ABSTRACT

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Ill-structured problem solving requires a variety of skills and strategies that K-12 students often lack due to limited exposure to these problems and a reliance on superficial problem-solving strategies (Greiff et al., 2013; Jonassen, 1997, 2000; Mayer & Wittrock, 2006). This study employed a computer-based problem-solving program called Solve It!, which scaffolds students through a general problem-solving process to identify and support solutions to ill-structured physics problems. Using a sequential explanatory mixed methods design, this study examined the impact of the prompt response and narrative writing tasks on seventh grade students’ \( N = 117 \) physics content knowledge and problem-solving strategy acquisition while solving ill-structured problems in Solve It!. Students were randomly assigned to one of four conditions, which varied in the type of writing tasks students completed. Findings from this study revealed a significant increase in physics knowledge and problem-solving strategies across conditions. Due to the small sample size and several limitations with the study design, condition effects did not emerge. However, students in the narrative writing condition with low physics prior knowledge did benefit from the narrative writing task. Implications for this research include the use of computer-based environments to teach both content and problem-solving strategies simultaneously and the potential to use narrative writing tasks for learning.
The Impact of Writing Prompts on Learning During Ill-Structured Problem Solving

by

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CHAPTER ONE

Introduction

Learners often lack the skills and strategies needed to be successful when solving ill-structured problems due to limited exposure to these problems and reliance on superficial problem-solving strategies (Greiff, et al., 2013; Jonassen, 1997, 2000; Mayer & Wittrock, 2006). An overreliance on guess-and-check methods is prevalent (Johanning, 2004), with little reflection on the problem design or strategies that were successful in order to promote future success (Fortunato et al., 1991). Further, many learners resist engaging with problems that do not have a clear, direct path to reach an explicitly stated goal.

Ill-structured problem solving skills can be improved with instruction focusing on general problem-solving strategies and the development of integrated problem representations (Ge & Land, 2004; Jonassen, 1997). Problem-solving instruction also benefits from the inclusion of metacognitive processes such as planning, monitoring, and reflection to assist learners in applying strategies and transferring the strategies to new situations (Bernardi-Coletta, 1995; Delclos & Harrington, 1991; Fortunato et al., 1991; King, 1991; Swanson, 1990). In an attempt to address skill deficits in students, the new Common Core Standards and the Next Generation Science Standards emphasize higher order thinking skills, such as problem solving and critical thinking (National Governors Assn., 2010; NGSS, 2013). Educators across disciplines are expected to improve student’s cognitive and metacognitive processes to assist them in solving challenging problems.
Unfortunately, limited tools have been provided to help teachers and students achieve these goals. Further, school curricula are dense with content, limiting teachers’ ability to include concepts or skills that are not essential to their instructional goals. The emphasis on high stakes testing results exacerbates this problem, as teachers are pressured to prepare students for tests rather than develop them as learners. In order to address problem-solving skill deficits in students while also meeting the curricular demands, problem-solving skill instruction is best suited to be integrated with regular classroom instruction. The incorporation of problem-solving skill instruction into existing curriculum is critical for improving students’ ability to solve complex problems. Cohesive lessons that integrate problem-solving skills within different content areas will also alleviate some of the time constraints that prevent teachers from developing problem-solving skills in their students.

Importantly, complex problem-solving opportunities may lead to deeper learning than traditional lessons, benefiting students’ conceptual understanding and skill development (Greiff et al., 2013). Furthermore, with appropriate instructional support across multiple content areas, students can even be taught to transfer these skills to new situations.

A successful problem-solving experience requires learners to be actively engaged with the problem-solving process, relevant domain knowledge, and their own metacognitive processes. Writing is a powerful learning tool that aligns well with ill-structured problem solving (Jonassen, 1997) and facilitates the transformation of knowledge to build more complex knowledge structures (Scardamalia & Bereiter, 1984). Writing-to-learn tasks can improve conceptual understanding (Bangert-Drowns et al, 2004; Chen et al., 2013),
metacognitive knowledge (Hand, Wallace, & Yang, 2004), and even cognitive skills (Rivard, 1994). While writing is frequently a component of ill-structured problem solving, limited research exists on the impact of writing on learning during ill-structured problem solving.

The diverse nature of ill-structured problems allows multiple types of writing tasks to be included in the problem solving process and solution justification. Multiple research studies have investigated the use of question prompts during problem solving that scaffold students through the problem-solving process (Bulu & Pederson, 2010; Chen & Bradshaw, 2007; Kauffman et al., 2008). Learners are required to write responses to these prompts whose purpose can be procedural, elaborative, or reflective (Ge & Land, 2004). Additionally, ill-structured problems can be presented as cases or narratives to provide context for the problem. This creates opportunities for students to present their solutions in various formats. Narrative writing, for instance, can be easier for some students and more motivating and also provide students with audiences beyond their teachers. However, little research has investigated narrative writing as a writing-to-learn task.

**Study Purpose**

The purpose of this study is to investigate the ability of narrative writing tasks to induce content learning and skill acquisition during ill-structured problem solving. The study utilizes a computer-based program, *Solve It!*, that presents students with ill-structured physics problems embedded in short narrative stories to provide context and increase engagement. The program scaffolds students through a five-step general problem-solving process that
supports their solution identification and justification. Students are then asked to finish writing the story to describe the solution and how the characters solve the problem. The program’s goals include both physics content learning and problem-solving strategy acquisition.
CHAPTER TWO

Review of the Literature

Problem Solving

Problem solving, as defined by Mayer and Wittrock (2006), is the goal directed cognitive process individuals engage in when they have no obvious solution to an encountered problem. According to Chi and Glaser (1985), two main factors affect problem solving, the nature of the problem-solving task and the knowledge of the problem solver. Individual differences such as prior problem solving experience, domain knowledge, metacognitive knowledge, and motivation for problem solving play an important role in problem-solving processes and success (Mayer, 2013).

