61.60 for 8 tickets

When writing the stems, effort was made to achieve a similar Lexile® measure – a measure of text complexity – and total word count for all item stems due to prior research indicating that text complexity of word problems impacts item difficulty (Walkington, Clinton, Ritter, & Nathan, 2015). Lexile measures and word counts of item stems were calculated after initially drafting items and were calculated two additional times after revisions due to subject matter expert reviews. When possible, words or phrases in stems were revised to achieve closer Lexile measures and word counts between generic word problems and TPWPs. Table 4 shows mean Lexile measures between generic word problems and TPWPs, and Table 5 present similar information for word counts. Tables with Lexile measures and word counts for individual items appear in Appendix C.

Table 4

Mean Lexile Measures of Item Stems

	Session 1	Session 2	Session 3
Generic Word Problems	703L	625L	933L
All TPWPs	794L	811L	1013L
Sports	717L	830L	1055L
Animals	760L	748L	972L
Science and Technology	837L	818L	1002L
Music, Television, and Movies	827L	805L	1003L
Travel	830L	852L	1035L

Table 5

Mean Number of Words In Item Stems

	Session 1	Session 2	Session 3
Generic Word Problems	25	30	51
All TPWPs	27	38	52
Sports	25	41	52
Animals	26	34	53
Science and Technology	27	35	50
Music, Television, and Movies	29	40	52
Travel	27	40	54

As seen in the tables, both Lexile measures and word counts for TPWPs were slightly higher than Lexile measures and word counts for generic word problems. Writing stems with exactly comparable text complexity and length is nearly impossible because the personalized nature of TPWPs requires unique language specific to the interest category. Generally, the TPWPs stems were more complex because of context-specific words related to the interest category. For example, science and technology word problems included words such as beakers, bacteria, microscope, megabyte, and volcanic that generally result in higher Lexile measures than words from the matched generic word problems such as pencils, dishes, allowance, water, and lunch. However, for a student choosing science and technology as the preferred interest category, that student might have more familiarity with science-specific words which might cause those words to function similarly – in terms of text complexity – to words in generic word problems. Thus, despite differences in Lexile measures across item stems, the stems represent roughly equivalent reading difficulty to the greatest extent possible while allowing for variation due to interest category and while preserving the sentence structure and mathematical content of the item.

Likewise, word counts for TPWPs were also slightly higher than generic word problems because of the need to provide enough context in the problem for the problem to be considered targeted to the interest category. Also, in some cases, a TPWP required additional words in order to provide enough background information for the student rather than assuming prior knowledge about the interest category. For example, Table 6 shows an example of a generic word problem and two matched TPWPs with varying stem lengths. Differences in word length can be attributed to variation in phrases that are specific to the topic. Although the item writing process included effort to achieve stems with similar word counts, these items illustrate how TPWPs generally required more words in the stem than matched generic word problems. Inevitably, when writing TPWPs, there is a tradeoff between the extent to which the problem is personalized and variation in characteristics of the problem as compared to the matched generic word problem.

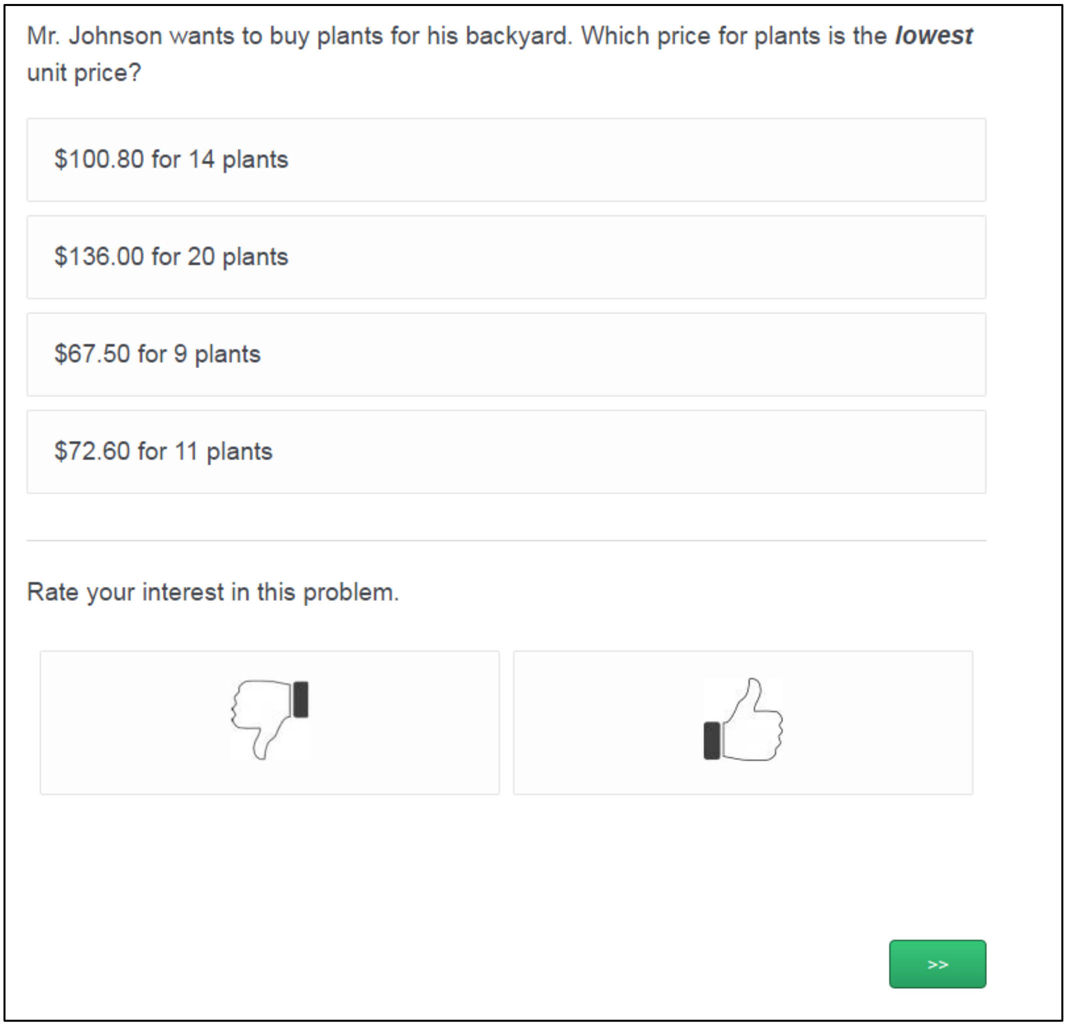
Table 6

Differences in Stem Word Counts Across Matched Word Problems

	Generic word problem	TPWP (animals)	TPWP (sports)
Stem	Theodore has $27 in his checking account. He deposits $4, takes out $12, and then deposits another $9. Which equation could be used to find the total amount of money in Theodore's bank account?	*Student Name* saw a monkey on a branch 25 feet above ground. The monkey jumped up 6 feet, swung down 14 feet, and then jumped up another 3 feet. Which equation could be used to find how many feet above ground the monkey is now?	*Student Name* cheers for a favorite football team who is at the 25 yard line on a football field. The team gained 6 yards, lost 14 yards, and then gained another 3 yards. Which equation could be used to find the yard line the team is at now?
Word count of stem	34 words	44 words	47 words

Items underwent a comprehensive review process involving five reviewers. After I wrote first drafts of items, the first reviewer – an individual with 30 years of mathematics teaching experience and an additional 16 years of experience in mathematics item writing – performed a subject matter expert check of item content, including checking for mathematical accuracy, plausibility of distractor rationales, alignment to grade-level appropriate content standards, meaningfulness of word problem context for each interest category, and use of grade-level appropriate language. The second reviewer then checked for spelling, grammar, punctuation, and consistency of language across item sets (e.g., if the generic problem said “per week” as opposed to “each week”, then the TPWPs were reviewed to make sure they all also said “per week”). Next, a third reviewer – an individual with nine years of experience conducting sensitivity reviews on mathematics items – performed a sensitivity review by checking for issues related to cultural appropriateness, gender appropriateness (e.g., not writing any sports problems about baseball since girls typically play softball instead of baseball) and vocabulary that may have been challenging or confusing for English language learners. Revisions were made after receiving each reviewer’s feedback. A fourth reviewer – an individual with 24 years of experience in mathematics item writing – then performed a holistic check of all of the previously mentioned criteria to ensure that revisions did not cause additional concerns and also that TPWPs were situated in a plausible real-life context.

Form design. The generic and personalized items were grouped into forms with 12 items each, six of which were TPWPs based on the student’s responses to the interest questionnaire and six of which were generic problems common to all students. The forms each had a particular content theme based on the content for the designated SMC week: session one, two, and three respectively included rates and ratios, integer operations, and equations and inequalities. Each form began with the student interest questionnaire and then presented the 12 word problems by alternating between a TPWP and a generic problem, with one problem displayed per screen as demonstrated in Figure 6.



Mr. Johnson wants to buy plants for his backyard. Which price for plants is the ***lowest*** unit price?

$100.80 for 14 plants

$136.00 for 20 plants

$67.50 for 9 plants

$72.60 for 11 plants

Rate your interest in this problem.

👎 👍

Figure 6. Example of item display for a generic word problem.

Additionally, on the same screen as the item as shown in Figure 6, students were asked to rate their interest in the problem using either the thumbs-up or thumbs-down options for like and dislike, respectively. The wording of the prompt, “Rate your interest in this problem”, was chosen because of the neutral language that not did invite a particular response, as opposed to a question such as “Did you like solving this problem?” Students were forced to rate each item before continuing to the next page, and they could not change their ratings to previous items.

The instrument delivery system randomized whether a student received a TPWP or generic word problem first. Constraints on randomization counterbalanced the type of problem a student received first, so that roughly half of participants received a TPWP first and the other half received a generic word problem first. Table 7 shows frequency counts of the number of students that completed at least six or more items on a given form, separated by interest category and whether the student received a TPWP or generic word problem first. Because assignment to a form including a TPWP first or a generic word problem first occurred immediately after completing the interest questionnaire, the counts of form types are not exactly equal since a student could have completed the interest questionnaire and then failed to complete any items, yet that student still received a form assignment that affected assignment of subsequent students to forms. In all, 295 out of 572 (51.6%) forms retained in the sample included a generic problem first, and 277 out of 572 (48.4%) forms included a TPWP first. The largest discrepancy between form type occurred during the first data collection session where it is possible that more students were exploring the activity (i.e., clicking on the link and completing the interest questionnaire) without completing word problems.

Table 7

Count of Students by Interest Category, Week, and Type of First Problem

	Session 1		Session 2		Session 3		All
	Generic problem first	TPWP first	Generic problem first	TPWP first	Generic problem first	TPWP first	
Animals	25	18	15	18	10	12	98
Movies	40	32	29	36	15	16	168
Science	18	21	14	10	7	8	78
Sports	45	39	33	32	19	14	182
Travel	8	6	11	8	6	7	46
All	136	116	102	104	57	57	572

Because the TPWPs were matched to the generic word problems in terms of the type of mathematical task, stem phrasing, and type of numbers, the items were ordered such that no two matched items appeared next to each other. This minimized the possibility of a student recognizing an item as similar to its matched item and possibly recalling a solution strategy used on the matched item rather than thinking through how to solve the item as if it had never been seen before. As an additional constraint on item ordering, the first six items included three complete pairs of matched TPWPs and generic word problems, and the last six items included the last three matched pairs. The rationale for including a complete set of three matched pairs in the first half of the instrument was to maximize the use of data from students that failed to complete the entire instrument. In other words, if a student completed only half of the problems, the data from that student still contained a complete set of three TPWPs and three matched generic items. Figure 7 shows the form design, where the labels indicate which items are matched to each other. For example, Personalized 1 and Generic 1 are matched, Personalized 2 and Generic 2 are matched, etc..

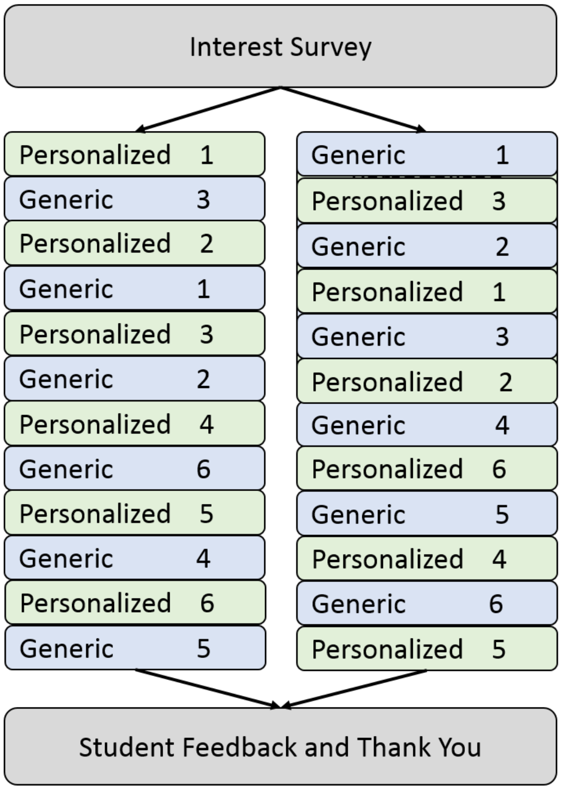
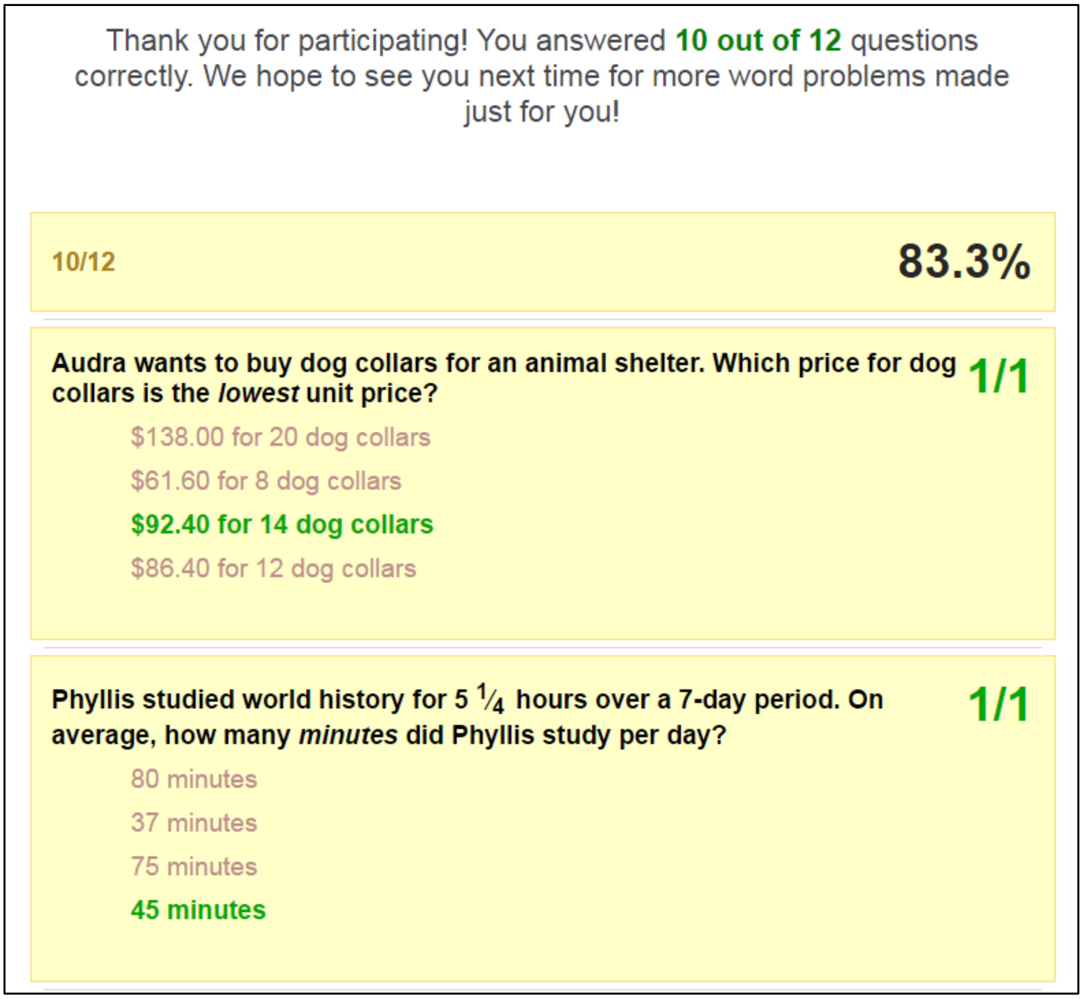


Figure 7. Form design.

Other features of the instrument design included randomizing answer choice ordering in order to again minimize similarity between generic problems and matched TPWPs and disabling the option to skip items. In other words, participants were forced to select an answer before moving to the next problem, and participants were not allowed to return to a previous question after submitting an answer. Finally, after completing the twelfth item, students received a page of feedback indicating which problems they missed and what the correct answers are, as demonstrated in Figure 8.



Thank you for participating! You answered **10 out of 12** questions correctly. We hope to see you next time for more word problems made just for you!

10/12 83.3%

Audra wants to buy dog collars for an animal shelter. Which price for dog collars is the *lowest* unit price? 1/1

$138.00 for 20 dog collars

$61.60 for 8 dog collars

$92.40 for 14 dog collars

$86.40 for 12 dog collars

Phyllis studied world history for 5 $\frac{1}{4}$ hours over a 7-day period. On average, how many *minutes* did Phyllis study per day? 1/1

80 minutes

37 minutes

75 minutes

45 minutes

Figure 8. Example of final webpage of instrument that provided feedback to students.

After writing items, the items were loaded into the Qualtrics data collection tool and reviewed by myself and an independent reviewer – the fifth reviewer in addition to the four reviewers that reviewed items prior to entering items into the data collection tool – to quality check the tool’s functionality in three different web browsers (i.e., Mozilla, Internet Explorer, and Chrome). These reviews consisted of checking that the instrument correctly randomized whether the student received a form with a personalized or generic problem first, routed to the appropriate set of items based on interest selection, ordered items as intended in the form design, presented names and friends’ names as intended, randomized answer choice order as intended, did now allow skipping of items or returning to previous items, and displayed appropriate feedback at completion of the activity. Both myself and the fifth reviewer checked every version of the data collection instrument (i.e., two forms – generic word problem first or TPWP first – per interest category across all three sessions for a total of 30 unique forms). Finally, as a last step, the items were cold solved in the data collection tool. Cold solving is a process where individuals that had not previously seen the items and were not familiar with the study design solved each item as a final holistic check. Cold solvers checked for clarity of language, correct answer keys, and any other issues seen in the items such as the possibility of two correct answers. Five unique reviewers unfamiliar with the study cold solved one form per interest category per data collection session; the cold solvers had not previously seen the items until this stage.

In addition to the previously-described item development and data collection tool quality checking process, several procedures were undertaken in order to ensure data quality once data collection began and after data were offloaded from the data collection tool. First, several MetaMetrics employees signed up as students in the SMC, which allowed us to receive daily SMC emails and access the SMC dashboard in the same manner as students. We checked functionality of the data collection tool using multiple web browsers, computers, and mobile devices during each week’s release through both the dashboard and the weekly Wednesday email. Second, SMC participants had a means to report any technical issues encountered while interacting with the SMC. Although minor problems were reported with other SMC activities (i.e., broken web links, incorrect answer keys), no problems were reported related to the data collection tool for this study. Finally, to ensure data quality of scored responses, item keys were checked after data collection ended by both entering the correct answer in the data collection tool and checking the offloaded data file and by reviewing item data for indications of key errors (i.e., a higher percent of responses for an answer other than the identified key). In summary, after a thorough quality checking process, there were no known data collection issues that would have affected data quality.

Data Preparation

Data from all three sessions were merged together to create one data set. Within the SMC, each student has a unique identification number assigned to him/her, though this number is maintained in the website database and never shown to the website user. Qualtrics has a feature known as embedded data that allowed for each student's unique SMC identification number to be passed to Qualtrics through a unique Qualtrics link assigned to each student, which meant that the exported data set from Qualtrics included students' SMC identification numbers. These identification numbers permitted merging data from all three data collection sessions into a single data set. This process also explains why the instrument did not require students to provide any identifying information when accessing the Qualtrics, though students did need to log-on to the SMC with a username and password.

Data from students' responses to the SMC word problems were cleaned for issues that would affect the validity of the data. Data cleaning considered characteristics of participant responses (i.e., participants that rapidly guessed or failed to answer a sufficient number of items) and characteristics of items (e.g., sufficiently high point-biserial correlations).

Participants. In sessions one, two, and three, 411, 308, and 207 students accessed the SMC link to the instrument and entered at least one response to the interest questionnaire, respectively. In the case where a student accessed the instrument multiple times (e.g., to redo the problems with a different category or different names), the student's initial attempt was retained and all subsequent attempts were omitted from data analysis based on a timestamp indicating when the student accessed the link. This omission resulted in 341, 253, and 169 remaining students in sessions one, two, and three, respectively. Moreover, data were cleaned according to three additional criteria: 1) the student entered valid names into the interest questionnaire, as opposed to entering a string of symbols or numbers, 2) the students completed at least the first six problems, as previously described, and 3) the student did not rapidly guess on six or more problems, where a rapid guess was defined as spending less than five seconds on an item's page.