Researchers define problems as scenarios that consist of an initial state, a goal state, and constraints, or obstacles, that prevent easily moving from the initial to goal state (Chi & Glaser, 1985; Davies, 2005; Jonassen, 1997, 2000; Mayer, 2013; Newell & Simon, 1972). Problems also consist of operators, which are the procedures or steps that move the problem from the initial to goal state (Chi & Glaser, 1985; Mayer, 2013). This broad definition encompasses a wide array of problems varying on multiple characteristics. In order to advance our understanding of problems and how they are solved, researchers classify problems into groups based on major characteristics and examine the solution processes for each type of problem.
Problems have been categorized into three major groups, puzzle problems, well-structured problems, and ill-structured problems, depending on several factors including how well defined the problems’ characteristics are, the number of available solutions and solution paths, and the problems’ context (Jonassen, 1997). Psychological research into problem-solving processes has relied heavily on puzzle problems (i.e. Tower of Hanoi, Nine Dots, Missionaries and Cannibals). Puzzles are context-free problems with a single correct answer and usually a single preferred solution path. Puzzle problems generally have a well-defined initial state, goal state, and set of constraints, allowing the solver to focus on the operators. While these problems have been useful in understanding how people search for solutions to problems and produce generalizable results, they are not tied to school or real world practices (Chi & Glaser, 1985; Jonassen, 1997). Further, examining problem-solving processes without considering the role of prior knowledge does not fully represent the processes that occur during well and ill-structured problem solving. This limits the applicability of research results from these studies, especially in instructional fields looking to improve students’ problem-solving skills.

The more realistic problems that represent what students and adults actually encounter are categorized as either well-structured or ill-structured problems (Chi & Glaser, 1985; Jonassen, 1997; Mayer, 2013; Mayer & Wittrock, 2006). Well-structured problems have clearly defined initial states, goal states, and operators that move the problem to its solution. Well-structured problems are often encountered in math classes where students apply practiced operators to move the problem from the initial to goal state. Well-structured
problems are more context-dependent than puzzles because their solution typically requires the problem solver to have domain specific knowledge, such as knowledge of mathematical formulas and operations. Ill-structured problems, on the other hand, have poorly defined components, making the solution more difficult to reach. Ill-structured problems are more representative of real-world scenarios that are encountered on a daily basis since they are heavily context dependent and have multiple possible solutions.

Well and ill-structured problem categories are not discrete. Depending on the information provided about the problem, the number of solutions, the number of solution paths, and the context, problems fall somewhere on a continuum between well and ill-structured (Jonassen, 1997). For example, well-structured problems tend to have a single correct answer, while ill-structured problems can have multiple solutions that need to be weighed against one another to determine the best course of action. The initial state, goal state, and constraints can be defined in varying levels, changing the problem from one with a prescribed set of operators to move from the initial to goal state (well-defined), to one with no established procedures for reaching the vague goal (ill-defined). Some problems do not clearly fit into a single category, as discussed by Jonassen, and instead possess features characteristic of both sides of the continuum (For a more detailed classification of problem types see Jonassen, 2000). Buying a car, for instance, can have a specific goal with defined parameters, but the methods for making the final selection are unclear.

Mayer and Wittrock (2006) also classified problems as routine or non-routine based on the knowledge of the problem solver. When the problem solver possesses knowledge of
how to solve a particular problem it is considered routine. If the problem solver does not have a previously learned solution procedure to apply, the problem is considered non-routine for that problem solver. For instance, students often find physics problems to be very routine because they practice the same problem types repeatedly. Physicists, however, encounter completely original, non-routine problems in their field that require them to devise new methods for finding a solution. Because well-structured problem-solving procedures can be taught and applied to all similarly structured problems, these problems often become routine, especially in school. On the contrary, ill-structured problems are often non-routine because no set procedure or formula exists to find the solution and they are less common in school curriculums.

**Understanding Problem Solving**

Historically, widespread interest in human problem solving began in Gestalt psychology with seminal works by Duncker (1945), Polya (1945) and Wertheimer (1945) (Novick & Bassok, 2005). The Gestalt perspective on problem solving emphasized the importance of problem representations rather than solution processes. Problem representations consist of an individual’s interpretation of the problem, integration of prior knowledge, and organization of information, and can determine how easily a problem will be solved (Chi & Glaser, 1985; Novick & Bassok, 2005). According to the Gestalt perspective, problem solvers’ success relies on the quality of the problem representation, especially in context dependent problems.
The rise of behavioral psychology pushed problem-solving research to the side for almost thirty years because behavioral psychologists believed that understanding individuals’ mental processes was impractical. However, with the rise of cognitive psychology and the publication of Newell and Simon’s *Human Problem Solving* in 1972, interest in problem-solving research was re-ignited. Newell and Simon’s seminal work examined problem-solving processes using puzzle problems to identify strategies and steps individuals applied to find solutions. This research was not interested in the representation of problems and instead focused on the search for a problem solution, explaining the reliance on context free puzzle problems. Participants completed think aloud protocols while solving the problems, which were analyzed to identify common problem-solving approaches. By choosing context-free problems, Newell and Simon were able to make generalizations about human problem solving processes that were tested using a computer-based problem-solving program, the General Problem Solver. In the late 1970’s, research into the importance of background knowledge combined with the popularity of Newell and Simon’s work renewed interest in problem representation (Novick & Bassok, 2005). Today’s problem-solving research tends to focus on problem-solving processes, problem representation, or a mix of both representation and processes.

The focus on either problem representation or problem-solving processes leads researchers to apply different learning theories when designing studies and interpreting results. Generally, research into problem representation relies on a constructivist approach to learning (Jonassen, 1997, 2000). By studying how problem solvers interpret the problem
information, integrate their own knowledge, and build a mental representation of the problem, this research naturally follows constructivist principles. Research into problem-solving processes, on the other hand, searches for generalizable skills and strategies, aligning with information processing theories of learning (Chi & Glaser, 1985; Jonassen, 1997; Novick & Bassok, 2005). Identifying common skills and strategies directs both future research and instructional practices in hopes of generalizing skills across various content areas and problem types.

Problem representation research and problem-solving process research also align with different types of problems. While information-processing theories generally rely on puzzle problems and well-structured problems, research applying constructivist principles to understand problem representation gravitates towards ill-structured problems and context dependent well-structured problems (Jonassen, 1997). To illustrate, Fuchs et al. (2003) used explicit instruction of problem-solving procedures and problem structure analyses to help third graders generalize problem-solving processes to new, similarly structured problems. This research aligns with Newell and Simon’s (1972) attempt to find processes that could be generalized between problems and between problem solvers, following an information-processing approach to learning. Chen and Bradshaw (2007) also wanted students to transfer skills between problems, but instead of applying practiced procedures students followed scaffolded question prompts to integrate their prior knowledge into an ill-structured problem representation. The scaffolding helped participants construct an understanding of the problem, which was used to identify possible solutions and paths to reach the solutions.
These studies illustrate how the problem type impacts design and theory selection in problem-solving research.

**Solving Problems**

As discussed, puzzle problems are context-free problems that can be solved with the application of general heuristics such as means-ends analysis. While a great deal of literature focuses on solving puzzle problems, these problems and the processes used to solve them are not representative of school and real world problems (Chi & Glaser, 1985). One of the major goals of this review is to identify ways to improve students’ ill-structured problem-solving skills, therefore puzzle problem solving will not be included in the following sections.

**Knowledge for problem solving.** Problem solving relies on domain knowledge, structural knowledge, and metacognitive knowledge (Chi & Glaser, 1985; Ge & Land, 2004; Jonassen, 1997; Mayer, 2013). As discussed earlier, problems that are contextualized rely on the solver’s relevant domain knowledge for a solution to be reached. Domain knowledge consists of facts, concepts, and principals in a specific content area. The amount of domain knowledge that is required to solve a problem varies by problem type and difficulty. Research in expertise has shown that individuals with high levels of domain knowledge are better able to represent problems (Novick & Bassok, 2005; Voss et al., 1983), organize information from the problem and integrate their own knowledge (Chase & Simon, 1973; Larkin et al., 1980), categorize problems according to previously solved problems (Novick & Bassok), and select and apply appropriate problem-solving strategies (Larkin et al.; Schunn, McGregor, & Saner, 2005).
Simply possessing relevant domain knowledge is not sufficient for improved problem solving. Structural knowledge, or how knowledge is organized and represented, makes relevant domain knowledge accessible to problem solvers (Chi & Glaser, 1985; Jonassen, 1997). The concept of a schema is useful in understanding how the organization of relevant knowledge can impact its retrieval and application. Schemas contain not only facts and concepts, but also how they are related to one another. These connections between concepts build a structured knowledge base that allows problem solvers to relate the problem to their prior knowledge and experiences to make the appropriate problem solving decisions (Ge & Land, 2004). Experts, for instance, have well organized knowledge structures allowing them to categorize problems, select appropriate strategies, and solve problems more efficiently than novices (Voss et al., 1983).

Metacognitive knowledge, the third type of problem-solving knowledge, consists of knowledge of cognition and regulation of cognition (Brown, 1987), which is necessary for problem solvers to set goals, select strategies, monitor progress, make adjustments when needed, and reflect on their process to improve future problem solving (Ge & Land, 2004; Kauffman, 2004). Problem solvers’ metacognitive knowledge plays an important role in problem solving and will be discussed in greater detail in the metacognition section.

**Well-structured problem solving.** Research into well-structured problem solving relies on seminal studies in solving puzzle problems. Based on their research into problem-solving processes, Newell and Simon (1972) proposed the concept of a problem space, which is the problem solver’s representation of a problem, and includes the initial state, goal state,
constraints, operators, and all possible intermediate steps that could be encountered while solving a problem. According to Newell and Simon’s model, problem solving is the search through the problem space to select the best operators and procedures to reach the goal state. While examining problem-solving processes using puzzle problems, several common heuristics were discovered and generalized between individuals. As Table 2.1 shows, there are three common heuristics that are well represented in research examining puzzle problems and well-structured problems. When problem solvers are taught these heuristics and how to apply them, there are improvements in individuals’ ability to solve problems (Barak, 2013). Heuristics, however, do not provide much insight into the role of knowledge in domain relevant problem solving and do not provide sufficient insight to understand how complex problems are solved.

Table 2.1

<table>
<thead>
<tr>
<th>Heuristic</th>
<th>Description</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means-ends Analysis</td>
<td>Identify differences between the initial and goal state and select operators that will eliminate or reduce the differences</td>
<td>Chi &amp; Glaser, 1985; Newell &amp; Simon, 1972; Novick &amp; Bassok, 2006;</td>
</tr>
<tr>
<td>Sub-Goaling</td>
<td>Decompose problems into sub-goals and select intermediate solution paths to smaller goals until the goal state is reached</td>
<td>Chi &amp; Glaser, 1985; Jonassen, 1997;</td>
</tr>
<tr>
<td>Generate and Test</td>
<td>Select possible solutions and evaluate their utility in solving the problem</td>
<td>Chi &amp; Glaser, 1985;</td>
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</table>
Research related to well-structured problem solving has expanded beyond heuristics rooted in puzzle problem research to include context dependent problems that rely on the solver’s relevant domain knowledge. General problem-solving processes, such as the four-step model presented by Polya (1945), provide a framework for approaching problems and finding a solution. Polya’s model teaches students to understand the problem, devise a plan, implement the plan, and then look back at their work. An individual’s ability to apply these general steps is reliant on them possessing the appropriate domain and structural knowledge for the problem. Polya and others’ research into mathematical problem solving has focused on first developing domain and structural knowledge by teaching students about problem structures and methods for solving them, and then helping students identify similarly structured problems using analogical reasoning. Once students understand the problem structure, they are able to apply previously learned procedures to solve the problem (Fuchs et al., 2003; Mayer, 2013). These general problem-solving steps prompt students to approach new problems systematically in hopes of cueing the transfer of their problem-solving knowledge to new problems.

Domain knowledge and structural knowledge play a key role in solving many well-defined problems. Cooper and Sweller (1987)’s research with middle and high school math students found that helping students automatize problem-solving procedures and develop schemas for classifying problems improved their problem solving and transfer of skills to new problems. This research focused on improving students’ domain and structural knowledge so they could more easily apply this knowledge to new problems. Fuchs et al.
(2003) used a similar approach with third graders, focusing first on developing their domain and structural knowledge in mathematics problem solving and then helping them analyze problem structures to transfer skills.

**Ill-structured problem solving.** With puzzle problems and well-structured problems, the necessary information has been provided to the solver and there is a single correct answer they are working to reach. This allows problem solvers to apply heuristics or follow a general strategy that cues them to categorize problems and apply learned operations. Ill-structured problems, however, are not clearly defined for solvers and their interpretations and solutions rely heavily on the problem solver’s prior knowledge and experiences. There are no prototypic cases for ill-structured problems, nor are there formulas or algorithms that can be applied to reach a definite answer. Additionally, numerous possible approaches and solutions often exist and must be weighed against one another to select a solution and support its utility. Due to these differences, research into ill-structured problem solving generally focuses on problem representation and solution argumentation rather than solution processes (Novick & Bassok, 2005).