The criteria for flagging an item as a rapid guess was based on methods used by Kong, Wise, and Bhola's (2007) regarding setting a response time threshold for a rapid guesses. In their work and other papers that use response time to identify rapid guesses, a response is flagged as a rapid guess if the response time is less than a set threshold, and this threshold may vary depending on features of the items or examinees (Setzer, Wise, van den Heuvel, & Ling, 2013; Wise & DeMars, 2005; Wise & Kong, 2005; Wise, Pastor, & Kong, 2009). Two of the methods used by Kong, Wise, and Bhaola (2007) are the *common threshold* method, where an item is flagged as a rapid guess if the response time is less than three seconds, and the *surface feature rule-based thresholds*. In the surface feature rule-based threshold, the response time threshold is based on the length of the stem or the presence of ancillary information (e.g., tables, graphs) in the item, where stems with 200 or fewer characters with no ancillary information – as was the case for almost all items in the present study – are set with a three second threshold. Items with longer stems or items with ancillary information may have longer thresholds. In the case of the present study, both the common threshold method and the surface feature rule-based threshold result in a three second threshold. However, since the participants in this study also had to click an icon to indicate their interest in an item in addition to clicking the answer choice, the three second threshold was raised to five seconds in order to adjust for the amount of time needed to click an addition button on the webpage. After applying all of the data removal criteria, the final data set included 252 students in session one, 206 students in session two, and 114 students in session three.

Item and form characteristics. Item statistics (i.e., p-value, point-biserial correlation, Cronbach's alpha with item removed) were computed and analyzed to ensure that all items were appropriate for retaining in data analysis. Table 8 shows summary item statistics by data collection session for generic word problems and TPWPs; *t*-tests for comparison of means of item statistics between generic word problems and TPWPs revealed no statistically significant differences in neither p-values, point-biserial correlations, nor Cronbach's alpha with the item removed. Appendix D presents item statistics for all individual items. The percent of correct answers by item (i.e., p-value) ranged from .37 to .93 with a mean of .72. Although this p-value would be considered high in many testing contexts, it is not surprising in this case considering that students in this study differed from typical rising eighth-graders because students completing summer mathematics activities presumably have greater motivation or work ethic and, likely, higher ability. Point-biserial correlations were all greater than or equal to .19 with a mean of .44, indicating a strong correlation between a student's performance on an item and the student's total score with the respective item removed from the total score.

Table 8

Summary Item Statistics for Generic Problems and TPWPs by Session Number

	p-value *M* (*SD*)		Point biserial correlation with item removed *M* (*SD*)		Cronbach's alpha with item removed *M* (*SD*)	
	Generic Word Problems	TPWPs	Generic Word Problems	TPWPs	Generic Word Problems	TPWPs
Session 1	.70 (.08)	.69 (.09)	.41 (.07)	.43 (.06)	.76 (.01)	.76 (~)
Session 2	.76 (.20)	.73 (.17)	.47 (.11)	.41 (.15)	.78 (.01)	.78 (.01)
Session 3	.72 (.11)	.70 (.13)	.44 (.08)	.48 (.14)	.79 (.01)	.79 (.02)

~ Less than .01.

Finally, the test forms had high reliability, based on calculating Cronbach's alpha for each set of 12 items across three sessions, where variants across the same item due to interest category were all treated as a common item. Cronbach's alpha for sessions one, two, and three was .77, .80, and .80, respectively. An examination of how Cronbach's alpha would increase or decrease if a particular item was removed showed that, in most cases, removing an item would decrease the internal consistency as expected. Although for a few items removing the item would slightly increase reliability, other indicators of item performance for these items (i.e., p-value, point-biserial correlation) did not support removing the item. Thus, all items were retained in analyses.

Item response times. Individual item response times were also examined to identify cases where a student rapidly guessed on a few items. Although serial rapid guessers (i.e., six or more rapid guesses per form) were identified and omitted as described above, individual rapid guesses were also flagged and removed on an item-by-item case based on the same criteria used earlier to identify rapid guessing (i.e., the student spent less than or equal to five seconds on the page). For example, if a student rapidly guessed on the last two items but seemingly did not rapid guess on the first 10 items, then the first 10 items were retained in data whereas the last two items were removed.

Additionally, items were also examined for abnormally long response times. Because students could freely walk away from the computer at any time during the session or leave the session and return to it on a different day, response times for these items in these cases were inaccurately and unreasonably high. To detect these cases, items were first subset into items with response times between 5 and 600 seconds (i.e., items that were not a rapid guess nor a somewhat obvious case of a student walking away from the computer) for each session. Based on these sets of items, the mean and standard deviation of response times within each session were calculated and items with response times greater than two standard deviations from the mean response time were excluded from response time analyses. To confirm these results, distributions of item response times by session were visually inspected for each session to confirm that the cut point of two standard deviations above the mean indeed reflected the upper tail of the distribution of response times. Figure 9, Figure 10, and Figure 11 show the distribution of response times for items in each session with response times between 5 and 600 seconds. The vertical red line on each figure indicates the threshold for classifying a response as an abnormally long response: 279 seconds in session one; 157 seconds in session two; and 308 seconds in session three. These thresholds are consistent with what would be expected based on the difficulty of items in each session; the session two items (i.e., integer operations) generally required fewer calculations as compared to session one and three items, and session three items required the most complex mathematics in the study (i.e., solving equations).

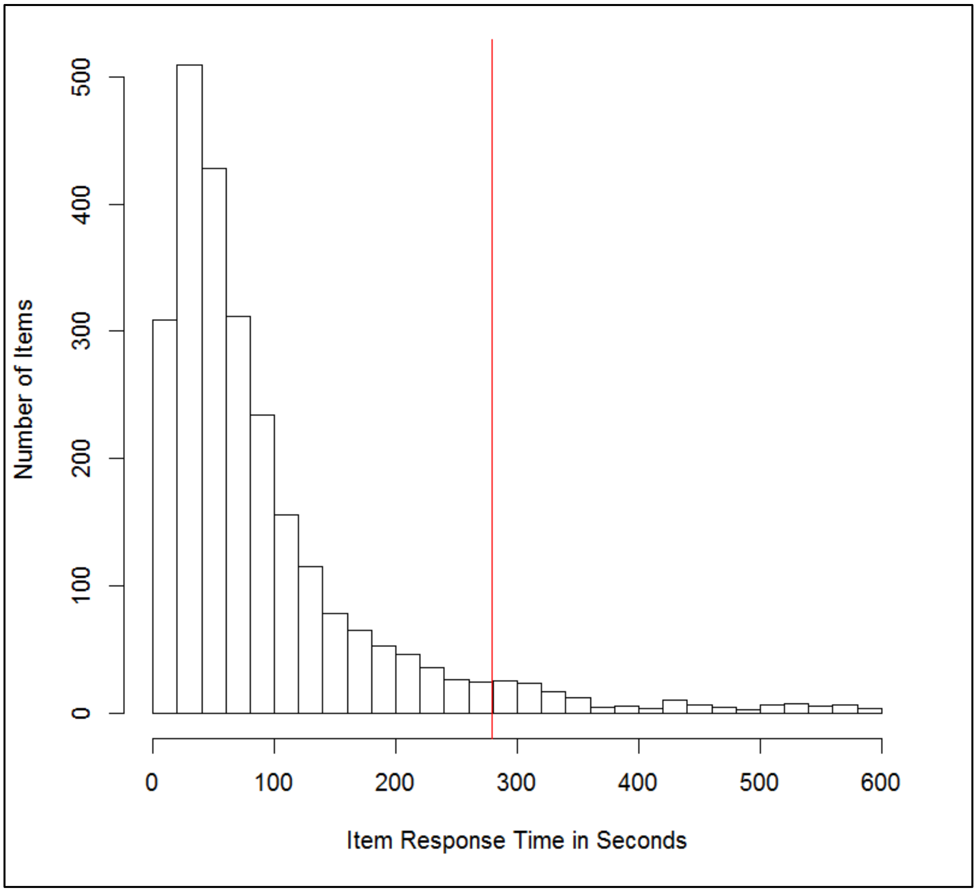


Figure 9. Distribution of response time in seconds to items in session one with response times between 5 and 600 seconds.

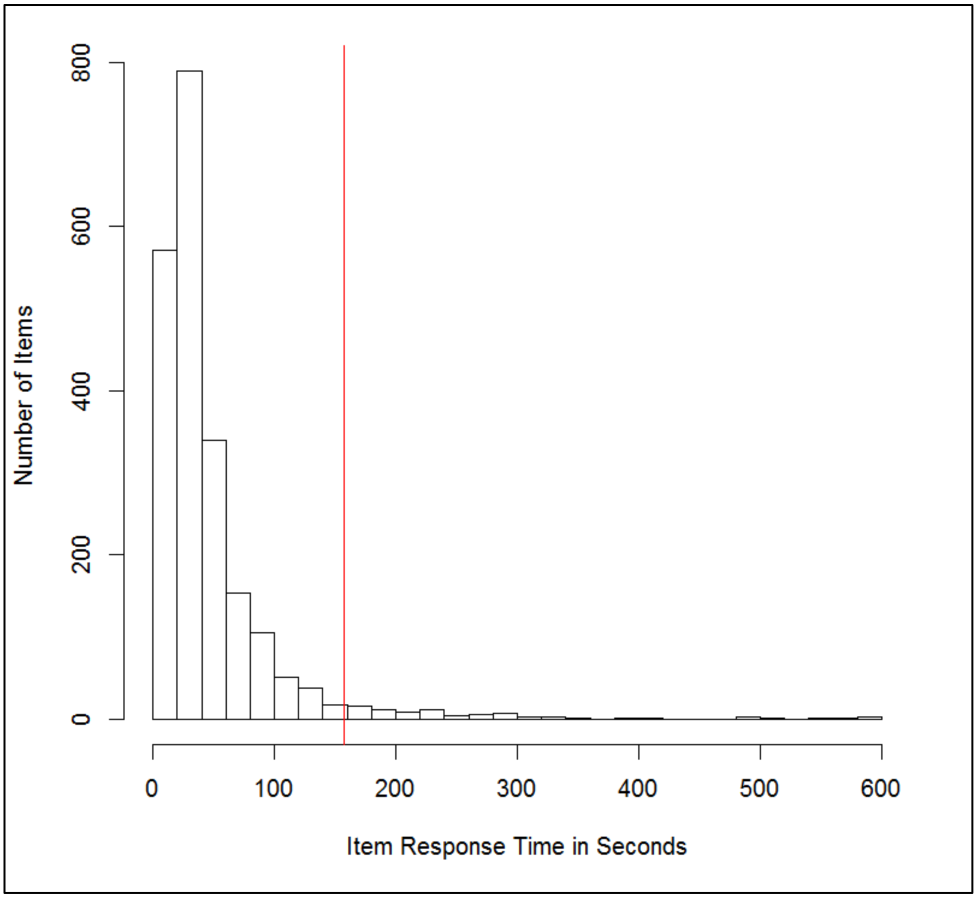


Figure 10. Distribution of response time in seconds to items in session two with response times between 5 and 600 seconds.

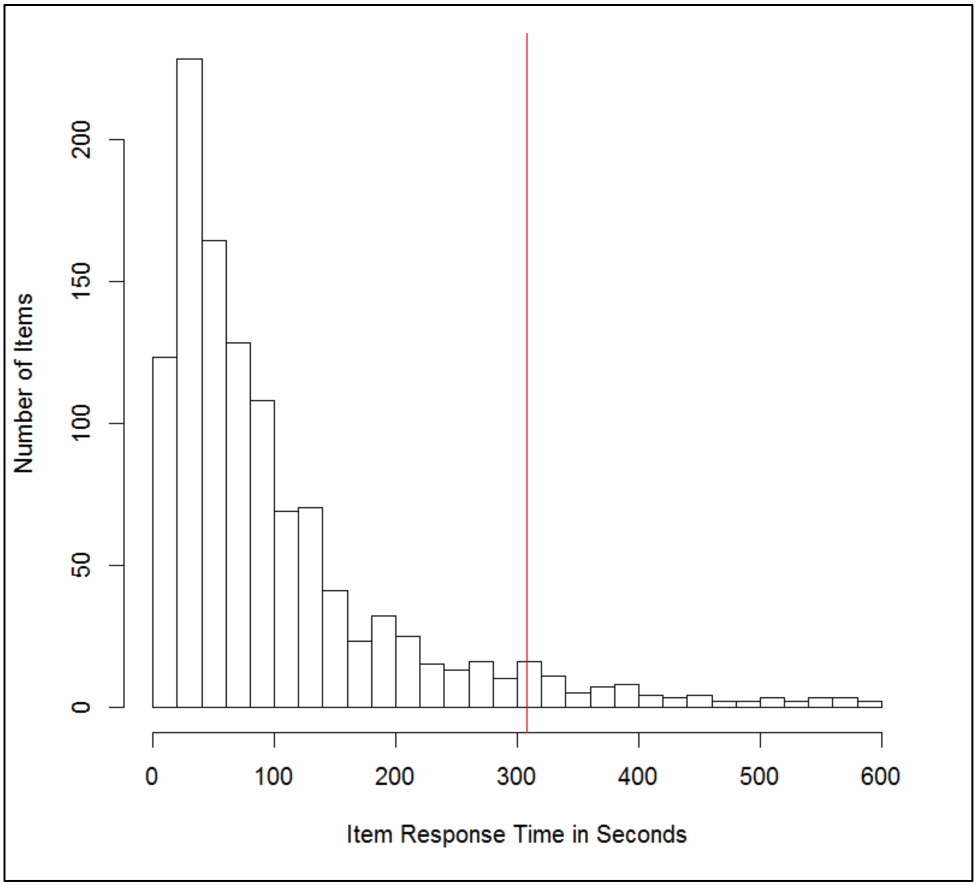


Figure 11. Distribution of response time in seconds to items in session three with response times between 5 and 600 seconds.

Items flagged for long response times were omitted from response time analyses but retained in accuracy and interest analyses. This was because the long response time presumably implied that the student left the computer while the item was on the screen but then returned to the item to answer the question and rate interest. After removing individual item responses and accounting for missing data from students not completing forms, the final data set contained 334 participants with 6,637 item responses for accuracy and interest data, and those same 334 participants with 5,982 item responses for response time data.

Data Analysis

For RQ1 (”Are rising eighth-graders more likely to rate TPWPs as interesting as compared to matched generic word problems?”) data were analyzed with a multilevel logistic model, with items nested in student, where the dependent variable was whether the student rated the problem as interesting or not and the independent variable of interest was whether the item was a TPWP or a generic word problem. For RQ2 (”Are rising eighth-graders more likely to answer TPWPs correctly as compared to matched generic word problems” and ”How do students' interest ratings of problems relate to the likelihood of answering the problem correctly?”) data were analyzed with a similar multilevel logistic model to that in RQ1, where the student's scored response (i.e., correct or incorrect) was the dependent variable and the independent variables of interest were whether the item was a TPWP or a generic word problem and whether the student rated the item as interesting or not. For RQ3 (“Do rising eighth-graders spend more or less time solving a TPWP as compared to a matched generic problem?” and “How does amount of time solving each type of problem relate to mathematical accuracy?”) data were analyzed with a multilevel linear model where response time in seconds was the dependent variable. Again, the independent variable of interest was whether or not the item was a TPWP or a generic word problem. For the second part of RQ3 (“How does amount of time solving each type of problem relate to mathematical accuracy?), the student's score on the item was included as an independent variable to determine how score related to response time.

For all three research questions, several control variables were included in models to account for the type of content in the item (i.e., rates and ratios, integer operations, or equations and inequalities), students' perceived ability level, whether the item was answered correctly or not, and several different types of interactions between these variables. Because of variation in text complexity of the stems as described above, two control variables for text complexity (i.e., Lexile measure of stem and number of words in stem) were also considered in analyses. Table 9 describes the variables used and specifies whether the variable was independent, dependent, or not included in each of the three research questions. R Version 3.3.1 was used for data preparation (e.g., item scoring, identifying rapid guesses) and calculations of descriptive statistics and item statistics. Multilevel modeling was conducted in HLM 7.

Table 9

Variables Used in Multilevel Models

Variable name	Type of variable in RQ1	Type of variable in RQ2	Type of variable in RQ3	Description	Coding scheme
interest	Dep.	Ind.	Ind.	Indicates whether the student liked or disliked the item	0=student liked the item 1=student disliked the item
correct	Ind.	Dep.	Ind.	Indicates whether the student answered the item correctly or not	0=student answered incorrectly 1=student answered correctly
time	n/a	n/a	Dep.	Response time	Number of seconds student spent on webpage with item
TPWP	Ind.	Ind.	Ind.	Indicates whether the item is a TPWP or generic word problem	0=generic word problems 1=TPWPs
integers	Ind.	Ind.	Ind.	Indicates whether the item came from week 2 (integer operations) or not	0=item is not from week 2 content 1=item is from week 2 content
equations	Ind.	Ind.	Ind.	Indicates whether the item came from week 4 (equations) or not	0=item is not from week 4 content 1=item is from week 4 content
ability	Ind.	Ind.	Ind.	Perceived student ability level	0=below grade level, 1=at grade level, 2=above grade level
lexile	Ind.	Ind.	Ind.	Text complexity of stem	Lexile measure of stem
words	Ind.	Ind.	Ind.	Length of stem	Total number of words in stem
order	n/a	n/a	Ind.	Item order on form	0= first item, 1= second item, etc.

Note. Ind. denotes an independent variable. Dep. denotes a dependent variable.

Summary

Using a within-subjects design, 334 rising eighth-graders were administered roughly 6,000 TPWPs and generic word problems in the context of a free, publically-availably online summer mathematics program. Problems were grouped into sets of 12 items – 6 TPWPs and 6 generic word problems – once a week for three weeks related to the content standards of rates and ratios, integer operations, and equations and inequalities. Items were administered through a computer-based test whereby students first completed an interest questionnaire and then were routed to an appropriate form consisting of half TPWPs and half generic items in alternating order, with counterbalancing such that roughly half of the forms administered a TPWP first and the other half administered a generic word problem first. Data were analyzed with a multilevel logistic model for RQ2 and RQ3 and with a multilevel linear model for RQ3.

Chapter 4: Results

This chapter presents results of students' interest in TPWPs and student performance on TPWPs in terms of accuracy and speed of responses as compared to generic word problems. First, descriptive statistics for variables used in multilevel models are presented, followed by the null, full, and final models for each of the three research questions. The chapter concludes with a power analysis.

Descriptive Statistics

Table 10 shows descriptive statistics for the variables used in multilevel models, with the omission of the variables equations and integers as those variables were dummy coded to reflect the data collection session. Because the variables correct and interest are coded as zero or one, the mean of those variables is the percent of participants answering the item correctly or rating the item as interesting, respectively. Thus, as seen in Table 10, the descriptive statistics indicated that students answered 71% of items correctly and rated 70% of items as interesting. By intentional design of the research study, 50% of items in the study were TPWPs, hence a mean of .50 for tpwp. The mean Lexile level of items was 779L, which corresponds to typical student reading ability estimates for students in grades four through seven as quantified by norm-referenced ranges of Lexile levels measured during the middle of the school year for readers falling between the 25th and 75th percentile of their grade level (MetaMetrics, Inc., 2016). Because students in this study had completed grade seven, the text demand of the items in the study was generally less than the expected reader ability for the targeted grade level. Item stems had on average about 34 words. Students took approximately 65 seconds to respond to each item or, equivalently, a mean logged response time of 3.83 seconds. Based on self-reported perceived mathematical ability on a scale from zero (i.e., generally below grade level) to two (i.e., above grade level) students were, on average, slightly above grade level (M= 1.32). Standard deviations are not reported for dichotomous variables (i.e., correct, interest, and tpwp).

Table 10

Descriptive Statistics of Variables Used in Multilevel Models

	N	*M*	*SD*	Min	Max
Level 1 variables					
correct	6,637	0.71	--	0	1
interest	6,637	0.70	--	0	1
tpwp	6,864	0.50	--	0	1
lexile	6,864	779.38	202.25	260	1,260
words	6,864	33.85	12.62	13	71
time	5,982	65.18	56.97	5.01	304.99
log(time)	5,982	3.83	0.86	1.61	5.72
Level 2 variable					
ability	334	1.32	0.68	0	2

Table 11, Table 12, and Table 13 present descriptive statistics for each of the three outcome variables of interest, correct, and response time, respectively. Within each table, results are shown separately by session number and for TPWPs and generic word problems. Across all three sessions, students rated a greater proportion of TPWPs as interesting as compared to generic word problems. In session one, 59% of generic word problems were rated as interesting as compared to 71% of TPWPs rated as interesting, a difference of 12%. In sessions two and three, the difference between the percent of TPWPs rated as interesting and the percent of generic word problems rated as interesting was 7% and 5%, respectively, where in all sessions students rated more TPWPs as interesting as compared to generic word problems. As seen in Table 12, students answered roughly the same percent of items correctly for both TPWPs and generic word problems. In session one, students answered the same percent of generic word problems and TPWPs correctly – 69% of TPWPs and 69% of generic word problems were answered correctly. In sessions two and three, students answered one to three percent more generic word problem items than TPWP items correctly. For response time, students responded to generic word problems on average about four seconds faster than TPWPs in sessions one and two and with about the same speed for generic word problems and TPWPs in session three.

Table 11

Descriptive Statistics for Proportion of Problems Rated as Interesting

	Generic word problems				TPWPs			
Session	N students (N items)	Min	Max	*M*	N students (N items)	Min	Max	*M*
1	252 (1,444)	0	1	0.59	252 (1,451)	0	1	0.71
2	206 (1,210)	0	1	0.73	206 (1,215)	0	1	0.80
3	114 (659)	0	1	0.63	114 (658)	0	1	0.68

Table 12

Descriptive Statistics for Proportion of Correct Responses

	Generic word problems				TPWPs			
Session	N students (N items)	Min	Max	*M*	N students (N items)	Min	Max	*M*
1	252 (1,444)	0	1	0.69	252 (1,451)	0	1	0.69
2	206 (1,210)	0	1	0.75	206 (1,215)	0	1	0.72
3	114 (659)	0	1	0.71	114 (658)	0	1	0.70

Table 13

Descriptive Statistics for Mean Response Time in Seconds

	Generic word problems					TPWPs				
Session	N students (N items)	Min	Max	*M*	*SD*	N students (N items)	Min	Max	*M*	*SD*
1	252 (1,290)	19.89	244.4	77.86	37.82	252 (1,299)	21.19	209.6	82.00	38.18
2	206 (1,100)	11.08	106.7	38.37	17.66	206 (1,128)	12.89	94.87	42.88	18.97
3	114 (580)	8.622	197.5	88.90	44.68	114 (585)	9.052	200.9	88.27	41.57

Correlation Matrix

Table 14 shows the correlation matrix for the variables used in the multilevel model analyses. It can be seen that the correlation between tpwp and interest is positive and statistically significant; however, the correlation between tpwp and correct is negative and not statistically significant. There is also a statistically significant positive correlation between correct and interest. Note that the correlation between tpwp and ability is zero because students of all self-reported ability levels received an equal number of TPWPs and generic word problems; thus, by design, there is no relationship between receiving TPWPs and ability level. Similarly, for the near-zero correlation between ability and lexile and between ability and words, students received the same items regardless of their ability level; however, students of particular ability levels may have participated more or less fully in the data collection, thus causing slight variation in the Lexile level and number of words in the specific items that students received.

Table 14

Correlation Matrix of Variables Used in Multilevel Models

	tpwp	correct	interest	lexile	words	time	log(time)
tpwp	1	--	--	--	--	--	--
correct	-0.02	1	--	--	--	--	--
interest	0.10***	0.13***	1	--	--	--	--
lexile	0.29***	-0.09***	-0.02	1	--	--	--
words	0.18***	-0.05***	0.01	0.70***	1	--	--
time	0.03*	0.05***	-0.05***	0.18***	0.13***	1	--
log(time)	0.05***	0.06***	-0.04**	0.21***	0.13***	0.90***	1
ability	0.00	0.19***	0.07***	-0.01	0.01	-0.05***	-0.06***

Note. N=6,637 items for all correlations except correlations involving time and log(time), for which *N*=5,982.
**p* < .05. ***p* < .01. ****p* < .001.

RQ1: Rating TPWPs as Interesting

For RQ1 (“Are rising eighth-graders more likely to rate TPWPs as interesting as compared to matched generic word problems?”), an unconditional random intercept logistic model was first fit to the data with students’ interest ratings as the dependent variable, where interest ratings for participant j to item i, $interest_{ij}$, were coded as one for problems rated as interesting and zero for problems rated as not interesting. For the model equations, p_{ij} is used to denote the probability of participant *j* rating item *i* as interesting; namely $p_{ij} = \Pr(interest_{ij} = 1)$. The unconditional level 1, level 2, and combined equations as shown in Equation 1 through 3 were:

Level 1 Model:

$$\log\left(\frac{p_{ij}}{1 - p_{ij}}\right) = \beta_{0j} \tag{1}$$

Level 2 Model:

$$\beta_{0j} = \beta_{00} + \mu_{0j} \tag{2}$$

Combined Model:

$$\log\left(\frac{p_{ij}}{1 - p_{ij}}\right) = \beta_{00} + \mu_{0j} \tag{3}$$

Although level 1 equations for linear unconditional models include an error term, the level 1 equation here (i.e., Equation 1) does not include an error term because in logistic models, as is the case here, the variance of the dependent variable is determined entirely by p_{ij} and thus no separate term is needed (Hox, 2002). Table 15 shows results for the unconditional model.

Table 15

Unconditional Model for RQ1

Fixed effect	Estimate	*SE*	*t*-ratio
Intercept	1.0174	0.0988	10.296***
Random effect	Variance		
Intercept between participants	2.7260		

***p < .001.

For multilevel logistic models, the intraclass correlation coefficient (ICC) is calculated as follows in Equation 4:

$$ICC = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\pi^2}{3}} \tag{4}$$

where σ_u^2 is the variance of the random intercept in the unconditional model (Guo & Zhao, 2000). In the case of the unconditional model with interest rating as the dependent variable, the variance of the random intercept was 2.726, resulting in an ICC of

$$\frac{2.726}{2.726 + \frac{\pi^2}{3}} = .4531 \tag{5}$$

This ICC indicated that 45.31% of variation in interest ratings was between participants and therefore multilevel modeling was an appropriate data analysis technique.

Equations 6 through 15 show the full model, which included level 1 variables for tpwp, correct, lexile, equations, and integers as described in Table 9 of Chapter 3. Although all variables could not be modeled as random effects due to failure of model convergence, the variable tpwp was modeled as a random effect rather than a fixed effect because it was the variable that was most central to the research question. The variance component of tpwp (.73) was statistically significant *(p*<.001), and therefore tpwp was retained as a random effect in the full and final models presented here. All other variables were modeled as fixed effects. Continuous level 1 variables (i.e., lexile, words) were grand mean centered in order to facilitate interpretation. Grand mean centering is a method whereby the overall mean of the variable is subtracted from the value of the variable for each record, resulting in a model where the intercept is the expected value of the dependent variable when the value of the independent variable equals the mean of that variable (Hox, 2002). Dummy coded variables (e.g., equations, integers) and dichotomous variables (e.g., correct, TPWP) were not centered because they already have an interpretable value of zero for the reference category (e.g., the value of the intercept when answering the item incorrectly, when receiving a generic word problem). Thus, the intercept of the models is interpreted as the logit (i.e., log odds ratio) of rating an item as interesting for an item of mean Lexile level and mean number of words that was answered incorrectly and not personalized from the rates and ratios data collection session. An interaction term between tpwp and correct was also included due to the possibility that answering a TPWP correctly had an added effect in terms of predicting interest ratings because of possible accumulating effects of a student both receiving a TPWP and being competent enough with the content to answer correctly.

Perceived student ability was entered into the model as a level 2 predictor of the intercept due to prior research indicating a relationship between student achievement and interest in mathematics (Schiefele, Krapp, & Winteler, 1992). Perceived student ability was also considered as a moderator of the slope of tpwp in order to investigate whether there was a different relationship between tpwp and interest for high-ability students versus low-ability students.

Level 1 Model:

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \pi_{0i} + \pi_{1i}{*}(correct_{ti}) + \pi_{2i}{*}(tpwp_{ti}) + \pi_{3i}{*}(correct{*}tpwp_{ti}) \\ + \pi_{4i}{*}(lexile_{ti}) + \pi_{5i}{*}(words_{ti}) + \pi_{6i}{*}(equations_{ti}) + \pi_{7i}{*}(integers_{ti}) \tag{6}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01}{*}(ability_{i}) + r_{0i} \tag{7}$$

$$\pi_{1i} = \beta_{10} \tag{8}$$

$$\pi_{2i} = \beta_{20} + \beta_{21}{*}(ability_{i}) + r_{2i} \tag{9}$$

$$\pi_{3i} = \beta_{30} \tag{10}$$

$$\pi_{4i} = \beta_{40} \tag{11}$$

$$\pi_{5i} = \beta_{50} \tag{12}$$

$$\pi_{6i} = \beta_{60} \tag{13}$$

$$\pi_{7i} = \beta_{70} \tag{14}$$

Combined Model:

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_{00} + \beta_{01}{*}\,ability_{i} + \beta_{10}{*}\,correct_{ti} + \beta_{20}{*}\,tpwp_{ti} \\ + \beta_{21}{*}\,ability_{i}{*}\,tpwp_{ti} + \beta_{30}{*}\,correct{*}tpwp_{ti} + \beta_{40}{*}\,lexile_{ti} \\ + \beta_{50}{*}\,words_{ti} + \beta_{60}{*}\,equations_{ti} + \beta_{70}{*}\,integers_{ti} + r_{0i} + r_{2i}{*}tpwp_{ti} \tag{15}$$

Results from multilevel logistic models produced five outputs for each variable in the model: 1) an estimate of the change in the dependent variable (i.e., change in logits) for each change of one unit in the independent variable, 2) the standard error of the estimate, 3) a *t*-ratio calculated as the estimate divided by the standard error, 4) a *p*-value for the *t*-ratio, and 5) the odds ratio, which is the exponentiated value of the estimate (i.e., if the estimate is *x*, then the odds ratio is e^{x} where e is the base of the natural logarithm) and defined as the ratio of the odds of an event under a particular exposure (e.g., treatment condition) to the odds of the event without exposure (e.g., control condition). In the case of the odds ratio for tpwp, it is the ratio of the odds of rating a TPWP as interesting to the odds of rating a generic word problem as interesting after controlling for other predictor variables and can be interpreted as the effect of tpwp on rating an item as interesting. When the odds ratio equals one, there is no effect, since then the odds of rating a TPWP as interesting then equal the odds of rating a generic word problem as interesting. When the odds ratio is greater than one, it means that students were more likely to rate TPWPs as interesting as compared to generic word problems by a factor equal to the odds ratio, after accounting for other predictor variables.

Results for the full model are presented in Table 16. After fitting the full model, variables that were not statistically significant in the full model were removed one at a time – starting those with the least statistical significance – until arriving at a model with only statistically significant effects or the corresponding main effects or dummy coded variables related to statistically significant effects.

Table 16

Full Model for RQ1

	Estimate	*SE*	*t*-ratio	*p*-value	Odds Ratio
Intercept	-0.1091	0.2599	-0.420	0.675	0.8967
ability	0.0909	0.1692	0.537	0.592	1.0951
correct	0.7218	0.1091	6.615	<0.001	2.0581
tpwp	0.3095	0.1985	1.559	0.120	1.3628
tpwp × ability	0.2368	0.1272	1.861	0.064	1.2671
correct × tpwp	0.0211	0.1508	0.140	0.889	1.0214
lexile	-0.0004	0.0003	-1.536	0.125	0.9996
words	0.0024	0.0054	0.438	0.662	1.0024
equations	0.7613	0.1039	7.328	<0.001	2.1410
integers	-0.1513	0.1540	-0.982	0.326	0.8596

As seen in the results for the final model in Table 17, the ratio of the odds of a student rating a problem as interesting if the problem were a TPWP to the odds of a student rating a problem as interesting if it were a generic word problem was 1.825, meaning the odds of rating a problem as interesting were 1.825 times greater if the problem were a TPWP as compared to a generic word problem after accounting for other level 1 predictors. To explain this result further, the intercept of the model, 0.0041, represents the log odds of rating an item as interesting when it was not a TPWP and when all other independent variables were zero. The log odds of rating an item as interesting when it was a TPWP and when all other independent variables were zero is then the intercept plus the estimate for TPWP, 0.0041 + 0.6016 = .6057. The ratio of these two exponentiated values yields the odds ratio shown in Equation 16.

$$\frac{odds\ of\ rating\ item\ as\ interesting\ when\ item\ is\ a\ TPWP}{odds\ of\ rating\ item\ as\ interesting\ when\ it\ a\ generic\ word\ problem} = \frac{e^{.6057}}{e^{0.0041}} = \frac{1.8325}{1.0041} = 1.825 \tag{16}$$

Perceived student ability was a statistically significant moderator of the slope of tpwp. Specifically, students with a higher perceived ability level were more likely to rate TPWPs as interesting as compared to students with a lower perceived ability level. Regarding control variables, students were also more likely to rate a problem as interesting if they answered the problem correctly. Finally, the type of mathematics content also affected the likelihood of rating a problem as interesting: students were more likely to rate equation and inequality problems as interesting and less likely to rate integer problems as interesting as compared to rates and ratios problems.

Table 17

Final Model for RQ1

	Estimate	*SE*	*t*-ratio	p-value	Odds Ratio
Intercept	0.0041	0.1321	0.031	0.975	1.0041
correct	0.7461	0.0798	9.355	<.001	2.1087
tpwp	0.6016	0.0858	7.010	<.001	1.8250
tpwp × ability	0.2665	0.1134	2.350	0.019	1.3054
equations	0.7935	0.0911	8.715	<.001	2.2111
integers	-0.1794	0.1059	-1.694	0.090	0.8358

Summary of RQ1. The answer to RQ1 ("Are rising eighth-graders more likely to rate TPWPs as interesting as compared to matched generic word problems?") is yes, students were more likely to rate a TPWP as interesting as compared to matched generic word problems. Specifically, the odds of rating a TPWP as interesting were 1.825 times the odds of rating a generic word problem as interesting after accounting for other statistically significant predictors in the final model (i.e., answering the problem correctly and the type of mathematics content of the problem).

RQ2: Accuracy of TPWPs

For RQ2 ("Are rising eighth-graders more likely to answer TPWPs correctly as compared to matched generic word problems, and how do students' interest ratings of problems relate to the likelihood of answering the problem correctly?"), a second multilevel logistic model was fit to the data, in this case with the dependent variable as whether or not the student answered the item correctly. Coding a correct response as one and an incorrect response as zero, p_{ij} was used to represent the probability that participant *j* answered item *i* correctly, namely $p_{ij} = \Pr(correct_{ij} = 1)$. Table 18 shows results from the unconditional model which followed the same structure as the level 1, level 2, and combined equations presented in Equation 1, Equation 2, and Equation 3. Based on Equation 4 for the ICC of logistic models, 25.89% of variation in correct responses was between participants and thus, similarly to RQ1, multilevel modeling was again an appropriate data analysis technique.

Table 18

Unconditional Model for RQ2

Fixed effect	Estimate	*SE*	*t*-ratio
Intercept	1.019	0.0675	15.095***
Random effect	Variance		
Intercept between participants	1.149		

***p < .001.

Equations for the full model are shown in Equations 17 through 26. The same centering methods as in RQ1 were used, whereby variables with a meaningful zero (i.e., tpwp, interest, integers, equations) were not centered but continuous variables (i.e., lexile, words) were grand mean centered. Although the model would not converge if all level 1 predictor variables were entered as random effects rather than fixed effects, the two variables most pertinent to the research question – namely, tpwp and interest – were first modeled as random effects in the full model to investigate whether the effect of these variables on student performance varied across students. Control variables in the model (i.e., integers, equations, lexile, and words were entered in the model as fixed effects to ensure model convergence. An interaction term for the interaction between TPWP and interest was also included due to the possibility that receiving a TPWP that a student rated as interesting might have had an added effect above and beyond the main effects of TPWP and interest. For example, it is possible that receiving a TPWP that a student finds interesting makes the problem easier but perhaps receiving a TPWP that a student does not find interesting has no effect on accuracy of response. Perceived student ability was also included as a level 2 predictor variable for both the intercept and the slope of TPWP due to prior research indicating that personalization of mathematics word problems may affect students differently based on students' ability level (Walkington, 2013). In other words, including ability as a moderator of the slope of TPWP meant testing for whether the effect of TPWP differed across students of different perceived ability levels.

Level 1 Model:

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \pi_{0i} + \pi_{1i}{*}(interest_{ti}) + \pi_{2i}{*}(tpwp_{ti}) + \pi_{3i}{*}(tpwp{*}interest_{ti}) + \pi_{4i}{*}(lexile_{ti}) + \pi_{5i}{*}(words_{ti}) + \pi_{6i}{*}(equations_{ti}) + \pi_{7i}{*}(integers_{ti}) \tag{17}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01}{*}(ability_i) + r_{0i} \tag{18}$$

$$\pi_{1i} = \beta_{10} + r_{1i} \tag{19}$$

$$\pi_{2i} = \beta_{20} + \beta_{21}{*}(ability_i) + r_{2i} \tag{20}$$

$$\pi_{3i} = \beta_{30} \tag{21}$$

$$\pi_{4i} = \beta_{40} \tag{22}$$

$$\pi_{5i} = \beta_{50} \tag{23}$$

$$\pi_{6i} = \beta_{60} \tag{24}$$

$$\pi_{7i} = \beta_{70} \tag{25}$$

Combined Model:

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_{00} + \beta_{01}{*}ability_i + \beta_{10}{*}interest_{ti} + \beta_{20}{*}tpwp_{ti} + \beta_{21}{*}ability_i{*}tpwp_{ti} + \beta_{30}{*}tpwp{*}interest_{ti} + \beta_{40}{*}lexile_{ti} + \beta_{50}{*}words_{ti} + \beta_{60}{*}equations_{ti} + \beta_{70}{*}integers_{ti} + r_{0i} + r_{1i}{*}interest_{ti} + r_{2i}{*}tpwp_{ti} \tag{26}$$

As seen in the full model results in Table 19, tpwp was not a statistically significant predictor of students' answering items correctly; however, students' interest ratings in problems was a statistically significant predictor of answering the item correctly. For the final model, tpwp was removed as a predictor variable along with removing interactions that were not statistically significant. Because one dummy-coded variable (i.e., integers) was statistically significant, its dummy-coded counterpart (i.e., equations) was retained in the final model. Regarding modeling interest and tpwp as random effects, the variance component of interest (.37) in the full model was statistically significant (*p*=.004), indicating that interest was appropriated modeled as a random effect. Interest was therefore retained as a random effect in the final model. On the other hand, the variance component of tpwp (.02) was not statistically significant (*p*>.5); hence, tpwp was modeled as a fixed effect in the final model.

Table 19

Full Model for RQ2

	Estimate	*SE*	*t*-ratio	*p*-value	Odds Ratio
Intercept	-0.5944	0.1696	-3.504	<0.001	0.5519
ability	0.7448	0.1068	6.975	<0.001	2.1060
interest	0.7417	0.1049	7.068	<0.001	2.0996
tpwp	0.1569	0.1506	1.042	0.298	1.1700
tpwp × ability	-0.1052	0.0891	-1.181	0.239	0.9001
tpwp × interest	-0.0251	0.1304	-0.192	0.848	0.9753
lexile	-0.0012	0.0002	-4.877	<0.001	0.9988
words	-0.0147	0.0048	-3.071	0.002	0.9853
equation	0.1295	0.0910	1.423	0.155	1.1383
integers	0.5902	0.1384	4.265	<0.001	1.8044

Results for the final model, shown in Table 20, indicated that the odds of answering an item correctly were 2.07 times greater when the item was rated as interesting than the odds of answering an item correctly when the item was not rated as interesting after accounting for other level 1 predictors. Also, students were also more likely to answer problems correctly when they perceived themselves to be of a higher ability level, and students were more likely to answer integer problems and equation and inequality problems correctly as compared to rates and ratio problems. Lastly, as the reading demand of the item stem increased, the likelihood of answering the problem correctly decreased.

Table 20

Final Model for RQ2

	Estimate	SE	*t*-ratio	*p*-value	Odds Ratio
Intercept	-0.5093	0.1505	-3.384	<0.001	0.6009
ability	0.6884	0.0947	7.267	<0.001	1.9905
interest	0.7273	0.0827	8.799	<0.001	2.0695
lexile	-0.0012	0.0002	-4.889	<0.001	0.9988
words	-0.0148	0.0048	-3.088	0.002	0.9852
equation	0.1286	0.0908	1.416	0.157	1.1372
integers	0.5826	0.1365	4.268	<0.001	1.7907

Summary of RQ2. For the first part of RQ2 ("Are rising eighth-graders more likely to answer TPWPs correctly as compared to matched generic word problems?"), no evidence was found to support the idea that students were statistically significantly more likely to answer a TPWP correctly as compared to a generic word problem above and beyond other predictor variables, based on the results that TPWP was not a statistically significant predictor of item scores in the full model. For the second part of RQ2 ("How do students' interest ratings of problems relate to the likelihood of answering the problem correctly?"), students were statistically significantly more likely to answer a problem correctly when rating the problem as interesting as compared to the likelihood of answering a problem correctly when rating it as not interesting after accounting for other level 1 and 2 variables, including the reading demand of the stem, the mathematics content of the item, and the students' perceived ability level.

RQ3: Response Time to TPWPs

For RQ3 (“Do rising eighth-graders spend more or less time solving a TPWP as compared to a matched generic problem, and how does amount of time solving each type of problem relate to mathematical accuracy?”), the dependent variable, response time, is a continuous variable and thus multilevel linear modeling was used as opposed to the logistic multilevel modeling used in RQ1 and RQ2. Response time often has a skewed distribution, as was the case here, and consequently a natural log transformation of response time was used in order to produce a dependent variable with a normal distribution. Sometimes an inverse transformation is used on a response time dependent variable (i.e., 1/response time) in order to create an easily interpretable dependent variable known as response speed that still produces a more normal distribution (Hox, 2002). However, in these data, the inverse transformation resulted in a highly skewed distribution and therefore was not used. Figure 12 and Figure 13 show the distribution of response time before and after the transformation, respectively.