Ill-structured problems are vaguely defined problems that are usually situated in the real world and rarely have a single correct solution (Jonassen, 1997). In contrast to Newell & Simon’s (1972) proposal of problem solving as a search through a problem space, solving ill-structured problems can be considered a design process. According to Jonassen, “the problem solver must frame the design problem, recognize divergent perspectives, collect evidence to support or reject the alternative proposals and ultimately synthesize their own
understanding of the situation rather than find a solution for a prescribed problem” (1997, pp. 79).

Using think-aloud protocols while adults solved ill-structured problems, Sinnott (1989) identified general steps for solving ill-structured everyday problems that align with this design process. Jonassen (1997) condensed Sinnott’s eleven steps into seven steps, which were further reduced to four general processes by Ge and Land (2003, 2004) as shown in Table 2.2. Ill-structured problem solving generally requires the problem solver to represent the problem, develop solutions, construct arguments to support solutions, and monitor and evaluate the problem-solving process, solution effectiveness, and the learners’ own cognitive processes. Similar to the design process, problem solvers are creating solutions that fit the problem constraints and meet the end goals of the problem. After comparing the solution options, the most appropriate solution is selected and applied to the problem.

Table 2.2
Ill-structured problem solving processes (Ge & Land, 2003, 2004)

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
<th>Other Models</th>
</tr>
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<tbody>
<tr>
<td>1. Problem Representation</td>
<td>Consists of the problem information, contextual constraints, relevant domain knowledge, relevant structural knowledge; Can potentially be multiple problem representations once alternative opinions and perspectives are considered</td>
<td>Sinnott- steps 1 through 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jonassen- Steps 1 and 2</td>
</tr>
<tr>
<td>2. Developing Solutions</td>
<td>Activate prior knowledge and connect the problem to existing problem schemas; Consider the problem goals and constraints when developing solutions; Consider alternative solutions;</td>
<td>Sinnott- Step 8?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jonassen- Step 3</td>
</tr>
<tr>
<td>3. Making Justifications</td>
<td>Solution choices are justified by developing an argument; Support with facts, supportive statements or conjectures;</td>
<td>Sinnott- Step 9?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jonassen- Step 4</td>
</tr>
<tr>
<td>4. Monitoring and Evaluations</td>
<td>Monitor the solutions to evaluate their utility in solving the problem; Monitor and reflect on their own processes, checking for errors and making adjustments; Evaluate the effectiveness of the solution if implemented;</td>
<td>Sinnott- Step 10 and 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jonassen- Step 5, 6, and 7</td>
</tr>
</tbody>
</table>

While heuristics are not particularly well suited for solving ill-structured problems as a primary strategy, they can be helpful when developing solution ideas. For instance, sub-goals are often used in ill-structured problems to create manageable goals and address different problem constraints (Chi & Glaser, 1985). If the problem has multiple constraints, the solver can create sub-goals to deal with groups of constraints rather than accounting for everything at once. The generate-and-test heuristic is useful when designing and comparing problem solutions to select the best option (Ge & Land, 2004; Jonassen, 1997). This process also provides important information to construct an argument supporting the chosen solution.
As in design theories, problem solvers create and test solutions to determine their utility in solving the ill-structured problem.

Having or developing appropriate domain knowledge to help in creating a solution is essential for solving ill-defined problems. Voss et al. (1991) compared ill-structured problem solving between experts and novices using social science problems. Experts in these studies used their extensive relevant domain knowledge to clearly define the problem and problem constraints. Additionally, the experts’ knowledge helped them group constraints into manageable sub-goals while the novices considered every constraint as a separate sub-goal. Larkin et al. (1980) also found that physics experts’ structural knowledge helped them define the problem and work towards the solution, rather than working backwards like the novices approached problems.

Along with applying relevant domain knowledge to construct a detailed problem representation and identify potential solutions, solving ill-structured problems requires solutions to be compared and evaluated. Careful comparison of the solution options to the problem constraints helps the solver select a solution and develop an argument to support this solution. Because ill-structured problems do not have a single defined goal state, it is important for the solver to consider and compare alternative solutions to construct a solid argument for the chosen path (Jonassen, 1997). By comparing alternative solutions, the problem solver considers multiple perspectives and collects evidence to justify their solution. This process also forces them to evaluate potential consequences for each solution, which is important to identify the best solution.
Transfer of Problem-Solving Skills

Transfer refers to the application of previously learned material to new situations (Mayer, 2013; Ritchhart & Perkins, 2005). The transfer of problem-solving skills involves taking already acquired problem solving skills or strategies and applying them to a new problem. The transfer of problem-solving skills is studied in relation to the difference between the problems solved during skill acquisition and the new problems that need to be solved. In immediate transfer the problems solved are very similar to the training problems, therefore the skills easily transfer to the new problems (Fuchs et al., 2003). In near transfer the problems being solved are similar to the training problems, but may differ on a few superficial characteristics. Far transfer, however, requires the problem solver to apply skills to contexts that are quite different from the original training contexts, often in different domains (Ritchhart & Perkins, 2005). Immediate, near, and far transfer represent three points on a continuum moving from common (immediate) to rarely achieved (far). Influencing far transfer is quite difficult, even though transforming learners into productive thinkers who spontaneously transfer skills between domains is a common goal in education.

While some studies have assumed that simply practicing problem-solving skills is sufficient for transfer, practice alone is not enough to cause transfer (Phye, 2011). The transfer of problem-solving skills relies on several factors including the problem solver’s ability to recognize the problem’s structure and relate it to previously solved problems. In order to identify analogous problems, individuals must first examine problem structures to create categories for future problems. Many problem-solving interventions provide specific
instruction on identifying problem structures and categorizing problems based on previously solved problems (Cooper & Sweller, 1987; Fuchs et al., 2003). Students’ self-developed categories tend to be quite narrow (Fuchs et al.) and even limited by superficial quantity labels (Bassok, 1990). Appropriate problem-solving instruction should assist students in broadening their categories in order to see past superficial problem details. Additionally, Schwartz et al. (2011) found that transfer of problem-solving strategies improved when learners were given the opportunity to develop formulas on their own to solve problems rather than simply being given the formulas. These students spent more time analyzing the problem’s structure and were able to identify similar structures in new problems which facilitated the transfer of skills.