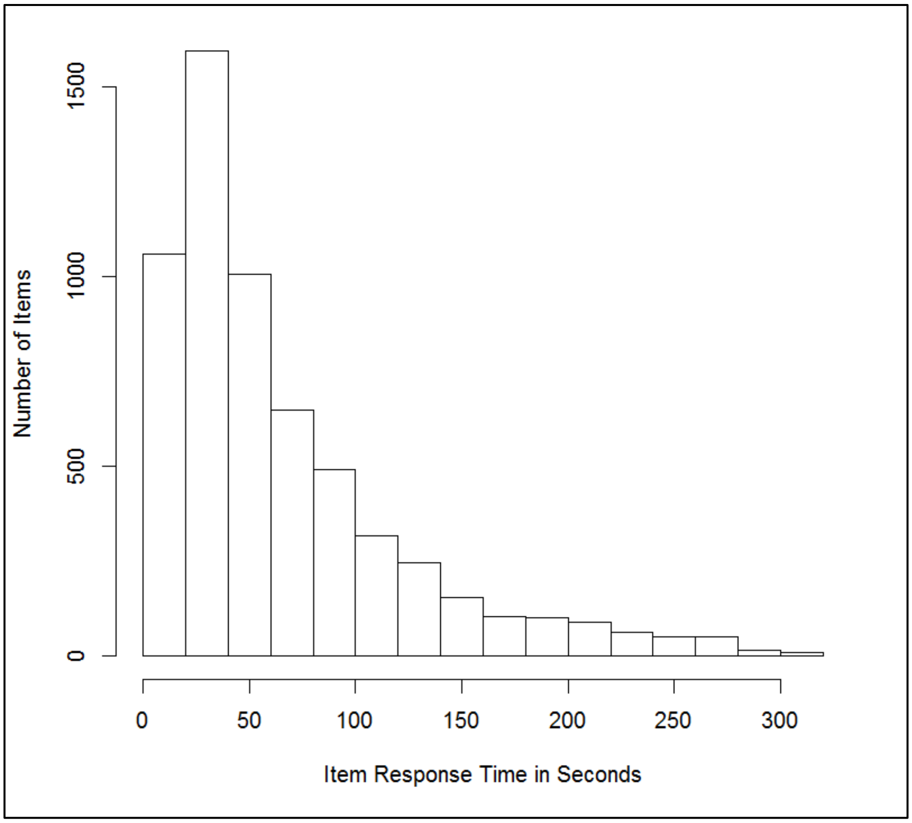


Figure 12. Distribution of response time prior to log transformation.

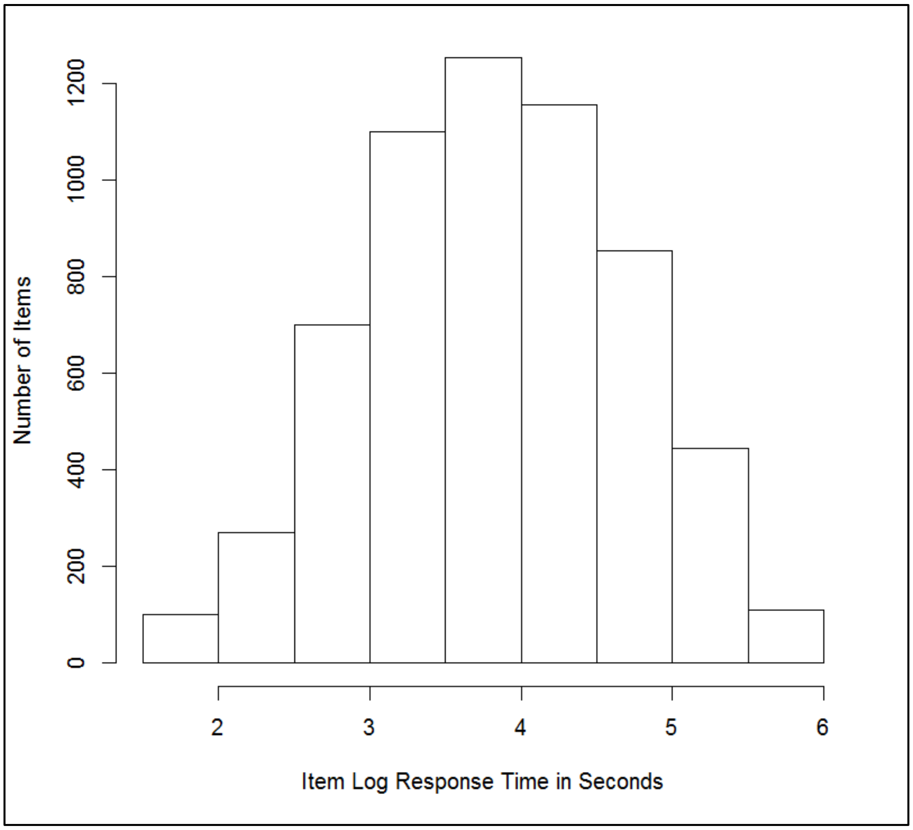


Figure 13. Distribution of response time after log transformation.

Equations 27 through 29 show the unconditional model with log response time as the dependent variable.

Level 1 Model:

$$ln(time)_{ti} = \pi_{0i} + e_{ti} \tag{27}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + r_{0i} \tag{28}$$

Combined Model:

$$ln(time)_{ti} = \beta_{00} + r_{0i} + e_{ti} \tag{29}$$

For multilevel linear models, the ICC is calculated as

$$ICC = \frac{\tau_{00}}{\tau_{00} + \sigma^2} \tag{30}$$

where τ_{00} is the amount of variance within participants and σ^2 is the amount of variance between participants in the unconditional model (Raudenbush & Bryk, 2002). In the case of the unconditional model with log response time in seconds as the dependent variable (Table 21), the resulting ICC was

$$\frac{0.173}{0.173 + 0.578} = .2301 \tag{31}$$

This ICC indicated that 23.01% of variation in response time was between participants and therefore multilevel linear modeling was an appropriate data analysis technique.

Table 21

Unconditional Model for RQ3

Fixed effect	Estimate	*SE*	*t*-ratio
Intercept	3.824	0.025	151.525***
Random effect	Variance		
Intercept between participants	0.173		
Level 1 error	0.578		

****p* < .001.

The full model for RQ3 is represented in Equations 32 through 45, which incorporated similar control variables as the models in RQ1 and RQ2. Also, in order to account for possible practice effects or fatigue effects as students progressed throughout a form, a level 1 predictor was included for item order, where the first item was coded as 0, the second item coded as 1, and so on and so forth until the twelfth item was coded as 11. Similarly to the models used for RQ1 and RQ2, continuous level 1 variables (i.e., lexile, words) were entered as grand mean centered and all other variables (i.e., order, correct, interest, tpwp, equations, integers, ability) were not centered as they have already had meaningful interpretations when their value was zero. Also similarly to RQ1 and RQ2, perceived student ability was included as a level 2 predictor of the intercept and as a predictor of the slope of tpwp, and interaction effects were again included for Correct × Tpwp, Correct × Interest , and Tpwp × Interest. Variables most pertinent to the research question (i.e., tpwp, interest, and correct) were modeled as random effects in the initial run of the full model, and all other variables were modeled as fixed effects to ensure model convergence.

Level 1 Model:

$$\begin{aligned} ln(time)_{ti} = \pi_{0i} + \pi_{1i}{*}(order_{ti}) + \pi_{2i}{*}(correct_{ti}) + \pi_{3i}{*}(interest_{ti}) + \pi_{4i}{*}(tpwp_{ti}) \\ + \pi_{5i}{*}(correct{*}tpwp_{ti}) + \pi_{6i}{*}(correct{*}interest_{ti}) + \pi_{7i}{*}(tpwp{*}interest_{ti}) \\ + \pi_{8i}{*}(lexile_{ti}) + \pi_{9i}{*}(words_{ti}) + \pi_{10i}{*}(equations_{ti}) + \pi_{11i}{*}(integers_{ti}) + e_{ti} \end{aligned} \tag{32}$$

Level 2 Model:

$$\pi_{0i} = \beta_{00} + \beta_{01}{*}(ability_i) + r_{0i} \tag{33}$$

$$\pi_{1i} = \beta_{10} \tag{34}$$

$$\pi_{2i} = \beta_{20} + r_{2i} \tag{35}$$

$$\pi_{3i} = \beta_{30} + r_{3i} \tag{36}$$

$$\pi_{4i} = \beta_{40} + \beta_{41}{*}(ability_i) + r_{4i} \tag{37}$$

$$\pi_{5i} = \beta_{50} \tag{38}$$

$$\pi_{6i} = \beta_{60} \tag{39}$$

$$\pi_{7i} = \beta_{70} \tag{40}$$

$$\pi_{8i} = \beta_{80} \tag{41}$$

$$\pi_{9i} = \beta_{90} \tag{42}$$

$$\pi_{10i} = \beta_{100} \tag{43}$$

$$\pi_{11i} = \beta_{110} \tag{44}$$

Combined Model:

$$\begin{aligned} \mathit{ln(time)}_{ti} = {} & \beta_{00} + \beta_{01}{*}\,\mathit{ability}_{i} + \beta_{10}{*}\,\mathit{order}_{ti} + \beta_{20}{*}\,\mathit{correct}_{ti} + \beta_{30}{*}\,\mathit{interest}_{ti} \\ & + \beta_{40}{*}\,\mathit{tpwp}_{ti} + \beta_{41}{*}\,\mathit{ability}_{i}{*}\,\mathit{tpwp}_{ti} + \beta_{50}{*}\,\mathit{correct}{*}\mathit{tpwp}_{ti} + \beta_{60}{*}\,\mathit{correct}{*}\mathit{interest}_{ti} \\ & + \beta_{70}{*}\,\mathit{tpwp}{*}\mathit{interest}_{ti} + \beta_{80}{*}\,\mathit{lexile}_{ti} + \beta_{90}{*}\,\mathit{words}_{ti} + \beta_{100}{*}\,\mathit{equations}_{ti} \\ & + \beta_{110}{*}\,\mathit{integers}_{ti} + r_{0i} + + r_{2i}{*}\,\mathit{correct}_{ti} + r_{3i}{*}\,\mathit{interest}_{ti} + r_{4i}{*}\,\mathit{tpwp}_{ti} + e_{ti} \end{aligned} \tag{45}$$

Table 22 displays results for the full model. Because the variance component of tpwp (.003) was not statistically significant (p>.5) when modeling tpwp as a random effect in the initial run of the model, the full model was reran with tpwp as a fixed effect. The other variables initially modeled as random effects – correct and interest – did have statistically significant variance components (.07, *p*<.001 for correct; .04, *p*=.014 for interest) and therefore were retained as random effects in the full model reported in Table 22. For the first part of RQ3 regarding whether or not participants spent more or less time on TPWPs as compared to generic word problems, participants took, on average, 0.009 more logged seconds to respond to TPWPs compared to generic word problems, after accounting for other predictor variables; however, this effect was not statistically significant. Perceived student ability was not statistically significant as a level 2 predictor of either the intercept or the slope of tpwp.

Table 22

Full Model for RQ3

	Estimate	*SE*	*t*-ratio	*p*-value
Intercept	4.4606	0.0673	66.310	<0.001
ability	-0.0615	0.0367	-1.676	0.095
order	-0.0507	0.0027	-19.101	<0.001
correct	0.1990	0.0434	4.583	<0.001
interest	-0.0018	0.0466	-0.039	0.969
tpwp	0.0086	0.0506	0.170	0.865
tpwp × ability	0.0014	0.0265	0.054	0.957
correct × tpwp	-0.0183	0.0405	-0.453	0.651
correct × interest	-0.0704	0.0468	-1.505	0.132
tpwp × interest	-0.0439	0.0400	-1.096	0.273
lexile	0.0004	<0.0001	5.252	<0.001
words	0.0171	0.0014	11.899	<0.001
equations	-0.7249	0.0269	-26.913	<0.001
integers	-0.4672	0.0409	-11.433	<0.001

Predictor variables that were not statistically significant in the full model were removed in the final model (Table 23). For the second part of RQ3 regarding whether correct responses were associated with faster or slower response time, there was a statistically significant effect for correct, indicating that students took .134 logged seconds longer to respond to problems when answering the problem correctly as compared to incorrectly.

Table 23

Final Model for RQ3

	Estimate	*SE*	*t*-ratio	*p*-value
Intercept	4.3712	0.0370	118.256	<0.001
order	-0.0509	0.0027	-19.194	<0.001
correct	0.1340	0.0256	5.236	<0.001
lexile	0.0003	<0.0001	4.867	<0.001
words	0.0170	0.0014	11.816	<0.001
equations	-0.7374	0.0267	-27.581	<0.001
integers	-0.4621	0.0403	-11.461	<0.001

Deviance can be used as an indicator of the extent to which the fit of the final model improved over the fit of the null model. More parsimonious models will have a greater percent decrease of deviance in the final model as compared to the null model. In the final model for RQ3, deviance was 12,955.5, which was a 9.3% reduction from the deviance of 14,291.5 in the null model. Deviance was not reported in RQ1 and RQ2 for logistic multilevel models as these statistics are unreliable in the case of logistic models (Raudenbush, Bryk, Cheong, Congdon, & du Toit, 2011).

Assessing assumptions of multilevel linear modeling. Linear multilevel modeling, as was used in RQ3, assumes that residuals are normally distributed and homoscedastic (i.e., error terms are equal across all values of independent variables). These assumptions are not made for logistic models (Hox, 2002), such as the models used in RQ1 and RQ2. To check these assumptions in the linear model for RQ3, I present two types of plots. For the assumption that residuals are normally distributed, Figure 14 shows a normal Q-Q plot of level 1 residuals for the final model for RQ3. The points on the Q-Q plot roughly fall on the 45 degree line, albeit with some deviation at the low and high ends which is expected near the tails, indicating sufficient normal distribution of residuals.

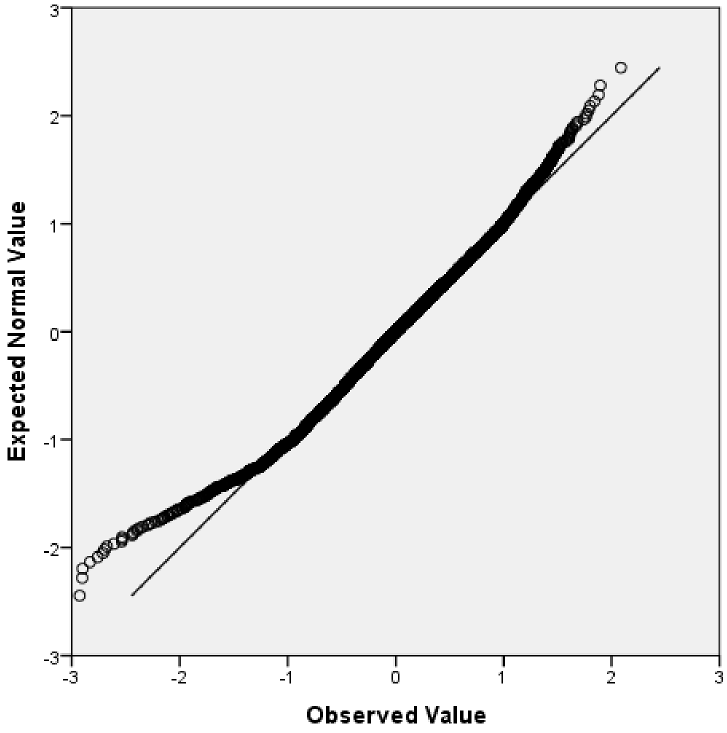


Figure 14. Normal Q-Q plot of level 1 residuals for final model in RQ3.

For the assumption of homoscedasticity, Figure 15 shows a scatter plot of standardized level 1 residuals plotted against standardized fitted values for the final model in RQ3. Although the plot shows some clustering indicating greater fitted values had larger negative standardized residuals, the majority of the points cluster toward the center of the scatter plot with no pattern, indicating sufficient homoscedasticity of residuals.

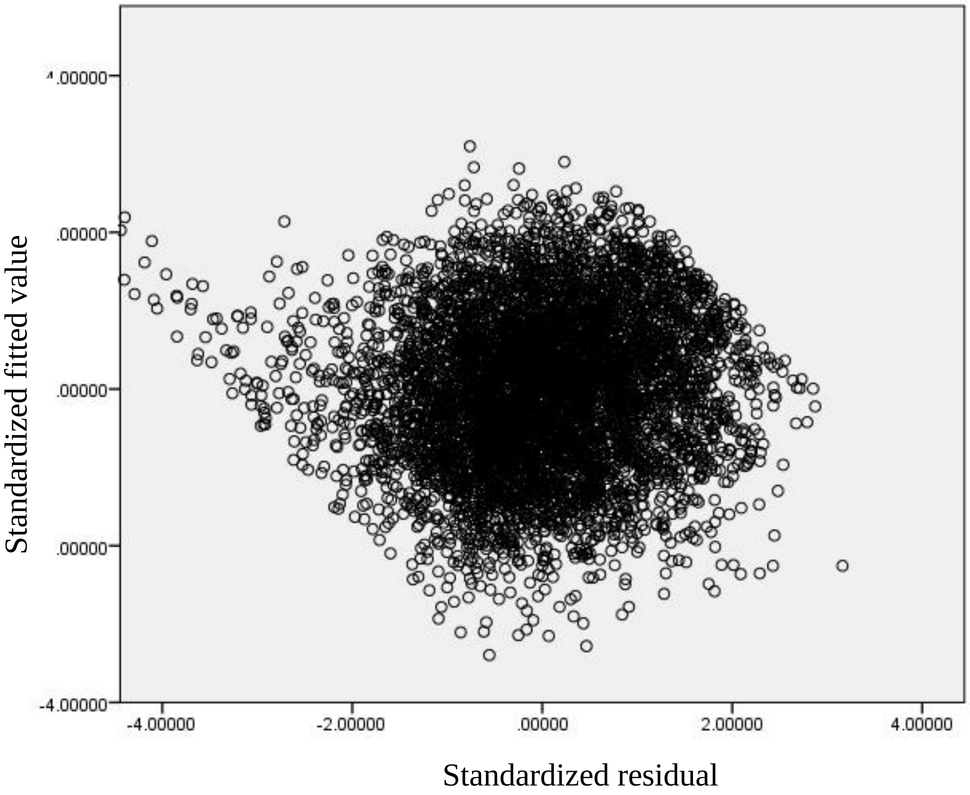


Figure 15. Plot of level 1 standardized residuals against standard fitted values in final model for RQ3.

For all three research questions, there were also no substantial concerns for multicollinearity. Coefficient estimates were stable when fitting different versions of models, and the correlation matrix of predictor variables did not show any particularly strong correlations between independent variables. The analysis software used, HLM 7, will also produce an error message when multicollinearity is a concern; in the models fit for the research questions, no such errors were produced.

Summary of RQ3. For the first part of RQ3 (“Do rising eighth-graders spend more or less time solving a TPWP as compared to a matched generic problem?”), no evidence was found to support the conclusion that TPWPs affected response time in either direction (i.e., neither faster nor slower response times) as compared to generic word problems, based on the results that tpwp was not a statistically significant predictor of logged response time in the full model. For the second part of RQ3 (“How does amount of time solving each type of problem relate to mathematical accuracy?”), students spent more time solving problems when answering problems correctly as compared to incorrectly.

Power Analysis

In statistical analysis, power refers to the probability of correctly rejecting the null hypothesis when the alternative hypothesis is true and depends on both type I error rate (i.e., error due to rejecting a true null hypothesis; denoted by α) and type II error rate (i.e., error due to failing to reject a false null hypothesis; denoted by β) (Cohen, 1988). Power is calculated as 1- β. In two-level multilevel modeling, power depends on the number of units at each level (i.e., number of items and number of participants) and the level at which key explanatory variables appear (Raudenbush & Bryk, 2002).

There are two common approaches for power analysis. In one approach, termed by Spybrook and colleagues (2011) as the *power determination approach*, a power analysis may be conducted during research design planning to determine the necessary sample size needed to detect a particular effect size with a particular amount of power. In other words, the researcher specifies the effect size he/she anticipates finding based on theory and then calculates the number of participants required to detect that effect with a specified power. (e.g., 0.8, 0.9, etc.). This type of power analysis is useful when researchers have the capability of varying sample size as needed based on data collection resources.

In other cases, when researchers have a set number of participants available and do not have the option to feasibly modify sample size, a power analysis can be conducted to calculate the effect size that would be detected with a specified power and static number of participants. Referred to by Spybrook and colleagues (2011) as the *effect size approach* and referred to by Moerbeek and Teerenstra (2016) as a *sensitivity analysis*, this type of power analysis seeks to calculate the minimum detectable effect size, defined as the smallest true effect found to be statistically significant with a predetermined sample size (Bloom, 1995).

Because participants were students voluntarily participating in a summer program and hence sample size was not able to be manipulated, I present a sensitivity power analysis. Snijders (2005) presented a formula that relates the ratio of a coefficient estimate, γ, to the standard error of that estimate to power, estimated as:

$$\frac{\gamma}{SE(\gamma)} \approx z_{1-\left(\frac{\alpha}{2}\right)} + z_{1-\beta} \tag{46}$$

for a two-tailed test at a significance level of α where $SE(\gamma)$ is the standard error of the coefficient estimate and $z_{1-\left(\frac{\alpha}{2}\right)}$ and $z_{1-\beta}$ are critical points of the *Z*-distribution for specified values of type I and type II errors, α and β. Setting α equal to .05 and finding the critical point of $z_{1-.05/2} = 1.96$ results in:

$$\frac{\gamma}{SE(\gamma)} \approx 1.96 + z_{1-\beta} \tag{47}$$

One can then use the standard error of the variable of concern in the full model as an estimate of the population error. The power analyses here concerns the variable tpwp in all three research questions. In RQ1, the standard error of tpwp was 0.0858. Equation 47 then becomes:

$$\frac{\gamma}{.0858} \approx 1.96 + z_{1-\beta} \tag{48}$$

By fixing the standard error, one can then find the value of β for a given γ and repeat the process for multiple values of γ to produce a graph relating the odds ratio (i.e., e^{γ}) to power (i.e., 1- β). The graph relating the odds ratio to power in RQ1 for the effect of tpwp on students' interest ratings is shown in Figure 16, and a sample of particular values represented in the graph are shown in Table 24. In RQ1, the estimate of tpwp was statistically significant with an odds ratio of 1.8, which corresponds to power equal to 1.

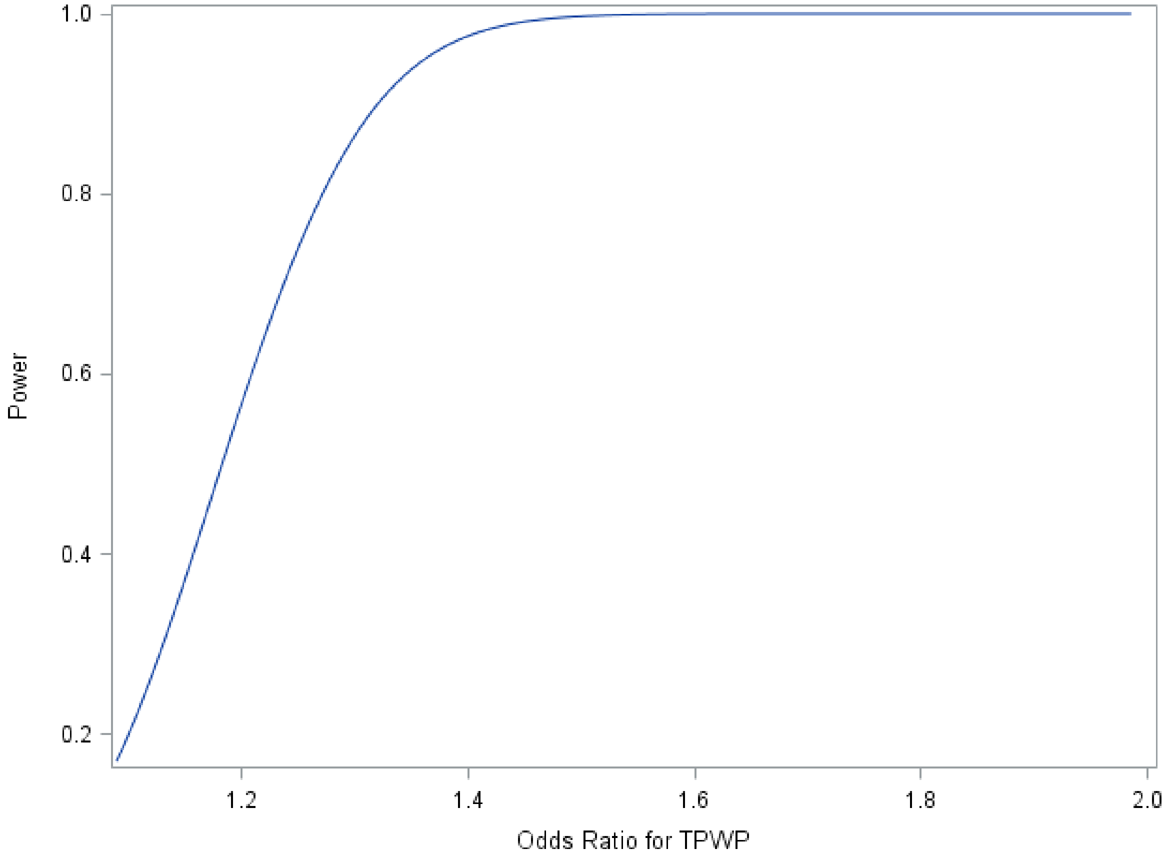


Figure 16. Graph relating the odds ratio for the effect of TPWP to power in RQ1.

Table 24

Selected Values of Odds Ratio and Power for TPWP Effect in RQ1

Odds Ratio	Power
1.10	.20
1.13	.30
1.16	.40
1.18	.50
1.21	.60
1.24	.70
1.27	.80
1.32	.90

Similarly, for RQ2, which concerned tpwp as a predictor of answering the item correctly, the standard error for tpwp was .1506. Applying Equation 47 with this standard error results in Figure 17, which shows the relationship between the odds ratio for the tpwp effect in RQ2 as a predictor of students' scores on an item above and beyond control variables. To recall the results of RQ2, tpwp was not a statistically significant predictor of students' scores on items above and beyond control variables. As seen in Table 25, if the odds ratio of tpwp was 1.53, meaning the odds of a participant answering a TPWP correctly was 1.53 times the odds of answering a generic word problem correctly, then there was an 80 percent chance of detecting this effect.

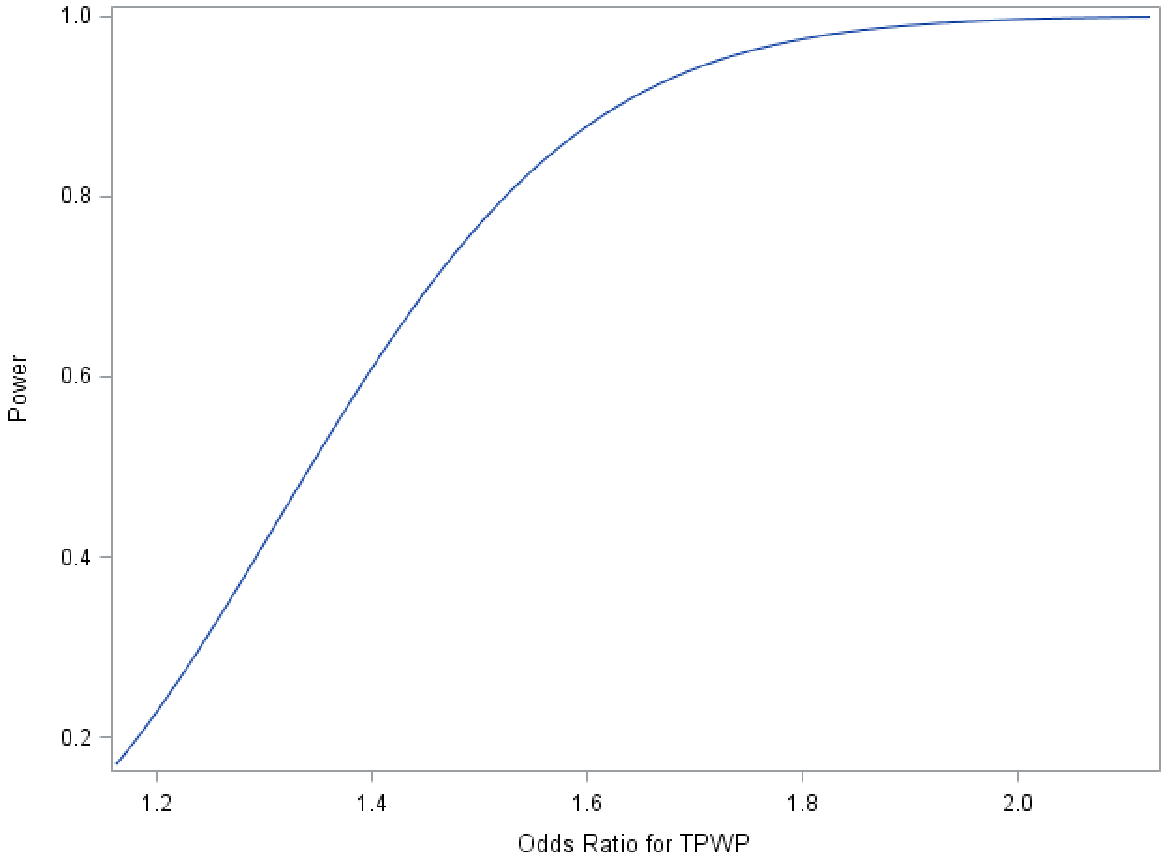


Figure 17. Graph relating the odds ratio for the effect of tpwp to power in RQ2.

Table 25

Selected Values of Odds Ratio and Power for TPWP Effect in RQ2

Odds Ratio	Power
1.18	.20
1.24	.30
1.29	.40
1.34	.50
1.40	.60
1.45	.70
1.53	.80
1.63	.90

For RQ3 relating tpwp to response time, using the standard error of .0506 for tpwp in RQ3, Figure 18 shows a similar graph of effect size and power. A table of selected values appears in Table 26. Since RQ3 was a linear model as opposed to the logistic models in RQ1 and RQ2, the *x*-axis of Figure 18 is now the effect size of the coefficient of tpwp (i.e., the estimate of the coefficient of tpwp in the model divided by the standard deviation of log response time) instead of an odds ratio. Thus, Figure 18 and Table 26 can be interpreted as identifying the power with which a given change in the standard deviation of logged response time would have been detected. For example, if the tpwp effect predicted a change in logged response time equivalent to .17 standard deviations of logged response time, then there was an 80% chance of detecting this change in logged response time.

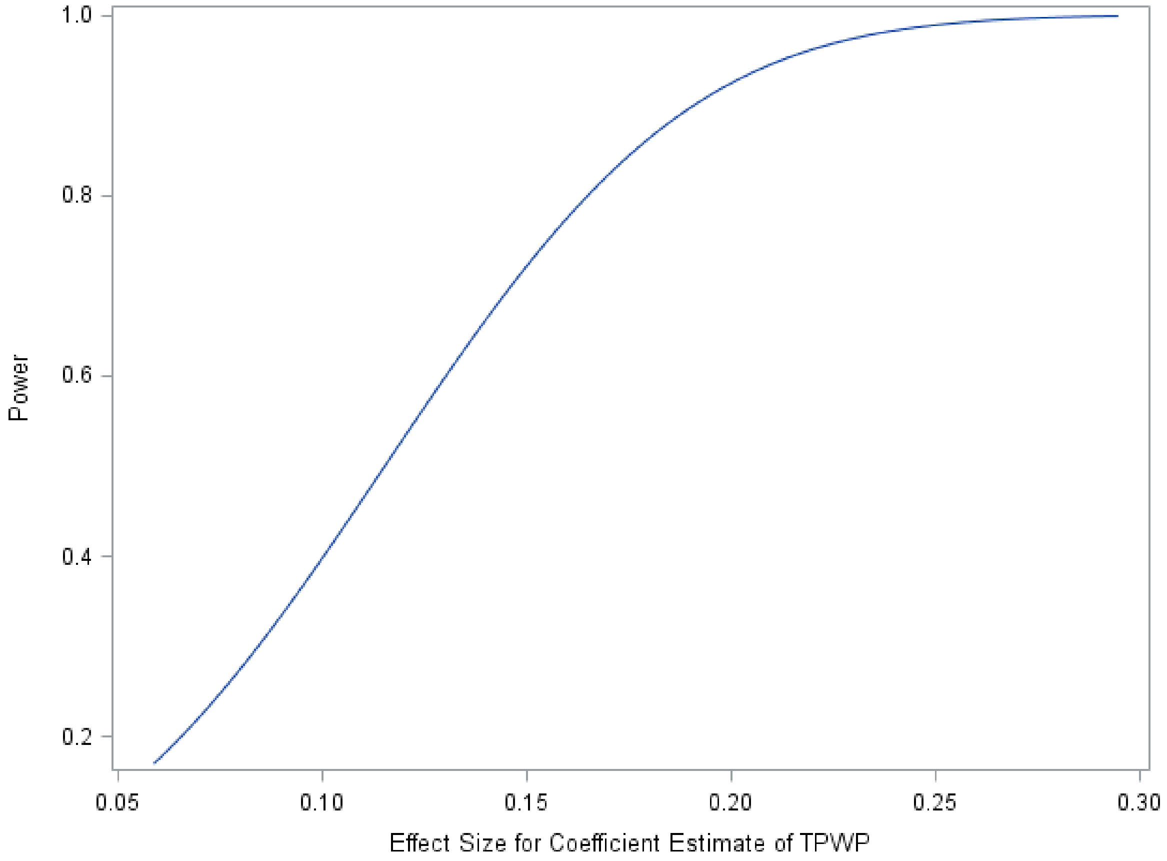


Figure 18. Graph relating the effect size of tpwp to power in RQ3.

Table 26

Selected Values of Effect Size and Power for TPWP Effect in RQ3

Effect Size	Power
.07	.20
.08	.30
.10	.40
.12	.50
.13	.60
.15	.70
.17	.80
.19	.90

In summary, in the analyses where a statistically significant effect was not detected for tpwp in RQ2 and RQ3, there was an 80% probability of detecting a relatively small effect (i.e., an odds ratio of 1.53 or greater in RQ2 and an effect size of .17 or greater in RQ3 above and beyond control variables) given the sample size used in the study.

Summary

Results of the multilevel models showed that students were more likely to rate problems as interesting when the problems were TPWPs as compared to generic word problems. In terms of the effect of TPWPs on accuracy of responses, no evidence was found that participants were more likely to answer TPWPs correctly as compared to generic word problems; however, students were more likely to answer items correctly when they rated the item as interesting as compared to items rated as not interesting. No statistically significant relationship was found between the logged number of seconds spent responding to an item and whether the item was a TPWP or a generic word problem. A sensitivity power analysis indicated sufficiently high power to detect a relatively small effect if the effect truly existed.

Chapter 5: Discussion

This chapter begins with a discussion of the significance and implications of the results presented in Chapter 4. I then discuss challenges related to using TPWPs as an instructional strategy, using computer technology to create TPWPs, and conducting research with TPWPs. The chapter concludes with consideration of the limitations of the present study and proposed directions for future research.

Significance and Implications of Results

Discussion of RQ1. RQ1 ("Are rising eighth-graders more likely to rate TPWPs as interesting as compared to matched generic word problems?") was posed to investigate whether TPWPs triggered students' interests. Prior research has largely assumed that personalization – either in the case of IPWPs or TPWPs – triggers students' interests without collecting data to determine if students find personalized word problems interesting (Bates & Wiest, 2004; Walkington, 2013). Results from RQ1 provided evidence that the use of TPWPs was indeed related to greater likelihood of rating an item as interesting as compared to matched generic word problems, thus supporting the hypothesis that TPWPs triggered students' interest in the problem. This result supports the idea that TPWPs are one means of helping students reach Phase I, triggered situational interest, of Hidi and Renninger's (2006) four-phase model of interest development. Once reaching Phase I, students may then move further along the four-stages of interest development until eventually students have a well-developed individual interest in mathematics. Thus, TPWPs may serve as a catalyst for stimulating students' future interest in mathematics. This result is similar to Cordova and

Lepper's (1996) findings that students were more interested in playing a mathematics game after school when the game had incidentally-personalized elements as compared to a version of the game with no personalization.

Results from RQ1 also indicated that students were more likely to rate problems as interesting when students answered problems correctly. In fact, prior research using large-scale longitudinal data bases has indicated that current achievement in mathematics predicted future interest in mathematics, but current interest did not predict future achievement (Ganley & Lubienski, 2016). Similar to this prior research, correct student responses may have led to feelings of interest, perhaps because of a feeling associated with being interested in tasks that one can do well. Although students were not provided with feedback about whether their responses were correct or incorrect until the end of the instrument after interest ratings were collected, students' perceptions of their mathematical ability may have been accurate enough whereby students could have accurately predicted whether they were answering items correctly or not. These predictions may have made students more likely to rate items as interesting when feeling like they responded correctly.

In addition to the item being a TPWP and students answering correctly, another variable that was a statistically significant predictor of students' interest ratings was whether or not the item came from the third data collection session in which the problems addressed equations and inequalities. There are two possible explanations for this result. First, the equation and inequality word problems generally had longer stems due to the need to explain a real-life situation modeled by an equation or inequality; therefore, the items had more interest-specific language than the items in the other two data collection sessions. Thus, it is possible that a certain extent of personalization must be required before triggering students' situational interest corresponding to Phase I of the four-phase mode of interest development (Hidi & Renninger, 2006). In other words, perhaps topic-personalization of only a few words in the stem – as was the case for most of the word problems about ratios and integers in the first two data collection sessions – was not sufficient to trigger situational interest. However, several sentences corresponding to a topic-personalized scenario, as was required for the equation and inequality word problems, may have been enough to trigger situational interest.

Second, as another possible explanation of why the equations variable was a statistically significant predictor of students' interest ratings, it is possible that students completing the final form of data collection (i.e., the equation and inequalities word problems) generally had greater interest in mathematics because they persisted throughout all three sessions of voluntary data collection over a four-week period. Hence, students in the third session could have been more likely to rate items as interesting due to those students having greater general interest in mathematics as opposed to finding equations more interesting than rates or integers. In other words, there was a confound between the type of mathematics content and the data collection session because each data collection session focused on a single content area.

Discussion of RQ2. Whereas RQ1 investigated the relationship between TPWPs and interest ratings, RQ2 ("Are rising eighth-graders more likely to answer TPWPs correctly as compared to matched generic word problems?" and "How do students' interest ratings of problems relate to the likelihood of answering the problem correctly?") focused on TPWPs and interest ratings as predictors of correct word problem responses. Results provided no evidence that students were more likely to answer an item correctly when the item was a

TPWP as compared to a generic word problem after accounting for other control variables including interest ratings. However, students were statistically significantly more likely to answer correctly if students rated the item as interesting. This finding implies that although personalization predicted interest – and interest predicted accuracy of responses – personalization did not predict accuracy of responses above and beyond the effect of interest. The finding also suggests that, regardless of whether items were personalized or not, triggering interest may indeed result in cognitive benefits leading to greater likelihood of an accurate response, as was hypothesized based on the literature presented in Chapter 2 about outcomes associated with triggering situational interest such as reduced cognitive load (McDaniel, Waddil, Finstad, & Bourg, 2000; Park, 2015), heightened attention (Hidi & Ainley, 2008; Walkington, 2015), or stronger feelings of caring about a task (Ainley, Hidi, & Berndorff , 2002). The fact that students performed better on items when rating the items as interesting implies that some of the aforementioned cognitive processes linked to triggering situational interest may have been occurring in the present study and could account for improved student performance on problems rated as interesting. Additional analysis could use path analysis to explore the possibility of interest as a mediator between personalization and accurate responses.

Discussion of RQ3. RQ3 (“Do rising eighth-graders spend more or less time solving a TPWP as compared to a matched generic problem?” and ”How does amount of time solving each type of problem relate to mathematical accuracy?”) was posed with a non-directional hypothesis about how TPWPs might affect response time. Competing theories suggested that either students might spend more time on TPWPs as compared to matched generic word problems due to increased effort or perseverance or that students might spend less time on TPWPs due to more efficient cognitive processing (e.g., reduced cognitive load) related to triggering situational interest (Ainley, Hidi, & Berndorff, 2002; Park, 2015). Results of RQ3 indicated no evidence that response time was affected by whether an item was a TPWP or a generic word problem, thereby failing to support either hypothesis that situational interest leads to either greater perseverance or reduced cognitive load when using the single measure of response time as an indicator. The response time results in the present study partially conflict with Walkington's (2013) results. In Walkington's study, students responded statistically significant more quickly to personalized word problems, though Walkington's study did not control for interest as was done in the present study. The difference between Walkington's results and the results of the present study could be attributed to interest as a control variable, since students in the present study did indeed respond more quickly to items rated as interesting.

Concluding remarks on results. Results showed that interest, not necessarily personalization, is related to accurate responses of mathematics items; however, personalization was a statistically significant predictor of self-reported interest in problems. These results imply that raising students' interest in solving problems can be a possible means of increasing student achievement and that personalizing problems to students' interests may be one means of raising interest. Still, because personalization was not statistically significant above and beyond the effect of interest, results imply that educators and other stakeholders should continue to identify ways of increasing student interest in mathematics using strategies including, but not limited to, personalization. Indeed, this would seem to be especially important because the time-intensive resources of writing personalized word problems could possibly be better redirected to more resource-efficient means of raising student interest in mathematics.

Challenges with Using TPWPs as an Instructional Strategy

This research study sought to explore TPWPs as an instructional strategy to increase student performance in mathematics, yet implementing TPWPs as an instructional strategy comes with several challenges. Users of TPWPs must consider the challenge of identifying mathematics content appropriate for TPWPs, the ability to modify problems to different interest categories, implications of assuming prior knowledge within an interest category, and the possibility that the novelty of and effect of increased interest stimulated by TPWPs may fade if students receive repeated exposure to TPWPs.