Even instruction on problem identification and categorization is not enough to guarantee transfer of problem-solving skills. Fuchs et al. (2003) found that in addition to broadening third graders’ math problem categories, they also needed to be explicitly taught to examine new problems’ structures. Without prompting or cueing students to identify problem structures they are not likely to spontaneously transfer skills to novel problems (Bassok, 1990; Cooper & Sweller 1987; Fuchs et al., 2003). Many studies have used question prompts to scaffold learners through problem solving, reminding them to examine problem structures and apply previously learned strategies where possible. These prompts form a general problem-solving procedure, similar to those suggested by Polya (1945) and Ge and Land (2004).
Research into the transfer of problem-solving skills is hindered by the importance of domain knowledge for problem solving. As Richhart and Perkins (2005) explain, the role of knowledge in problem solving and the limitations associated with situated cognition pose challenges for instilling transfer. Experts, for instance, are superior problem solvers in their domains due to the extensive domain knowledge and experience they possess (Chi & Glaser, 1985; Novick & Bassok, 2005 Ritchhart & Perkins, 2005). In a comparison of experts and novices solving problems in the experts’ domains, relevant domain knowledge was vital for analyzing problems and identifying the best solution path (Larkin, 1980). In spite of experts’ domain specific problem-solving expertise, these skills do not transfer to different contexts (Ritchhart & Perkins, 2005). While domain knowledge is important in problem solving, it is possible that general problem-solving strategies can be transferred between domains.

**Transfer of ill-structured problem-solving skills.** Real world, ill-structured problems are diverse, non-routine problems, decreasing the likelihood of expertise development in solving these problems (Mayer, 2013; Ritchhart & Perkins, 2005). The diversity in ill-structured problems and their solutions does not open them up to simple structure identification and formula application like well-structured problems. Instead, ill-structured problem solving benefits from a general pattern of processing that can be applied to all problems. Rather than providing instruction on problem structure and formulas for solution, ill-structured problem solving benefits from thinking procedures or guidelines that help the problem solver reach a solution.
Numerous studies use question prompts as scaffolds for students’ problem-solving processes and to instill general processing skills that are important in solving ill-structured problems (Bulu & Pederson, 2010; Chen & Bradshaw, 2007; Chen & Ge, 2006; Davis, 2000; Delclos & Harrington, 1991; Ge & Land, 2003, 2004; Kauffman, 2004; Kauffman et al., 2008; King, 1991; King & Rosenshine, 1993). Question prompts are instructional supports that can focus the problem solver’s attention on the appropriate features of the problem-solving process to help them develop skills and integrate knowledge (Davis, 2000; King, 1991; King & Rosenshine, 1993; Scardamalia & Bereiter, 1994). Problem-solving scaffolds aid students in solving problems that might be too difficult for them without support. As discussed by Vygotsky (1978), support provided from a more knowledgeable person aids students in moving from their current level of understanding to the next level. Question prompts can scaffold students working in the zone of proximal development (ZPD) by providing the necessary support for students to learn to solve the problems independently. These scaffolds can potentially improve students’ problem-solving skill acquisition and transfer.

While not many studies have examined the effectiveness of scaffolding prompts for transferring problem-solving skills between ill-structured problems, their success in helping students work through these processes is promising. Ge and Land (2004) classified question prompts into three categories: procedural prompts, elaboration prompts, and reflection prompts. Procedural prompts are aimed at students completing specific tasks, while elaboration prompts lead “learners to articulate thoughts and elicit explanations (Ge & Land,
Procedural prompts can help students learn cognitive strategies like problem solving, compared to elaboration prompts, which are geared towards knowledge construction. Reflection prompts, on the other hand, are metacognitive prompts that ask learners to plan, monitor, and evaluate their progress and their processes.

Research examining the use of problem-solving scaffolds in computer-based learning environments (CBLE) has grown in recent years (Bulu & Pederson, 2010; Dabbagh & Kitstansis, 2005; Graesser, McNamara, & VanLehn, 2005; El Saadawi et al., 2010; Roll et al., 2011; Ward & Clark, 1989; White & Frederiks, 1998) and provides opportunities for examining the impact of prompts on problem-solving skill transfer. Bulu & Pederson (2010) examined the impact of continuous and faded question prompts with either domain-specific or domain-general content. Results of their study with sixth graders playing Alien Rescue, a problem-based CBLE, indicated that continuous domain-specific scaffolds improved content knowledge and problem representation. However, when faded, the domain-specific scaffolds were not transferred to new problem scenarios. The domain-general prompts helped participants develop solutions, make justifications, and monitor and evaluate their problem solving. Importantly, the domain-general scaffolds transferred to new problems when faded. Additional studies have shown benefits of scaffolding in problem solving, but have not examined transfer of these skills (Chen & Bradshaw, 2007; Davis, 2003; Ge & Land, 2003; Ge, Chen, & Davis, 2005; Kauffman, 2004; Kauffman et al., 2008).

Research in the use of scaffolds generally shows positive results for applying these instructional supports to help students solve problems, but additional questions remain. As
shown in Bulu & Pederson’s (2010) study, fading scaffolds can be detrimental depending on the purpose of the supports. In order to show learners have internalized and transferred problem-solving processes the scaffolds must be removed, but the specific timing for removing scaffolds is unknown. Some CBLEs aim to develop real-time learning diagnoses and adaptive scaffolding, but this is quite complex and still in development (Azevedo et al., 2010). Greene and Land (2000) also found that over burdening learners with excessive prompts is detrimental to their learning and engagement. Finally, the type of question prompt (e.g. cognitive, metacognitive, content focused) results in different learning outcomes (Chen & Bradshaw, 2007; Davis, 2003; Ge & Land, 2003; Ge, Chen, & Davis, 2005), but the best mix of each type without overburdening the learner is yet to be determined.

A review of problem solving research suggests that the transfer of cognitive skills is rarely attainable. However, studies examining transfer often expect participants to make large leaps between both content areas, learning activities, and even problem types without explicit instruction on how cognitive skills can be used in different ways (Richhart & Perkins, 2005; Singley, 1989). A more pedagogically sound approach to transfer research might be to first consider the difficulty of the transfer task and then customize supports for participants. Studies that carefully analyze transfer tasks to determine the necessary knowledge to transfer skills from one task to another and explicitly train participants with this knowledge will add significantly to the literature.