Fit of mathematics content. When developing TPWPs, the intended learning goals must first be considered to determine if TPWPs are an appropriate instructional strategy. Not all mathematics content naturally lends itself to world problems; moreover, not all content lends itself to multiple, authentic applications for word problems in different interest categories. For example, consider the two geometry problems shown in Figure 19 and Figure 20, which include skills aligned to seventh-grade CCSSM. In Figure 19, the student must identify the value of angles *A* and *B* using properties of vertical angles. In Figure 20, the student must again use properties of vertical angles to find the value of variables *a* and *b*, which requires solving a system of equations with two unknown variables. Although, hypothetically, these mathematical skills may be applied to a real-life scenario, it is likely that such a scenario would only naturally occur in a highly-technical career (e.g., engineering or physics) where the application of the mathematics within that career would be unfamiliar to students in the grade level where the content is taught. In other words, although these mathematical skills certainly have real-life applications used by certain people, it is likely that the applications do not occur in seventh-graders' day-to-day life outside of school.

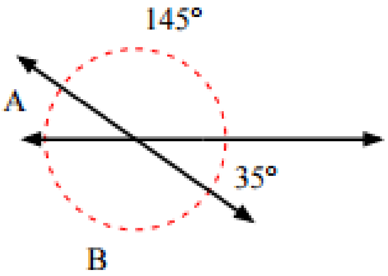


Figure 19. Example geometry problem 1 (Common Core Sheets, 2015).

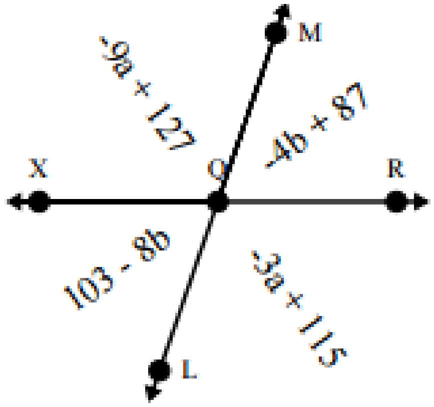


Figure 20. Example geometry problem 2 (Common Core Sheets, 2015).

In fact, it is arguably true that, generally, the skills taught in a particular grade level have real-life applications only for individuals far beyond that grade level. For example, a twelfth-grader learning calculus likely would not have a need to use calculus in his/her life outside of school until entering a post-college career, meaning the genuine real-life application occurs several years after initially learning calculus. Hence, when attempting to personalize problems to students' interests or even just when attempting to find any real-life application of a mathematical skill, it is sometimes difficult to match the content to an age-appropriate application without forcing fabricated contexts on problems. Future work with TPWPs could perhaps first consider which types of interest categories naturally apply to particular mathematical learning standards and then only offer those interest categories as choices, as opposed to offering the most popular interest categories for all mathematics standards.

Potential of TPWPs to positively affect learning. Even if it is determined that certain content could potentially be applied to word problems across different interest categories, some content may not benefit from personalization due to the nature of the particular skills. For example, consider the problem*: The equation 3(5+x) can be simplified as 3(5)+3x. Which property describes how this equation was simplified? A) associative, B) distributive, C) commutative.* The stem could potentially be rewritten so that the equation modeled a real-life situation relevant to a particular interest category, but identifying the mathematical property used to simplify an equation may be a skill that would not necessarily be affected by personalization because of how the core skill of the question (i.e., identifying the property) is irrelevant to the context in which the equation is presented, though future research would need to confirm this hypothesis.

The need for expert knowledge in interest categories. When particular mathematical content is determined appropriate for personalization, it may be necessary to consult experts in the relevant interest categories in addition to consulting with mathematics content experts. For example, persons with expertise in science or sports may have better ideas about meaningful applications of mathematics in science or sports, respectively, beyond what a mathematics teacher may know depending on the teacher's background and interest. This need to consult with experts in various interest categories can be challenging and time-consuming; yet, if not done, TPWPs may only have surface-level personalization that is not meaningful to the particular category. Also challenging is that experts within interest categories may not be familiar with the mathematical skills and prior knowledge students have in particular grade levels, thus making it difficult for experts to suggest meaningful mathematical applications that are grade-level appropriate. Inevitably, experts from various interest categories and mathematics content experts need to collaborate in order to create meaningful TPWPs.

When to assume interest-specific prior knowledge. Yet another challenge with using TPWPs is the question of when it should or not be assumed that the student has particular prior knowledge in the interest category. In typical instructional materials, either no prior context knowledge is assumed (although prior mathematical knowledge may be assumed) or the necessary background information is provided for the student. For example, if a student selects sports as the interest category, should it be assumed that the student knows what it means to gain or lose yards in football? If no prior knowledge is assumed, then word problems would become lengthy by providing all of the necessary background knowledge. Yet, if some prior knowledge was assumed, it is possible that TPWPs would be more difficult for students if that assumption was false because then students would not have sufficient prior context knowledge permitting correct interpretation of the TPWP.

Possible novelty effect. As is often the case with new pedagogical strategies, there is the possibility that the ability for TPWPs to trigger situational interest may have a novelty effect whereby students initially find TPWPs interesting and then that effect wears off after repeated exposure to TPWPs. Although future research would need to explore whether such an effect exists, teachers could potentially reduce the effect of novelty by minimizing the frequency with which students were exposed to TPWPs. Using a variety of instructional strategies to trigger situational interest, including TPWPs and other techniques, could help maintain the novelty—and, hence, effectiveness—of those strategies as compared to repeatedly using the same strategy for triggering situational interest.

Challenges with Using Technology to Create TPWPs

Although TPWPs can be created without the use of computer technology (for example, a teacher could write individual TPWPs based on the teacher's knowledge of the students and community), TPWPs in this study were created with the aid of computer technology which relied on programmatically substituting students' names and friends' names into templates of items based on the responses students provided. Computer-generating TPWPs – whether for research or practice – presents challenges related to students' entering inaccurate interest questionnaire responses, modifying the context of the problem in a meaningful way, and considering gender pronouns.

Inaccurate interest survey responses. Allowing students to enter responses that then populate templates for TPWPs can be problematic in several ways. First, students may not read or follow directions, resulting in students entering different responses than intended by the directions. For example, based on a visual inspection of name responses provided in this study, it appeared that a handful of students may have entered a first and last name instead of their name and a friend's name. Also, in some cases, students only entered an initial instead of a full name or did not use proper capitalization on names (e.g., entering names in all lowercase or all uppercase letters). Additionally, some students entered inappropriate terms or symbols into text boxes for their names and friends' names. In a few additional cases, students entered the same name for themselves as the name entered for the friend's name, which would result in a nonsensical word problem instead of one intended to compare two people. In these cases, the resulting TPWPs would likely be more difficult than a generic word problem because of nonsensical content in the stem of the TPWP resulting from programmatically substituting incorrect or non-meaningful names.

It is possible that some of these issues could be avoided by providing automatic error messages after students entered responses, such as “Please use a different name for yourself and your friend” or “Please do not use any numbers in your name”, and capitalization issues could be automatically fixed by changing the text so that the first letter was capitalized and all other letters were lowercase. Some other issues, however, would likely not be easily identifiable by a computer, such as when a student entered his/her last name instead of a friend’s name. Also, as students learn that their responses are populating word problems, some students may be tempted to provide inappropriate responses due to the potential humor found in seeing inappropriate mathematical word problems. This type of behavior could be reduced with some teacher or parent oversight, but the amount of time for an adult to check student responses may not be feasible.

Modifying context of problem. Another challenge related to using computers to generate TPWPs relates to modifying the context of the problem. In this study, problems were manually written for each interest category, which had the limitation of only broadly personalizing problems to students’ interests. It is possible that future work could mine data from other student activities to collect more detailed information on interests and then use natural language generation methods to populate models of problems. For example, in the case of educational technology programs, if students were asked to rate their interest in problems, as they were in this study, the educational technology could adapt future curriculum for individual students based on accumulating interest data and learning, so to speak, what the student findings interesting.

Use of gender pronouns. In this study, pronouns for gender (e.g., he/she, his/her) were not manipulated, as students were not asked to indicate their gender. Problems instead avoided use of any gender pronouns. This led to some awkward phrasing of item stems because the student's name was repeated instead of using a he/she pronoun. A more advanced TPWP generator could ask the student to report his/her gender on the interest survey, which could include the option to report preference for use of gender-neutral pronoun (e.g., they, them), and substitute pronouns appropriately.

Challenges with Conducting Research on TPWPs

In addition to challenges with using TPWPs as an instructional strategy, several challenges exist related to conducting research on TPWPs due to the need to have matched sets of generic word problems and TPWPs. In order to create matched pairs of TPWPs and generic word problems for research purposes, careful attention must be paid to several features of the item (e.g., text complexity of stem, characteristics of numbers used, mathematical content, etc.) as was done in this study. To understand the level of challenge demanded by this task, consider an item that required that a student solve the equation $2x+8=20$ with a distractor $x=14$, where that distractor is based on the student mistake of adding 20 and 8 before dividing by 2 (i.e., solving $2x=28$). Now, when considering writing a matched equation to $2x+8=20$ that has similar numbers, the equation $3x+6=14$ might be a possibility. Both equations are two-step equations with positive numbers; the coefficient and the constant are single-digit numbers; and the number on the right side of the equation is a two-digit number. Yet, if the same distractor rationale whereby the student added the constant terms together before dividing by the coefficient was applied to the second equation, the resulting equation would be $3x=20$ and hence $x=6.67$. Now, due to applying the same distractor rationale, the attempt at the matched equation has a decimal in the answer choices which likely makes the two items function differently for students or possibly no longer match the appropriate grade-level standard.

The aforementioned example is merely one illustrative sample of the challenge of creating matched problems, and that example only considered the challenge of matching numbers without regard to the word problem context. For TPWPs, the numbers must also be applicable to all of the interest categories in a realistic way. For example, consider the real-life TPWPs presented in Table 27 that utilize factual data and focus on the mathematical skill of calculating a unit rate. These problems have the benefit of including facts relevant to the interest categories that may result in a genuine student desire to solve the problem, for example if a student genuinely wanted to know how many points per game Michael Jordan scored during his career, as in the case in the sports example. These problems show how it is possible to achieve somewhat similar numbers across different interest categories and within the same mathematical skill, yet there are still differences between numbers. To mention one difference, the science and animals problems involve dividing a four-digit number by a two-digit number, but the sports and history problems have a three-digit divisor. Subtle differences in numbers can affect item difficulty (Simpson et al., 2015), however previous research has shown that differences in number types affect item difficulty less as students become higher ability (e.g., the difference between dividing a three-digit or four-digit number might be significant for a fourth-grader but may not matter for a seventh-grader; Kosh, Simpson, & Bickel, 2015). The questions then becomes “to what extent should numbers be matched?” and “what criteria would constitute numbers as sufficiently matched?”. Matching for all possible characteristics of numbers is arguably impossible because there will also be a more fine-grained characteristic of numbers that differences (e.g., are the numbers 15 and 16 matched because they are consecutive, or are the numbers 15 and 20 matched because they are both multiples of 5?). And, even after numbers and context are determined, care must be paid to the length of the stem and the vocabulary level of the words in the stem in order to achieve stems with similar text complexity.

Table 27

Example TPWPs with Factual Data

Interest Category	Example Real-Life Problem
Sports	During the beginning of Michael Jordan’s professional career, he scored 8,630 points in 327 games. About how many points per game did Michael Jordan score?
History	During Lewis’s and Clark’s expedition from North Dakota to the Pacific Ocean and back, the men traveled about 7,000 miles in 860 days. About how many miles per day did they travel?
Science	A satellite can complete 34 orbits around the earth in 3,065 minutes. About how many minutes per orbit does the satellite travel?
Animals	A great white shark holds the record for the fastest migration from South Africa to Australia. The shark swam 6,900 miles in 99 days. About how many miles did the shark swim per day?

In summary, in order to improve research designs to investigate the effects of TPWPs on any student outcome (e.g., achievement, engagement, etc.) it is necessary to have an equivalent control group. In the case of this study, the control group was a set of generic word problems matched to the TPWPs. Yet, the challenge with conducting research on TPWPs is that the underlying theory behind why TPWPs might be beneficial to students is because they allow for customization to the students’ interests beyond what a generic word problem can do; it is this customization that is hindered by the research design due to the need to create pairs of equivalent items. When attending to so many details of the problems in order to create equivalent pairs, there may be little room left for variation according to the interest category.

Limitations of the Present Research Design

Besides the overarching challenges of conducting research on TPWPs, there were also specific limitations associated with this study.

Data collected after instruction occurred. As a first limitation, data for this study were collected the summer following the grade level in which the mathematical skills of the items were taught, assuming that students' curriculum during seventh-grade was aligned to the seventh-grade CCSSM. It is possible that student performance benefits of TPWPs would only occur during introduction to new material because, perhaps, students have already solidified their ideas and processes for mathematical skills by the time instruction ends.

Limitations of the interest categories. A second limitation of this study relates to how the interest categories where developed, where responses to the question "What do you want to read about?" were coded to identify themes in students' interests. Results from this method indicated a wide range of sub-interests within an interest category (e.g., ice skating, motocross, and football were all coded as sports), thus possibly indicating that the level of granularity in the interest categories was not fine-grained enough to sufficiently match to students' interests. For example, a student may select "sports" as the interest category because he or she enjoys tennis. But, if all of the sports-targeted problems were about soccer, baseball, football, and basketball, then the student would not have received a context targeted to his or her main interest. Similarly, a student may not have been interested in any of the available categories. Also, relying on responses to the question "What do you want to read about today?" could yield different responses for students' interests in reading as compared to topics students might want to see in mathematics problems. Finally, the interest category that was identified in inductive coding but removed from the study, history, was also the category with the greatest frequency of coded responses, thus perhaps removing a large percentage of students' first-choice topic interests.

Limitations of the participant sample. Another limitation relates to the sample obtained for the study. Students voluntarily participated in the SMC, and participation rates tended to decrease as the program progressed throughout the six-weeks of the SMC. Thus, the students that completed all three sessions of data collection – and hence were more strongly represented in data analysis – for this study were possibly more intrinsically motivated and potentially higher-achieving students as compared to the general population of middle school students. Additionally, in order to access the SMC, students had to have internet access and access to computers over the summer, which could have resulted in a sample of participants that excluded students of lower socioeconomic status who may not have had access to such resources. Furthermore, the study only included one grade level of students, and students' grade level was self-reported. It is possible that some students enrolled in the SMC as a rising eighth-grader were actually enrolled in a different grade in school.

Possible Hawthorne effect. The Hawthorne effect (Cook, 1962) is when study participants may modify their behavior when they know they are in a treatment group for a research study. In this study, due to Institutional Review Board requirements, students were informed they were participating in a research study. Also, due to the need to explain to parents and students why data were being collected about students' interests, students' names, and students' friends' names, students were told that they would receive word problems customized to their interests. Due to this transparency, it is possible that students guessed the purpose or hypothesis of the research study and were more likely to rate TPWPs as interesting because students perceived that was the behavior that aligned to the research hypothesis.

Future Research

Directions for future research could include both modifying the existing study to reduce the aforementioned limitations as well as posing additional research questions.

Modifications to research design in this study. The limitations of this study could be addressed with future research in at least five ways. For one, a study could be situated in the context of students learning new material as opposed to reviewing material the summer after the school year in which it was taught. Second, relatedly, a study could use a between-subjects design that randomly assigned students to a personalized condition or a control condition, where the personalized condition focused on instruction of new material with personalization. Third, a student interest inventory in mathematics could be used as a level-2 predictor to control for students' overall interest in mathematics, which would help clarify results about how personalization, interest, and performance relate to each other. Fourth, the level-2 variable used in the present study, perceived student ability, could also be replaced with a more reliable measure with valid inferences of study ability, as opposed to the minimally-informative measure in this study that merely asked whether the child generally found math at grade level easy, about average, or difficult. Fifth, a study could separate the effects of incidental personalization and topic personalization in order to avoid confounding the two types of personalization by offering four types of problems to students: 1) generic word problems, 2) word problems personalized only with incidental features, 3) word problems personalized only to interest category, and 4) word problems personalized both to interest categories and with incidental personalization as well. This type of design would allow estimates of main effects for incidental and topic personalization as well as the interaction (i.e., combination) of both incidental and topic personalization.

Exploring the possible mechanism of action. The mechanism of action, presented in Chapter 1, theorized that students might perform better when receiving TPWPs as compared to generic word problems because TPWPs would trigger situational interest and hence capitalize upon the heightened attention, increased affect, and reduced extrinsic cognitive load associated with situational interest (Ainley, Hidi, & Berndorff, 2002; Hidi & Renninger, 2006; Hidi & Ainley, 2008; McDaniel, Waddil, Finstad, & Bourg; 2000; Yen, Chen, Lai, & Chuang, 2015; Park, 2015). Although TPWPs predicted a greater likelihood of rating a problem as interesting and hence provided evidence that TPWPs triggered situational interest, no statistically significant effect was found for the effect of TPWPs on student performance beyond the effect of interest. Future research could collect data on these outcomes of situational interest (e.g., heightened attention, increased affect, and reduced extrinsic cognitive load) in both the case of TPWPs and other means of triggering situational interest in order to further understanding about when situational interest may or may not lead to improved student performance or learning outcomes. Such research would help educators better understand how to trigger students' situational interest in ways that would effectively and efficiently improve student learning.

Effects of TPWP on variables besides student performance. I focused on the effect of TPWPs on student performance, including accuracy and speed of answering word problems.

It is possible that TPWPs may positively affect other variables, such as students' overall interest in mathematics, student engagement in mathematics activities, or students' perceptions about the relevance of mathematics to their personal lives. In fact, although not formally explored in this study as a research question, data cleaning revealed that many students completed the data collection instrument more than once by completing the instrument for a particular interest category and then completing it again for a different interest category, possibly indicating an engagement effect. No formal conclusions can be drawn from this, however, because no comparison data were included in this study about how many students may or may not have also repeated other activities in the SMC.

Future research could investigate effects of TPWPs on variables beyond student performance, for example by randomly assigning students to either receive TPWPs or generic word problems and then providing an instrument after administering the problem to measure students' perceptions about mathematics (e.g., an instrument that asked students to agree or disagree to statements such as "I believe I will need to use math in my career" or "The skills I learn in math class are important"). Relatedly, if researchers were trying to increase students' feelings of mathematics as a beneficial field of study, problems could be personalized according to students' career goals (A. Stenner, personal communication, September 21, 2015). For example, if a student indicated wanting to be a doctor, that student would receive word problems reflecting the type of mathematics doctors do in their everyday jobs. Another example, related to collecting data on student engagement, is to assign participants to receive either all TPWPs or all generic word problems and see if students receiving TPWPs complete more problems than students receiving generic word problems, thus indicating how many problems students voluntarily completed in a low-stakes environment. Variables such as these (e.g., perceptions about mathematics, engagement) may have a future effect on achievement or on the likelihood of students pursuing advanced mathematics training or entering careers with a mathematical focus.

Potential applications of TPWPs in student assessment. Although TPWPs were posed as a potential instructional strategy in the context of this study, TPWPs may also have applications in assessment of student learning. The use of TPWPs on assessment could potentially increase student motivation for completing test items; future research could use response time data to identify if students are possibly less likely to rapidly guess on TPWPs as compared to generic problems. As a first step, however, the psychometric properties of matched items in different interest categories should be compared to ensure that items across different interest categories function similarly psychometrically. For example, a student receiving a set of TPWPs about sports and a different student receiving a set of TPWPs about animals would need to receive comparably difficult items in order to produce fair, parallel tests. Future research would need to investigate these psychometric properties, likely beginning with the use of TPWPs on low-stakes tests.

Summary

The purpose of this study was to investigate student performance on TPWPs in middle school mathematics by 1) determining how TPWPs related to students' ratings of problems as interesting or not, 2) determining how TPWPs and interest ratings related to correct response to word problems, and 3) exploring how TPWPs affected the amount of time students spent solving problems. Using a sample of 343 rising eighth-graders completing approximately 6,000 items, results indicated that TPWPs triggered students interests as compared to matched generic problems and that students were more likely to answer problems correctly when students rated the problem as interesting. No evidence was found that students were more likely to answer TPWPs correctly after accounting for other control variables, including interest ratings; however, students were more likely to answer word problems correctly when students found the problems interesting. No evidence was found for an effect of TPWPs on response time. Results suggest the strong role of student interest in particular word problems as a predictor of student performance on those same problems.

In this final chapter, I discussed challenges of developing TPWPs and conducting research with TPWPs, such as the difficulty of modifying word problems to match a wide range of students' interests and developing matched generic word problems with a sufficient level of comparability to TPWPs. I also delineated limitations of the research, including the fact that data collection occurred after instruction of mathematics concepts as opposed to during learning new material, the broad nature of the interest categories, a rather homogenous sample with respect to ability and motivation, and a possible Hawthorne effect. Future research should consider additional predictor variables (e.g., a more detailed ability measure or an overall interest measure) and possibly consider how TPWPs affect other outcome variables besides accuracy and response time, such as student engagement or students' perceptions of mathematics as an important topic of study.

Despite the limitations of the present study and the challenges with producing TPWPs, the results of this research support the possible role that educators can have on students' mathematics learning when they incorporate strategies to heighten student interest and engagement in mathematics. Results indicated that student performance – as measured by mathematical accuracy – was predicted by students' interest in the mathematics content.