Some research also suggests that teaching for the transfer of cognitive skills will not be successful unless the individuals possess a disposition for transfer (Boscolo & Mason,
Bereiter (1995) argued that the transfer of cognitive skills is actually a disposition or behavioral tendency. The transfer of cognitive skills relies on additional training to improve the disposition towards thinking and application of thinking skills. Additional metacognitive instruction can improve the transfer of skills by helping students understand when and why these skills are used (Delclos & Harrington, 1991). If students see the value and purpose of transferring skills, they may be more inclined to do so in new situations. While it may take a long time to develop behavioral tendencies, helping individuals see the value and purpose of transfer is an important first step.

**Examining Problem Solving**

Early problem-solving research was largely descriptive in order to identify problem-solving strategies and processes. For example, Newell and Simon (1972) and Sinnott (1989) used think aloud protocols to identify common problem-solving strategies. These studies provided valuable data that was used to design further research and experimentation. The majority of current research studies are experimental, often testing the impact of a problem-solving intervention.

In problem-solving research, the design and measurement tools are based on the type of problem being studied and whether the researcher is interested in the problem representation or problem-solving process. An additional factor in selecting designs and measurement is whether problem-solving transfer is being examined.

**Measuring problem solving.** Think aloud protocols are commonly used for investigating problem-solving skills. Newell and Simon (1972) used participants’ think aloud
protocols while solving puzzle problems to identify commonly used heuristics. Sinnott (1989) also used think aloud protocols to examine adults’ problem-solving skills on slightly altered versions of Piaget’s formal operational problems. Analyzing the think aloud protocols helped Sinnott identify general processes that problem solvers used during ill-structured problem solving. Many studies still use think alouds to capture online processing while participants complete a problem-solving task. There are concerns with think aloud protocols, however, including interference with thinking processes, participants’ selection of what to report, the think aloud protocol’s influence on the behaviors of the participants, and their difficulty in capturing high-level metacognitive activities that direct problem-solving processes. Many problem-solving studies also use question prompts to scaffold participants through the problem-solving process. Participants’ responses to these question prompts can be examined to identify the steps taken and reasons for these steps.

Studies aimed at teaching participants to solve a particular type of problem can use pre and post problem-solving assessments to find changes in problem-solving performance. These assessments are usually researcher designed since they must align specifically with the intervention. Fortunato et al. (1991) also created a metacognitive problem-solving checklist that allowed students to report the metacognitive strategies that used before, during, and after solving mathematics problems. This checklist can be used to assess students’ self-reported problem-solving processes.

Studies examining the transfer of skills, especially far transfer, can also design a transfer task activity for participants to complete. These activities are then evaluated for signs
of skill transfer and success. Fuchs et al. (2003) designed transfer tasks that assessed immediate, near, and far transfer in mathematics problems by varying the problems’ cover stories, superficial problem features, problem structures, and by adding novel problem characteristics. Problem-solving transfer can also be assessed immediately after the intervention or after a delay. Phye (2001), for instance, measured problem-solving transfer after a two-day delay. The context of the transfer task can also be altered from the training context. For instance, if the intervention occurred within a computer program the transfer task can be moved from the computer to a paper and pencil assessment.

**Problem-Solving Skills in Elementary and Middle School Students**

The development of problem-solving skills is both a challenging and critical area of research in education. While the ultimate goal of education is to help students retain information and transfer this information to new situations (Mayer & Wittrock, 2006; Phye, 2001), traditional instruction and assessment appears, all too often, to emphasize rote memorization rather than application and problem solving (Anderson, 2012; Taconis et al., 2002). The importance of problem solving in education has been highlighted by the recent release of the Common Core Standards in K-12 language arts, mathematics, and the Next Generation Science Standards (NGSS; NGSS, 2013; National Governors Assn., 2010). These standards emphasize the need for students to understand problems, reason through them, and persevere in finding solutions (NGSS, 2013; National Governors Assn., 2010).

Students will benefit from solving ill-structured problems that are more representative of problems they will encounter in their lives and future professions. School curricula,
however, lack experiences that develop students’ real world problem-solving skills (Greiff et al., 2013; Jonassen, 1997, 2000; Mayer & Wittrock, 2006). Students are rarely exposed to meaningful, complex problem solving in schools, and instead spend their time repeatedly solving well-structured mathematical problems (Anderson, 2012; Chi & Glaser, 1985; Taconis et al., 2001). The NGSS (2013) emphasize the importance of learning through inquiry and using the engineering design process to solve everyday problems. Both inquiry learning and design processes provide students opportunities to struggle with ill-structured problems in order to learn and improve their problem-solving skills. These approaches have been underutilized, however, as teachers primarily base their instruction on state tests (Anderson, 2012).

Problem-solving skills often suffer because students are not taught the proper domain, structural, and metacognitive knowledge to improve their skills. Current models of instruction emphasize problem solving during learning and assessment, (Jonassen & Hernandez-Serrano, 2002), but many instructors expect students to independently apply content knowledge to problem solving without instruction on how to do so. Direct instruction and modeling of problem-solving skills is necessary for students to acquire problem-solving skills (Mayer & Wittrock, 2006). King’s (1991) research shows that teaching students problem-solving strategies, such as guided questioning, leads to an increased ability to solve problems. Fifth grade students who received problem-solving training outperformed their peers on new problem-solving tasks, more effectively communicated through questioning and explanation techniques, and demonstrated improved problem-solving abilities.
Physics problem solving in K-12 learning environments. One domain in particular that lacks rich problem-solving instruction and experiences for K-12 students is physics. When compared to previous generations and students in other countries, students in our school system are underperforming in physics (Sinatra & Taasoobshirazi, 2011). The practice and study of physics relies on high level models, abstract concepts, and high level mathematical calculations in order to move the field forward (Briscoe & Prayaga, 2004). Physics education in K-12 schools attempts to mimic these practices, often to the disservice of learning and conceptual understanding of physics concepts. High school physics classes typically focus on quantitative, well-structured problem solving with a single correct answer and solution path (Sinatra & Taasoobshirazi). However, this quantitative problem solving does not translate to conceptual understanding or conceptual problem solving (Mualem & Eylon, 2010).