Thus, when educators, parents, or curriculum developers incorporate strategies to raise student interest in content, students may demonstrate greater academic performance. It is possible that this result extends to content areas beyond mathematics, and stakeholders should investigate means of increasing student interest and engagement beyond the strategy that was investigated in the present study (i.e., TPWPs), particularly because of the resource-intensive nature of writing word problems for multiple interest categories and the limited amount of personalization that can be achieved with using a computer-based template approach to TPWP generation. For example, educators could incorporate a variety of informal learning activities, real-life applications, classroom games, innovative and exciting new technology, and other means to trigger students' situational interest and eventually lead students toward a well-developed interest in mathematics.

APPENDIX A: RECRUITMENT EMAILS

Session One Recruitment Email

Welcome back to the Summer Math Challenge for Real-World Wednesday!

Today your child will have an exciting opportunity to practice unit rates with real-life problems customized to his or her interests! Is your child a sports fan, animal lover, budding scientist, world explorer, or pop culture enthusiast?

We are piloting new educational technology that will provide your child with personalized real-life problems that are tailored to his or her interests. Today's activity is part of a research study about how to design more effective learning materials for students.

Your child's participation is voluntary, and all results will be anonymous. We hope your child will participate so that we can better understand how students learn mathematics best. Here are the directions your child should follow:

- Click the link below.
- Complete the interest survey with three questions.
- You will be given 12 real-life problems, one at a time.
- Work independently to see how many questions you can answer correctly.

After completing the activity, your child will see how many problems he or she answered correctly.

Session Two Recruitment Email

Welcome back to the Summer Math Challenge for Real-World Wednesday!

Today your child will have an exciting opportunity to practice integer operations with real-life problems customized to his or her interests! Is your child a sports fan, animal lover, budding scientist, world explorer, or pop culture enthusiast?

We are piloting new educational technology that will provide your child with personalized real-life problems that are tailored to his or her interests. Today’s activity is the second part of a research study about how to design more effective learning materials for students.

Your child’s participation is voluntary, and all results will be anonymous. We hope your child will participate so that we can better understand how students learn mathematics best.

Here are the directions your child should follow:

- Click the link below.
- Complete the interest survey with three questions.
- You will be given 12 real-life problems, one at a time.
- Work independently without a calculator to see how many questions you can answer correctly.

After completing the activity, your child will see how many problems he or she answered correctly.

Session Three Recruitment Email

Welcome back to the Summer Math Challenge for Real-World Wednesday!

Today your child will have an exciting opportunity to practice equations and inequalities with real-life problems customized to his or her interests! Is your child a sports fan, animal lover, budding scientist, world explorer, or pop culture enthusiast?

We are piloting new educational technology that will provide your child with personalized real-life problems that are tailored to his or her interests. Today's activity is part of a research study about how to design more effective learning materials for students.

Your child's participation is voluntary, and all results will be anonymous. We hope your child will participate so that we can better understand how students learn mathematics best.

Here are the directions your child should follow:

- Click the link below.
- Complete the interest survey with three questions.
- You will be given 12 real-life problems, one at a time.
- Work independently to see how many questions you can answer correctly.

After completing the activity, your child will see how many problems he or she answered correctly.

APPENDIX B: ITEMS USED FOR DATA COLLECTION

Note: Throughout this appendix, some items are not shown, as indicated by "Redacted" in the tables, in order to retain test security for items in possible current use. The key always occurs in position A in these tables, although key position was randomized in the data collection instrument.

Session One Items

Table B1

Generic Problem One and Matched TPWPs in Session One

Problem type	Item
Generic	Redacted
Sports	*Student Name* wants to buy soccer trophies for a group of friends. Which price for soccer trophies is the ***lowest*** unit price? A) $92.40 for 14 soccer trophies B) $138.00 for 20 soccer trophies C) $86.40 for 12 soccer trophies D) $61.60 for 8 soccer trophies
Animals	*Student Name* wants to buy dog collars for an animal shelter. Which price for dog collars is the ***lowest*** unit price? A) $92.40 for 14 dog collars B) $138.00 for 20 dog collars C) $86.40 for 12 dog collars D) $61.60 for 8 dog collars
Science and Technology	*Student Name* wants to buy beakers for a science lab. Which price for beakers is the ***lowest*** unit price? A) $92.40 for 14 beakers B) $138.00 for 20 beakers C) $86.40 for 12 beakers D) $61.60 for 8 beakers
Music, Movies, and Television	*Student Name* wants to download music albums. Which price for album downloads is the ***lowest*** unit price? A) $92.40 for 14 albums B) $138.00 for 20 albums C) $86.40 for 12 albums D) $61.60 for 8 albums
Travel	*Student Name* wants to buy tickets for a group of friends to ride cable cars in San Francisco. Which price for tickets is the ***lowest*** unit price? A) $92.40 for 14 tickets B) $138.00 for 20 tickets C) $86.40 for 12 tickets D) $61.60 for 8 tickets

Table B2

Generic Problem Two and Matched TPWPs in Session One

Problem type	Item
Generic	Redacted
Sports	*Student Name* made 57 hockey goals in a 12-month period. *Friend Name* made 39 hockey goals in the same period of time. On average, how many more hockey goals per month did *Student Name* make than *Friend Name*? A) 1.5 goals per month B) 0.67 goals per month C) 4.75 goals per month D) 18 goals per month
Animals	By *Student Name*'s house, 57 baby birds hatched in a 12-week nesting period. By *Friend Name*'s house, 39 baby birds hatched in the same 12-week nesting period. On average, how many more birds per week hatched near *Student Name*'s house than near *Friend Name*'s house? A) 1.5 birds per week B) 0.67 birds per week C) 4.75 birds per week D) 18 birds per week
Science and Technology	*Student Name* analyzed 57 bacteria samples in a 12-month period. *Friend Name* analyzed 39 bacteria samples in the same period of time. On average, how many more bacteria samples per month did *Student Name* analyze than *Friend Name*? A) 1.5 samples per month B) 0.67 samples per month C) 4.75 samples per month D) 18 samples per month
Music, Movies, and Television	*Student Name* watched 57 episodes of a favorite TV show in a 12-month period. *Friend Name* watched 39 episodes of the show in the same period of time. On average, how many more episodes of the TV show per month did *Student Name* watch than *Friend Name*? A) 1.5 episodes per month B) 0.67 episodes per month C) 4.75 episodes per month D) 18 episodes per month
Travel	*Student Name* mailed 57 postcards in a 12-month period. *Friend Name* mailed 39 postcards in the same period of time. On average, how many more postcards per month did *Student Name* mail than *Friend Name*? A) 1.5 postcards per month B) 0.67 postcards per month C) 4.75 postcards per month D) 18 postcards per month

Table B3

Generic Problem Three and Matched TPWPs in Session One

Problem type	Item
Generic	Phyllis studied world history for 5 $\frac{1}{4}$ hours over a 7-day period. On average, how many ***minutes*** did Phyllis study per day? A) 45 minutes (Key) B) 37 minutes (Student multiplied 5.25*7 and rounded up) C) 75 minutes (Student divided 5.25 by 7 and did not convert to minutes) D) 80 minutes (Student divided 7 by 5.25 and then multiplied by 60.)
Sports	*Student Name* swam for 2 $\frac{3}{4}$ hours over a 5-day period. On average, how many ***minutes*** did *Student Name* swim per day? A) 33 minutes B) 14 minutes C) 55 minutes D) 109 minutes
Animals	*Student Name* trained a horse for 2 $\frac{3}{4}$ hours over a 5-day period. On average how many ***minutes*** did *Student Name* train the horse per day? A) 33 minutes B) 14 minutes C) 55 minutes D) 109 minutes
Science and Technology	*Student Name* used a telescope to observe stars for 2 $\frac{3}{4}$ hours over a 5-day period. On average, how many ***minutes*** did *Student Name* observe stars per day? A) 33 minutes B) 14 minutes C) 55 minutes D) 109 minutes
Music, Movies, and Television	*Student Name* watched movies at a movie theater for 2 $\frac{3}{4}$ hours over a 5-day period. On average, how many ***minutes*** did *Student Name* watch movies per day? A) 33 minutes B) 14 minutes C) 55 minutes D) 109 minutes
Travel	*Student Name* spent 2 $\frac{3}{4}$ hours at a park in London over a 5-day period. On average, how many ***minutes*** did *Student Name* spend at the park per day? A) 33 minutes B) 14 minutes C) 55 minutes D) 109 minutes

Table B4

Generic Problem Four and Matched TPWPs in Session One

Problem type	Item
Generic	Redacted
Sports	*Student Name* purchased 45 ounces of a sports energy drink for $6.30. *Friend Name* purchased 20 ounces of the drink for $3.20. How much more per ounce did *Friend Name* spend than *Student Name*? A) $0.02 per ounce B) $0.12 per ounce C) $0.14 per ounce D) $0.08 per ounce
Animals	*Student Name* purchased a 45-ounce bag of cat food for $6.30. *Friend Name* purchased a 20-ounce bag for $3.20. How much more per ounce did *Friend Name* spend than *Student Name*? A) $0.02 per ounce B) $0.12 per ounce C) $0.14 per ounce D) $0.08 per ounce
Science and Technology	*Student Name* purchased a box of fossil samples for $6.30 that weighed 45 ounces. *Friend Name* purchased a box for $3.20 that weighed 20 ounces. How much more per ounce did *Friend Name* spend than *Student Name*? A) $0.02 per ounce B) $0.12 per ounce C) $0.14 per ounce D) $0.08 per ounce
Music, Movies, and Television	*Student Name* purchased a 45-ounce bag of movie popcorn for $6.30. *Friend Name* purchased a 20-ounce bag for $3.20. How much more per ounce did *Friend Name* spend than *Student Name*? A) $0.02 per ounce B) $0.12 per ounce C) $0.14 per ounce D) $0.08 per ounce
Travel	*Student Name* purchased a 45-ounce bag of green tea in Japan for $6.30. *Friend Name* purchased a 20-ounce bag for $3.20. How much more per ounce did *Friend Name* spend than *Student Name*? A) $0.02 per ounce B) $0.12 per ounce C) $0.14 per ounce D) $0.08 per ounce

Table B5

Generic Problem Five and Matched TPWPs in Session One

Problem type	Item
Generic	Redacted
Sports	*Student Name* made 12 shots from half-court in a 60-minute practice session. Which equation can be used to find the average number of minutes, *x*, it takes *Student Name* to make one shot from half-court? A) $60 = 12x$ B) $(60)(12) = x$ C) $\frac{12}{60} = x$ D) $60 = x + 12$
Animals	*Student Name* can wash 12 dogs in 60 minutes. Which equation can be used to find the average number of minutes, *x*, it takes *Student Name* to wash one dog? A) $60 = 12x$ B) $(60)(12) = x$ C) $\frac{12}{60} = x$ D) $60 = x + 12$
Science and Technology	*Student Name*'s new 3D printer can print 12 projects in 60 minutes. Which equation can be used to find the average number of minutes, *x*, it takes the printer to print one project? A) $60 = 12x$ B) $(60)(12) = x$ C) $\frac{12}{60} = x$ D) $60 = x + 12$
Music, Movies, and Television	*Student Name* can memorize the lyrics to 12 favorite songs in 60 minutes. Which equation can be used to find the average number of minutes, *x*, it takes *Student Name* to memorize the lyrics of one song? A) $60 = 12x$ B) $(60)(12) = x$ C) $\frac{12}{60} = x$ D) $60 = x + 12$
Travel	*Student Name* visited 12 museum exhibits in Washington, D.C. in 60 minutes. Which equation can be used to find the average number of minutes, *x*, *Student Name* spent visiting one exhibit? A) $60 = 12x$ B) $(60)(12) = x$ C) $\frac{12}{60} = x$ D) $60 = x + 12$

Table B6

Generic Problem Six and Matched TPWPs in Session One

Problem type	Item
Generic	A scooter traveled 100 meters in 12 seconds. Which was the scooter's average speed? A) 8.33 m/s (Key) A) 0.12 m/s (Student divided 12/100.) C) 12.0 m/s (Student used number for time.) D) 20.0 m/s (Student used 12 seconds as 1/5 a minute = 20 seconds and confused the units.)
Sports	Redacted
Animals	*Student Name*'s pet lizard ran 100 meters in 15 seconds. Which was the lizard's average speed? A) 6.67 m/s B) 0.15 m/s C) 15.0 m/s D) 25.0 m/s
Science and Technology	In physics class, *Student Name* calculated that a ball rolled 100 meters in 15 seconds. Which was the ball's average speed? A) 6.67 m/s B) 0.15 m/s C) 15.0 m/s D) 25.0 m/s
Music, Movies, and Television	*Student Name* saw a popular musician in Hollywood and ran 100 meters in 15 seconds to get an autograph. Which was *Student Name*'s average speed? A) 6.67 m/s B) 0.15 m/s C) 15.0 m/s D) 25.0 m/s
Travel	While white water rafting in the Amazon, *Student Name*'s raft traveled 100 meters in 15 seconds. Which was the raft's average speed? A) 6.67 m/s B) 0.15 m/s C) 15.0 m/s D) 25.0 m/s

Session Two Items

Table B7

Generic Problem One and Matched TPWPs in Session Two

Problem type	Item
Generic	A mountain has an elevation of 5,797 feet above sea level. A cave has an elevation of 275 feet below sea level. Which is the difference in these elevations? A) 6,072 feet (Key) B) 5,522 feet (Student subtracted 5,797-275) C) 5,972 (Student did not regroup in hundreds place correctly) D) 5,797 (Student used number in stem)
Sports	*Student Name* trained for the Olympics at the high-altitude city of Flagstaff, Arizona at 6,989 feet above sea level. *Friend Name* trained for the Olympics in Death Valley, California at an altitude of 282 feet below sea level. Which is the difference in these elevations? A) 7,271 feet B) 6,707 feet C) 7,171 feet D) 6,989 feet
Animals	*Student Name* saw an eagle at an altitude of 6,989 feet above sea level. *Friend Name* saw a mountain lion in a valley at an altitude of 282 feet below sea level. Which is the difference in these elevations? A) 7,271 feet B) 6,707 feet C) 7,171 feet D) 6,989 feet
Science and Technology	*Student Name* has much less oxygen at an elevation of 6,989 feet above sea level than *Friend Name* has at an elevation of 282 feet below sea level. Which is the difference in these elevations? A) 7,271 feet B) 6,707 feet C) 7,171 feet D) 6,989 feet
Music, Movies, and Television	Movie star *Student Name* filmed an action scene on a mountain at an elevation of 6,989 feet above sea level. *Friend Name* filmed a deep sea scene at an elevation of 282 feet below sea level. Which is the difference in these elevations? A) 7,271 feet B) 6,707 feet C) 7,171 feet D) 6,989 feet
Travel	*Student Name* visited a peak in California at an elevation of 6,989 feet above sea level. *Friend Name* visited the lowest point in California, Death Valley, at an elevation of 282 feet below sea level. Which is the difference in these elevations? A) 7,271 feet B) 6,707 feet C) 7,171 feet D) 6,989 feet

Table B8

Generic Problem Two and Matched TPWPs in Session Two

Problem type	Item
Generic	Joanna saved \$13 to go out to lunch with her friends. She paid \$7 for the lunch. Which expression could be used to find the amount of money Joanna had after lunch? A) $13 + (-7)$ (Key) B) $-13 + (-7)$ (Student confused sign on first operand.) C) $-13 + 7$ (Student confused sign on both operands.) D) $13 + 7$ (Student confused sign on second operand.)
Sports	Redacted
Animals	At a zoo, 12 baby tigers were born. Zookeeper *Student Name* released 8 tigers to the wild. Which expression could be used to find the number of tigers at the zoo after the release? A) $12 + (-8)$ B) $-12 + (-8)$ C) $-12 + 8$ D) $12 + 8$
Science and Technology	*Student Name* read about an ion that has 12 electrons with a negative electrical charge and 8 protons with a positive electrical charge. Which expression could be used to find the net electrical charge of the ion? A) $12 + (-8)$ B) $-12 + (-8)$ C) $-12 + 8$ D) $12 + 8$
Music, Movies, and Television	*Student Name* saved \$12 to see a newly-released movie. The cost of the movie was \$8. Which expression could be used to find the amount of money *Student Name* has in savings after the movie purchase? A) $12 + (-8)$ B) $-12 + (-8)$ C) $-12 + 8$ D) $12 + 8$
Travel	*Student Name* added 12 gallons of gas to a car for a trip to the beach. The car used 8 gallons on the trip. Which expression could be used to find the number of gallons of gas in the car after the trip? A) $12 + (-8)$ B) $-12 + (-8)$ C) $-12 + 8$ D) $12 + 8$

Table B9

Generic Problem Three and Matched TPWPs in Session Two

Problem type	Item
Generic	Redacted
Sports	The outside temperature was 24°F when *Student Name* went snowboarding. The next day the temperature dropped to -4°F. How many degrees did the temperature drop? A) 28°F B) 96°F C) 20°F D) 6°F
Animals	*Student Name* measured the temperature in a polar bear zoo exhibit as 24°F. That night the temperature dropped to -4°F. How many degrees did the temperature drop? A) 28°F B) 96°F C) 20°F D) 6°F
Science and Technology	*Student Name* measured the temperature of a substance as 24°F. For an experiment, the temperature of the substance needed to be -4°F. How many degrees did *Student Name* need the temperature to drop? A) 28°F B) 96°F C) 20°F D) 6°F
Music, Movies, and Television	The temperature was 24°F when *Student Name* was in line to buy tickets to see a favorite band. That night the temperature dropped to -4°F. How many degrees did the temperature drop? A) 28°F B) 96°F C) 20°F D) 6°F
Travel	During *Student Name*'s trip to Alaska, the temperature was 24°F during the day. That night the temperature dropped to -4°F. How many degrees did the temperature drop? A) 28°F B) 96°F C) 20°F D) 6°F

Table B10

Generic Problem Four and Matched TPWPs in Session Two

Problem type	Item
Generic	Redacted
Sports	The attendance at *Student Name*'s school's championship baseball game decreased by 80 people over a period of 4 years. Which is the average yearly change in the number of people at the game? A) -20 people B) -320 people C) -80 people D) -4 people
Animals	*Student Name*'s research showed that the number of bears in a region decreased by 80 bears over a period of 4 years. Which is the average yearly change in the number of bears? A) -20 bears B) -320 bears C) -80 bears D) -4 bears
Science and Technology	*Student Name* tracked the price of tablet computers. The cost of a new tablet decreased by $80 over a period of 4 years. Which is the average yearly change in the cost of the tablet computer? A) $-20 B) $-320 C) $-80 D) $-4
Music, Movies, and Television	*Student Name* tracked the price of backstage passes to a concert. The cost of a backstage pass decreased by $80 over a period of 4 years. Which is the average yearly change in the cost of the backstage pass? A) $-20 B) $-320 C) $-80 D) $-4
Travel	Park ranger *Student Name* found that the number of visitors to a campground in Yosemite National Park decreased by 80 people over a period of 4 years. Which is the average yearly change in the number of visitors? A) -20 people B) -320 people C) -80 people D) -4 people

Table B11

Generic Problem Five and Matched TPWPs in Session Two

Problem type	Item
Generic	A helicopter began descending from 12 meters above sea level. The helicopter then landed in a canyon at 56 meters below sea level. Which is the number of meters that the helicopter descended? A) 68 meters (Key) B) 44 meters (Student did 56-12) C) 56 meters (Student used number in stem) D) 12 meters (Student used number in stem)
Sports	In hockey, players are rated by the goals scored for their team (a positive number) or the goals scored for the opposing team (a negative number) while the player is on the ice. *Friend Name*'s rating was 42 points scored by the opposing team. *Student Name*'s rating was 14 points scored by their team. Which is the difference in the ratings of FRIEND and *Student Name*? A) 56 points B) 28 points C) 42 points D) 14 points
Animals	*Student Name* found bats in a cave at 42 feet below sea level. *Student Name* then saw a fox at 14 feet above sea level. Which is the difference in the elevations of the animals? A) 56 feet B) 28 feet C) 42 feet D) 14 feet
Science and Technology	*Student Name* super-cooled a container of water to 42^{o} C below zero. The water was then heated to 14^{o} C above zero. Which is the number of degrees that the water temperature changed? A) 56 °C B) 28 °C C) 42 °C D) 14 °C
Music, Movies, and Television	*Student Name* borrowed $42 to see a movie and go to dinner. *Student Name* then mowed lawns and earned enough money to pay back the debt and still have $14. Which is the amount of money *Student Name* earned mowing lawns? A) $56 B) $28 C) $42 D) $14
Travel	*Student Name* traveled by boat and then dived to 42 feet below sea level to see the coral reefs in Australia. *Student Name*'s boat then returned to a port that was 14 feet above sea level. Which is the difference between the two elevations? A) 56 feet B) 28 feet C) 42 feet D) 14 feet

Table B12

Generic Problem Six and Matched TPWPs in Session Two

Problem type	Item
Generic	Theodore has $27 in his checking account. He deposits $4, takes out $12, and then deposits another $9. Which equation could be used to find the total amount of money in Theodore’s bank account? A) 27+4+(-12)+9=$28 (Key) B) 27+4-(-12)+9=$52 (Student included double negative for 12) C) 27+(-4)+12+(-9)=$26 (Student interchanged meaning of deposit and “takes out”) D) 27+(-4)+(-12)+(-9)=$2 (Student counted all bank actions as negative)
Sports	*Student Name* cheers for a favorite football team who is at the 25 yard line on a football field. The team gained 6 yards, lost 14 yards, and then gained another 3 yards. Which equation could be used to find the yard line the team is at now? A) 25+6+(-14)+3=20 yard line B) 25+6-(-14)+3= 48 yard line C) 25+(-6)+14+(-3)=30 yard line D) 25+(-6)+(-14)+(-3)=2 yard line
Animals	*Student Name* saw a monkey on a branch 25 feet above ground. The monkey jumped up 6 feet, swung down 14 feet, and then jumped up another 3 feet. Which equation could be used to find how many feet above ground the monkey is now? A) 25+6+(-14)+3=20 feet B) 25+6-(-14)+3=48 feet C) 25+(-6)+14+(-3)=30 feet D) 25+(-6)+(-14)+(-3)=2 feet
Science and Technology	During a science experiment, chemist *Student Name* measured the temperature of a chemical as 25^{o}F. *Student Name* raised the temperature by 6 ^{o}F, lowered it by 14 ^{o}F, and then raised it again by 3 ^{o}F. Which equation could be used to find the final temperature of the chemical? A) 25+6+(-14)+3= 20 ^{o}F B) 25+6-(-14)+3=48 ^{o}F C) 25+(-6)+14+(-3)=30 ^{o}F D) 25+(-6)+(-14)+(-3)=2 ^{o}F
Music, Movies, and Television	At the beginning of a tour, musician *Student Name* set concert ticket prices at $25. During the tour, *Student Name* then raised the price of the concert tickets by $6, decreased the price by $14, and then raised the price again by $3. Which equation could be used to find the final price of a ticket to see *Student Name*? A) 25+6+(-14)+3=$20 B) 25+6-(-14)+3=$48 C) 25+(-6)+14+(-3)-$30 D) 25+(-6)+(-14)+(-3)=$2
Travel	*Student Name* read that tickets to a popular art museum in Paris cost $25 in June. The tickets increased in price by $6 in July, decreased by $14 in August, and increased by $3 in September. Which equation could be used to find the price of the art museum tickets in September? A) 25+6+(-14)+3=$20 B) 25+6-(-14)+3=$48 C) 25+(-6)+14+(-3)=$30 D) 25+(-6)+(-14)+(-3)=$2

Session Three Items

Table B13

Generic Problem One and Matched TPWPs in Session Three

Problem type	Item
Generic	Redacted
Sports	*Student Name*'s hockey team has \$115 in a savings account now and wants to buy new hockey sticks for next season that cost \$320. The team plans to put \$14 into the savings account each month. The equation 14x + 115 = 320 models this situation, where x is the number of months the team saves. After how many months will *Student Name*'s hockey team have enough money for the new hockey sticks? A) 15 months B) 14 months C) 8 months D) 2 months
Animals	*Student Name* has \$115 in a savings account now and wants to sign up for horseback riding lessons that cost \$320. *Student Name* plans to put \$14 into the savings account each month. The equation 14x + 115 = 320 models this situation, where x is the number of months *Student Name* saves. After how many months will *Student Name* have enough money for the horseback riding lessons? A) 15 months B) 14 months C) 8 months D) 2 months
Science and Technology	*Student Name* has \$115 in a savings account now and wants to buy a microscope that costs \$320. *Student Name* plans to put \$14 into the savings account each month. The equation 14x + 115 = 320 models this situation, where x is the number of months *Student Name* saves. After how many months will *Student Name* have enough money for the microscope? A) 15 months B) 14 months C) 8 months D) 2 months
Music, Movies, and Television	*Student Name* has \$115 in a savings account now and wants to buy concert tickets for a group of friends that cost \$320. *Student Name* plans to put \$14 into the savings account each month. The equation 14x + 115 = 320 models this situation, where x is the number of months *Student Name* saves. After how many months will *Student Name* have enough money for the concert tickets? A) 15 months B) 14 months C) 8 months D) 2 months
Travel	*Student Name* has \$115 in a savings account now and wants to buy a plane ticket to Seattle that costs \$320. *Student Name* plans to put \$14 into the savings account each month. The equation 14x + 115 = 320 models this situation, where x is the number of months *Student Name* saves. After how many months will *Student Name* have enough money for the plane ticket? A) 15 months B) 14 months C) 8 months D) 2 months

Table B14

Generic Problem Two and Matched TPWPs in Session Three

Problem type	Item
Generic	Louise wants to rent a truck. The rental company charges a one-time $15 cleaning fee and a $7 hourly fee. Which inequality shows the greatest number of hours, *h*, Louise can rent a truck if she wants to pay less than $40? A) $7h+15<40$ (Key) B) $7h<40$ (Student left off term for cleaning fee.) C) $7+15h<40$ (Student confused cleaning fee and hourly rate.) D) $15h<40$ (Student thought cleaning fee was a rate.)
Sports	*Student Name* wants to buy a tennis racket and tennis balls. The tennis racket costs $40 and each tennis ball costs $3. Which inequality shows the greatest number of tennis balls, *b*, *Student Name* can buy in order to spend less than $90? A) $40+3b<90$ B) $3b<90$ C) $40b+3<90$ D) $40b<90$
Animals	*Student Name* wants to buy frogs and a terrarium that will house the frogs. The terrarium costs $40 and each frog costs $3. Which inequality shows the greatest number of frogs, *f*, *Student Name* can buy in order to spend less than $90? A) $40+3f<90$ B) $3f<90$ C) $40f+3<90$ D) $40f<90$
Science and Technology	*Student Name* wants to upgrade a cell phone and install new apps. The phone upgrade costs $40 and each app costs $3. Which inequality shows the greatest number of apps, *p*, *Student Name* can buy in order to spend less than $90? A) $40+3p<90$ B) $3p<90$ C) $40p+3<90$ D) $40p<90$
Music, Movies, and Television	*Student Name* has a gift card for $90 to join a music club. The membership fee is $40 and each song download costs $3. Which inequality shows the greatest number of songs, *s*, *Student Name* can download with the gift card? A) $40+3s<90$ B) $3s<90$ C) $40s+3<90$ D) $40s<90$
Travel	*Student Name* wants to buy a train ticket to New York City and also buy bus passes. The train ticket costs $40 and each bus pass costs $3. Which inequality shows the greatest number of bus passes, *p*, *Student Name* can buy in order to pay less than $90 for transportation costs? A) $40+3p<90$ B) $3p<90$ C) $40p+3<90$ D) $40p<90$

Table B15

Generic Problem Three and Matched TPWPs in Session Three

Problem type	Item
Generic	A shampoo supplier offers two different payment options. Plan A costs $1.99 per ounce of shampoo and has no shipping fee. Plan B costs $0.29 per ounce of shampoo and has a $27.20 shipping fee. How many ounces of shampoo would need to be bought in order for the plans to cost the same? A) 16 ounces (Key) B) 14 ounces (Student added 0.29 and 27.20 and divided the result by 1.99, rounded up.) C) 12 ounces (Student added 1.99 to 0.29 and divided 27.20 by the result.) D) 28 ounces (Student wrote equation 1.99x=29x+27.20 and solved by dividing (29+27.20) by 1.99.)
Sports	A batting cage facility offers two different payment plans. *Student Name* pays $1.89 per minute of batting cage use and no monthly fee. *Friend Name* pays $0.39 per minute of batting cage use and a $25.50 monthly fee. How many minutes would *Student Name* and *Friend Name* need to use the batting cage in order to pay the same each month? A) 17 minutes B) 14 minutes C) 11 minutes D) 34 minutes
Animals	A pet store offers two different rabbit food buying plans. *Student Name* pays $1.89 per pound of food and no monthly fee. *Friend Name* pays $0.39 per pound of food and a $25.50 monthly membership fee. How many pounds of food would need to be bought in order for *Student Name* and *Friend Name* to pay the same each month? A) 17 pounds B) 14 pounds C) 11 pounds D) 34 pounds
Science and Technology	An Internet company offers two different payment plans. *Student Name* pays $1.89 per megabyte of data and no monthly fee. *Friend Name* pays $0.39 per megabyte of data and a $25.50 monthly fee. How many megabytes of data would *Student Name* and *Friend Name* need to use in order to pay the same each month? A) 17 megabytes B) 14 megabytes C) 11 megabytes D) 34 megabytes
Music, Movies, and Television	A new movie website offers two different payment plans. *Student Name* pays $1.89 per movie and no monthly fee. *Friend Name* pays $0.39 per movie and a $25.50 monthly fee. How many movies would *Student Name* and *Friend Name* need to watch in order to pay the same each month? A) 17 movies B) 14 movies C) 11 movies D) 34 movies
Travel	*Student Name* and *Friend Name* each rent a car to visit the Grand Canyon. *Student Name* pays $1.89 per mile and no reservation fee. *Friend Name* pays $0.39 per mile and a $25.50 registration fee. How many miles would *Student Name* and *Friend Name* need to drive in order to pay the same amount for the rental car? A) 17 miles B) 14 miles C) 11 miles D) 34 miles

Table B16

Generic Problem Four and Matched TPWPs in Session Three

Problem type	Item
Generic	Redacted
Sports	*Student Name* has won 30 games so far during this season's tennis practices. *Student Name* plans to win 5 additional tennis games during each week's practice. Which equation could be used to determine n, the number of tennis games *Student Name* will have won after 8 more weeks if *Student Name*'s plan works? A) $n = 30 + 8(5)$ B) $n = 30 \times 5$ C) $n = 30 + 5 + 8$ D) $n = 30(5) + 8$
Animals	*Student Name* has 30 chickens on a farm. Each week *Student Name* plans to add 5 additional chickens. None of the chickens are removed. Which equation could be used to determine n, the number of chickens at *Student Name*'s farm after 8 weeks if *Student Name* follows the plan? A) $n = 30 + 8(5)$ B) $n = 30 \times 5$ C) $n = 30 + 5 + 8$ D) $n = 30(5) + 8$
Science and Technology	*Student Name* knows the chemical symbols for 30 elements on the periodic table. *Student Name* plans to learn 5 additional symbols each week. Which equation could be used to determine n, the number of chemical symbols *Student Name* will have learned after 8 weeks if *Student Name* follows the plan? A) $n = 30 + 8(5)$ B) $n = 30 \times 5$ C) $n = 30 + 5 + 8$ D) $n = 30(5) + 8$
Music, Movies, and Television	*Student Name* has seen 30 episodes of a favorite TV show. *Student Name* plans to watch 5 additional episodes each week. Which equation could be used to determine n, the number of episodes *Student Name* will have watched after 8 weeks if *Student Name* follows the plan? A) $n = 30 + 8(5)$ B) $n = 30 \times 5$ C) $n = 30 + 5 + 8$ D) $n = 30(5) + 8$
Travel	*Student Name* has visited 30 state parks. *Student Name* plans to visit 5 additional state parks each year. Which equation could be used to determine n, the number of state parks *Student Name* will have visited after 8 years if *Student Name* follows the plan? A) $n = 30 + 8(5)$ B) $n = 30 \times 5$ C) $n = 30 + 5 + 8$ D) $n = 30(5) + 8$

Table B17

Generic Problem Five and Matched TPWPs in Session Three

Problem type	Item
Generic	The equation $18.5(x+30)=592$ describes Ms. Robinson’s plan to give prizes to all 592 students at a middle school over the next 18.5 weeks. She wants to give away 30 pencils per week and x erasers per week for a total of 592 prizes. How many erasers, x, should Ms. Robinson give away each week so that every student receives a prize? A) 2 erasers (Key) B) 62 erasers (Student distributed correctly to arrive at $18.5x+555=592$ but then added 555 and 592 before dividing by 18.5.) C) 30 erasers (Student solved $18.5x+30=592$.) D) 12 erasers (Student added 18.5+30 and divided 592 by result.)
Sports	Redacted
Animals	The equation $16.5(x+20)=396$ describes *Student Name*’s animal adoption plan for the next 16.5 weeks. *Student Name*, the animal shelter manager, wants to have 20 cats per week and x dogs per week adopted for a total of 396 animals. How many dogs, x, does *Student Name* need to have adopted each week in order to achieve this goal? A) 4 dogs B) 44 dogs C) 23 dogs D) 11 dogs
Science and Technology	The equation $16.5(x+20)=396$ describes *Student Name*’s geology sample collection plan for the next 16.5 weeks. *Student Name* wants to collect 20 volcanic rocks per week and collect x oceanic rocks per week for a total of 396 rocks. How many oceanic rocks, x, should *Student Name* collect each week in order to achieve this goal? A) 4 ocean rocks B) 44 ocean rocks C) 23 ocean rocks D) 11 ocean rocks
Music, Movies, and Television	The equation $16.5(x+20)=396$ describes *Student Name*’s music practice plan to prepare for performances in the next 16.5 weeks. *Student Name* wants to practice guitar 20 hours per week and take voice lessons x hours per week for a total of 396 hours of practice. How many hours, x, should *Student Name* take voice lessons in order to achieve this goal? A) 4 hours B) 44 hours C) 23 hours D) 11 hours
Travel	The equation $16.5(x+20)=396$ describes *Student Name*’s plan to learn new languages over the next 16.5 weeks in preparation for traveling to Europe. *Student Name* wants to study German for 20 hours per week and study French for x hours per week for a total of 396 hours. How many hours, x, should *Student Name* study per week in order to achieve this goal? A) 4 hours B) 44 hours C) 23 hours D) 11 hours

Table B18

Generic Problem Six and Matched TPWPs in Session Three

Problem type	Item
Generic	Anisha designs jewelry and earns beads for washing the dishes. The equation $b=30+5w$ models the number of beads, b, Anisha has in her bead jar after w weeks. Which is the ***best*** interpretation of the term $5w$ in this equation? A) Anisha receives 5 beads per week. B) Anisha washes the dishes 5 times. C) Anisha receives a bead after she washes the dishes 5 times. D) Anisha starts with 5 beads in her jar.
Sports	*Student Name* keeps track of how many hockey goals were scored since joining a hockey league. The equation $g=20+7p$ models the number of goals, g, *Student Name* has scored after attending p team practices this season. Which is the ***best*** interpretation of the term $7p$ in this equation? A) *Student Name* scores 7 goals per hockey practice. B) *Student Name* belongs to 7 hockey leagues. C) *Student Name* scored 1 goal after 7 hockey practices. D) *Student Name* scored 7 goals before the season started.
Animals	*Student Name* works to improve the habitat of an endangered bird by planting trees. The equation $b=20+7y$ models the number of birds, b, in a region after y years. Which is the ***best*** interpretation of the term $7y$ in this equation? A) The bird population increases by 7 birds per year. B) *Student Name* planted 7 trees. C) The bird population increases by 1 bird every 7 years. D) The bird population was 7 birds before *Student Name* planted trees.
Science and Technology	*Student Name* measures a plant's growth after giving the plant an experimental fertilizer. The equation $h=20+7m$ models the height, h, in centimeters of the plant after m months. Which is the ***best*** interpretation of the term $7m$ in this equation? A) The plant grows 7 centimeters per month. B) *Student Name* gave the plant 7 different fertilizers. C) The plant grows 1 centimeter every 7 months. D) The plant was 7 centimeters tall before receiving the fertilizer.
Music, Movies, and Television	*Student Name* made a music video and uploaded it to a website that pays *Student Name* based on how many people share the video. The equation $m=20+7p$ models how much money in dollars, m, *Student Name* earned from the video after p people shared the video. Which is the ***best*** interpretation of the term $7p$ in this equation? A) The website pays *Student Name* $7 per video share. B) *Student Name* made 7 different videos. C) The website pays *Student Name* $1 after the video receives 7 shares. D) The website paid *Student Name* $7 for making the video.
Travel	Money in Denmark is called the krone. *Student Name* wants to exchange krones for American dollars. The equation $k=20+7d$ models the number of krones, k, *Student Name* will have after the exchange of d dollars. Which is the ***best*** interpretation of the term $7d$ in this equation? A) *Student Name* receives 7 krones per American dollar exchanged. B) *Student Name* exchanged 7 American dollars. C) *Student Name* receives 7 American dollars per krone exchanged. D) *Student Name* started with 7 American dollars.

APPENDIX C: TEXT COMPLEXITY OF ITEMS

Table C1

Lexile Level of Session One Item Stems

	Generic	Animals	Sports	Science and Technology	Music, Television, and Movies	Travel	Mean of TPWPs
Item 1	670	830	830	770	750	930	822
Item 2	790	1000	800	910	900	780	878
Item 3	750	740	650	870	860	820	788
Item 4	740	660	690	810	690	720	714
Item 5	830	810	970	1000	1020	960	952
Item 6	440	520	360	660	740	770	610
Mean of Category	703	760	717	837	827	830	794

Table C2

Lexile Level of Session Two Item Stems

	Generic	Animals	Sports	Science and Technology	Music, Television, and Movies	Travel	Mean of TPWPs
Item 1	640	810	960	1050	970	930	944
Item 2	550	700	750	1130	630	760	794
Item 3	260	540	410	570	550	450	504
Item 4	850	930	930	760	810	1070	900
Item 5	760	660	1020	560	810	880	786
Item 6	690	850	910	840	1060	1020	936
Mean of Category	625	748	830	818	805	852	811

Table C3

Lexile Level of Session Three Item Stems

	Generic	Animals	Sports	Science and Technology	Music, Television, and Movies	Travel	Mean of TPWPs
Item 1	880	930	1030	860	940	930	938
Item 2	980	900	1000	960	900	1090	970
Item 3	1010	970	1020	910	860	870	926
Item 4	540	730	1110	1020	940	920	944
Item 5	1010	1200	1200	1100	1260	1230	1198
Item 6	1180	1100	970	1160	1120	1170	1104
Mean of Category	933	972	1055	1002	1003	1035	1013

Table C4

Number of Words in Session One Item Stems

	Generic	Animals	Sports	Science and Technology	Music, Television, and Movies	Travel	Mean of TPWPs
Item 1	18	20	21	18	16	26	20
Item 2	37	41	34	34	43	31	37
Item 3	23	25	21	27	27	28	26
Item 4	27	27	30	33	27	29	29
Item 5	28	28	33	32	35	29	31
Item 6	14	15	13	20	23	21	18
Mean of Category	25	26	25	27	29	27	27

Table C5

Number of Words in Session Two Item Stems

	Generic	Animals	Sports	Science and Technology	Music, Television, and Movies	Travel	Mean of TPWPs
Item 1	29	37	43	33	41	40	39
Item 2	32	33	37	36	34	42	36
Item 3	21	26	24	31	31	26	28
Item 4	29	32	32	35	38	37	35
Item 5	33	33	63	32	38	42	42
Item 6	34	44	47	44	57	51	49
Mean of Category	30	34	41	35	40	40	38

Table C6

Number of Words in Session Three Item Stems

	Generic	Animals	Sports	Science and Technology	Music, Television, and Movies	Travel	Mean of TPWPs
Item 1	61	64	71	59	65	63	64
Item 2	42	41	41	40	39	50	42
Item 3	54	56	57	51	51	52	53
Item 4	36	45	49	46	43	41	45
Item 5	61	55	48	52	57	60	54
Item 6	49	55	48	52	57	60	54
Mean of Category	51	53	52	50	52	54	52

APPENDIX D: ITEM STATISTICS

Table D1

Item Statistics for Generic Problems and TPWPs by Session Number

		N student responses	p-value	Point biserial correlation with item removed	Cronbach's alpha with item removed
Session 1	Generic 1	252	.75	.45	.75
	Generic 2	252	.75	.49	.75
	Generic 3	252	.61	.33	.77
	Generic 4	234	.63	.46	.75
	Generic 5	225	.66	.34	.77
	Generic 6	229	.82	.39	.76
	TPWP 1	252	.77	.44	.76
	TPWP 2	252	.73	.53	.75
	TPWP 3	252	.59	.40	.76
	TPWP 4	236	.64	.43	.76
	TPWP 5	227	.60	.39	.76
	TPWP 6	232	.80	.37	.76
Session 2	Generic 1	206	.37	.56	.77
	Generic 2	206	.93	.33	.79
	Generic 3	206	.78	.52	.78
	Generic 4	200	.85	.45	.78
	Generic 5	194	.75	.60	.76
	Generic 6	198	.86	.35	.79
	TPWP 1	206	.45	.57	.77
	TPWP 2	206	.82	.19	.80
	TPWP 3	206	.77	.57	.77
	TPWP 4	202	.87	.41	.79
	TPWP 5	197	.59	.43	.78
	TPWP 6	198	.85	.29	.79
Session 3	Generic 1	114	.64	.42	.79
	Generic 2	114	.84	.33	.80
	Generic 3	114	.64	.46	.79
	Generic 4	111	.87	.43	.79
	Generic 5	105	.63	.58	.78
	Generic 6	103	.70	.41	.79
	TPWP 1	114	.69	.46	.79
	TPWP 2	114	.86	.40	.80
	TPWP 3	114	.57	.56	.78
	TPWP 4	107	.87	.52	.79
	TPWP 5	102	.59	.66	.76
	TPWP 6	107	.63	.25	.81

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