Physics is often regarded as a difficult subject in K-12 schools. Many core concepts that are taught in physics are relevant and helpful when learning about other sciences like biology and chemistry (Sinatra & Taasoobshirazi, 2011). However, students often possess misconceptions about even basic physics concepts, such as force and motion (Geary, 2008; Mayer, 2013). Force and motion science lessons generally ask students to memorize Newton’s laws and then solve well-structured, math-based physics problems. These low quality lessons do not ask students to apply concepts, but instead use memorized formulas to solve similarly structured problems.
An alternative to the low quality physics problem solving is to allow students to engage in meaningful problem solving which can help students discover errors in their knowledge, address misconceptions and engage in conceptual change (Mayer, 2013). Meaningful, challenging problem solving will not only improve students’ physics content knowledge (Sinatra & Taasoobshirazi, 2011), but will also improve their problem-solving skills for the future (Hartman, 2001b). Chen, Hand, and McDowell (2013) engaged elementary students in a letter writing activity to communicate their physics knowledge to high school physics students. Elementary students completed experiments and researched topics to discover answers to the high school students’ questions, improving their conceptual understanding, writing, and argumentation skills. This meaningful, ill-structured problem task improved physics knowledge and cognitive skills. Hein (1999) also used writing to improve college students’ physics knowledge by asking them to write about conceptual physics problems.

Computer based physics programs have been designed that engage students in well-structured (Cheema & LaViola, 2012; Wolff, 2009) and ill-structured (Myneni et al., 2013; Shute, Ventura, & Kim, 2013; White & Fredericksen, 1998) problem solving tasks. Newton’s Playground, for instance, develops students’ knowledge of simple machines by drawing and applying simple machines to basic motion problems (Shute et al., 2013). Each problem in Newton’s Playground asks students to reach the same goal state, but alters the constraints to the problem. Simple machines are applied to the problems to overcome the obstacles. Shute et al. (2013) have found significant gains in knowledge from pre to post tests after playing.
the game. ThinkerTools Inquiry Curriculum is another computer-based game that was designed to improve students’ knowledge of inquiry practices as well as force and motion concepts (White & Frederiksen, 1998). Both of these programs aim to improve students’ conceptual knowledge of force and motion using ill-structured problems. ThinkerTools, however, explicitly focuses on the inquiry processes, which can improve their future problem-solving approaches. While both of these programs were designed for middle school students, their general principals would also be useful with both younger and older students learning physics concepts.

It is important for K-12 students to engage in meaningful physics problem solving that extends beyond basic math problems. Computer-based programs that use complex ill-structured problems to engage learners with real-world physics problems could be useful in helping students advance both their physics conceptual understanding and problem-solving skills. These programs can scaffold students through a general problem-solving process and provide additional support and resources to identify a solution to the problem. With repeated exposure to the general problem-solving process, students will hopefully internalize the strategy and apply it to future problems.

**Writing-to-Learn**

Writing-to-learn is an instructional strategy based on the belief that learning occurs during and as a result of writing (Klein, 1999). Writing-to-learn became popular when the focus in writing instruction shifted from the product to the process of writing, and content
area writing became an important part of content instruction (Ackerman, 1993). Writing serves as an opportunity for learners to organize ideas, make connections, reflect, explore new ideas, and construct knowledge (Baker et al., 2008; Chen, Hand, & McDowell, 2013; Newell, 2006). As Emig (1977) explained, “writing serves learning uniquely because writing as a process-and-product possesses a cluster of attributes that correspond to certain powerful learning strategies” (pp. 122). She further explained that writing integrates multiple representations of information, produces powerful self-provided feedback, aids in making connections between concepts, and is an active, engaging process. Since Emig’s initial description of how writing aligns with learning, research has continued to explore how writing can be used to learn.

There are several theories used to explain learning from writing. Some researchers suggest that learning occurs with any language, verbal or written, because language organizes and assigns meaning to thoughts and ideas (Britton, 1970). Other researchers hypothesize that writing causes learning by actually preserving ideas so they can be expanded upon and grown, which is known as the forward-search hypothesis (Klein, 1999). A third hypothesis that will be the basis for this review indicates that writing leads to the construction and transformation of knowledge (Scardamalia & Bereiter, 1984).

**Writing and Learning**

Writing is a complex cognitive process requiring the writer to create a physical product that accurately represents their understanding. Writers engage in active cognitive processing while writing which heavily taxes their working memory. Metacognitive
processes are simultaneously engaged to plan, monitor, and evaluate the writing process and products (Hacker, Keener, Kircher, 2009). Bereiter and Scardamalia (1987) hypothesized that during this active processing of old and new information in relation to the writing goal, individuals construct a new, deeper understanding of the concepts. Interactions occur between content space and rhetorical space as the writer attempts to meet writing goals, leading to a change in the content and organization of the writer’s knowledge (Bereiter & Scardamalia, 1987). Knowledge transformation is a valuable by-product of the writing process and a desirable goal in learning situations.

Bereiter and Scardamalia (1987) categorized writing tasks as either knowledge-telling or knowledge-transforming. While some writing assignments simply allow the author to state what they know, other writing tasks demand a higher level of cognitive processing that leads to changes in the structure of knowledge. Schumacher and Nash (1991) describe three types of learning that can occur: accretion, tuning, or restructuring. Accretion, or the assimilation of knowledge, results from adding new knowledge to existing structures. Tuning is simply making slight adjustments to knowledge structures to accommodate new information such as transferring one problem strategy to a similar problem. Truly transformative learning, on the other hand, causes a restructuring of knowledge and potentially a completely different understanding. Writing has the potential to lead to knowledge restructuring, but is highly dependent upon the context and nature of the writing task itself.

A variety of writing tasks exist that may or may not result in learning. The extent of idea manipulation that occurs during writing impacts the amount of learning that occurs
In order to understand how writing can lead to learning, researchers classified writing tasks into three categories: restricted writing, summary writing, and analytic writing (Newell, 2006). Restricted writing represents tasks with very little if any actual composition such as answering study questions. Learners simply identify the factual answer and respond to the question, requiring no additional processing of the information. During summary writing tasks, learners survey a larger body of information to combine and integrate ideas. While this requires more processing than a restricted writing task, summaries still result in superficial learning because the contents tend to focus on major ideas presented linearly.

Analytic writing tasks require learners to examine the relationships between ideas, often leading the writer to formulate and support an argument (Newell, 2006). This task demands extensive manipulation of ideas, and therefore provides opportunities for learners to restructure and transform their understanding of the topic. Argumentative writing assignments improve learning beyond restricted and summary tasks and are powerful learning tools for content areas (Chen et al., 2013).

School based writing assignments are often non-transformative, especially in the more challenging, abstract classes that could benefit from writing-to-learn activities (Honig, 2010; Lerner, 2007; Reynolds et al., 2012). Science classes, for instance, often consider knowledge-telling assignments such as note-taking, fill in the blank worksheets, and chapter summaries to be appropriate writing tasks (Bereiter & Scardamalia, 1987; Yore, Bisanz, & Hand, 2003). However, these assignments rely on memorization and regurgitation of facts.
rather than active, constructive knowledge processing. Writing assignments that require analysis and argumentation are much better suited for both learning and practicing science (Rivard, 1994). Writing to learn using argumentation and analysis is a great way to not only improve learners’ understanding in content areas, but also to show learners that writing is a versatile, necessary tool.

Contextual factors beyond task selection influence learning from writing (Ackerman, 1993; Bangert-Drowns et al., 2004; Langer & Applebee, 1987). Engaging students in meaningful learning processes during writing requires authentic writing tasks (Chen et al., 2013). Assignments completed solely for a grade do not provide a purpose for learners beyond reproducing the required facts. Authentic writing tasks, such as letters or learning reflections, have an inherent purpose that appeals to learners. These tasks also require learners to manipulate their ideas in order to clearly communicate their understanding. Likewise, writing tasks with audiences other than teachers encourage learners to make connections between the real world and course content (Chen et al., 2013; Yore et al., 1999). Writing to other audiences also requires students to translate content area vocabulary to general terms and elaborate on their ideas by providing examples. Finally, contextual features that encourage revisions and redrafts benefit learning, especially if feedback is provided to encourage learners to provide additional details and explanations (Chen et al., 2013; Hein, 1999; Yore et al., 1999). Careful analysis of writing tasks’ contextual factors is important to understand writing’s impact on learning.
As noted before, the writing to learn movement was influenced by the need to increase writing across the curriculum. Many of the initial studies were completed at the high school and college level, where writing skills were not thought to interfere with learning from writing (Rivard, 1994). Bangert-Drowns et al.’s (2004) meta-analysis of writing-to-learn research revealed that writing studies completed with middle school students had negative effects on learning, suggesting that writing may not benefit young learners. However, research has shown that young students can benefit from writing to learn, particularly when the proper support is provided and the selected tasks provide the appropriate cognitive demands (Chen et al., 2013; Klein, 1999; Klein & Yu, 2013; Peasley, Rosaen, & Roth 1992). Bangert-Drowns et al.’s (2004) results were based on a small sample of studies (six) and do not account for important factors such as students’ recent transition to subject-specific writing in middle school or features of traditional classroom instruction and assessment that impact the results. Further, only two of the six studies were based in science writing. A more updated meta-analysis would likely include a greater number of studies and potentially have different results for middle school aged children.

The use of computers and word processing software is quite common and beneficial for writing. The cognitive processes that occur during writing do not change when writing is completed on the computer (Hartley & Tynjala, 2001). Meta-analyses of the literature also indicates that elementary and adolescent students actually benefit from using computers for composition (Graham & Perin, 2007; Graham et al., 2012).
**Measuring Learning from Writing**

Measuring learning from writing requires making inferences and assumptions about the writer’s prior knowledge, current knowledge, the strategic processes that were used to get there, and what is being measured with the assessment tools. Thus far, results from writing-to-learn research have been mixed (Bangert-Drowns et al., 2004; Klein & Yu, 2013), bringing the utility of writing into question. Often, the mixed results in the writing-to-learn literature are a result of inappropriate measurement tools. In order to measure learning from writing, research must first select measurement tools that are specific to the writing task and expected learning outcomes.

According to Ackerman (1993), the lack of contextual information in the writing to learn research contributes to the ambiguous results. Writing research that lacks details about the type of writing task and the type of learning expected (content, metacognitive, strategic) limits the interpretability of the results. In order to measure learning from writing, the writing task itself must first be selected carefully and analyzed to determine the cognitive processes required of the writer during composition (Schumacher & Nash, 1991). As discussed above, analytic writing assignments are more likely to lead to learning because they require the writer to restructure their knowledge to meet the demands of the task. However, even analytic essay writing has not shown consistent gains in knowledge because additional factors such as the context of the writing task, its purpose, and the writer’s interpretation of the task influence the amount of learning that occurs. (Ackerman, 1993). Writing to learn requires the writer to believe that writing is important for learning in order to engage them
with the challenging process (Boscolo & Mason, 2001; Hand, Prain, & Yore, 2001). Task selection, intervention strategies, and contextual measures are important factors in measuring learning from writing, and attention to these details can improve findings in this area.

A second important aspect of measuring writing from learning is selecting the method of measurement. In spite of writing-to-learn’s shift towards more process based methods of assessment, research studies often rely on recall and recognition assessments to show a growth in knowledge (Ackerman, 1993; Bangert-Drowns et al., 2004; Schumacher & Nash, 1991). Schumacher and Nash (1991) questioned this methodology since these assessments measure the accretion of knowledge but not the restructuring or transformation of knowledge, which are considered the important results of writing-to-learn. These assessments can be improved by including high level questions that address conceptual understanding. For instance, Rivard (1996) included multiple-choice questions that address simple knowledge and questions addressing integrated knowledge. Further, essay questions were also used to assess students’ understanding in this study and were scored for both simple knowledge and integrated knowledge.

Rather than traditional content assessments, another option for measuring learning from writing is to score the written products (Durst, 1987; Newel, 1984). Glogger et al. (2012) analyzed ninth grade students’ mathematics and biology journals and identified both cognitive and metacognitive strategies within the writing. While scores derived from the writing samples can offer some information about the resulting knowledge structure, they do not provide an initial measure of the knowledge structure. Additionally, the final product is
not representative of the knowledge transformation process the writer engaged in and only represents the information the writer determined necessary to convey their ideas (Hacker et al., 2009). A carefully designed task with specific, identifiable learning outcomes is necessary for measuring learning from writing.

Think aloud protocols have also been used to examine the writing process (Hayes & Flower, 1980; Klein, 1999; Langer & Applebee, 1987; Scardamalia et al., 1984). Analysis of verbal protocols allows researchers to identify strategies and steps writers use to reach their goals. Based on Flower and Hayes’s (1981) cognitive process theory of writing, Klein (1999) analyzed verbal protocols of elementary school students writing about a science concept (buoyancy or balance) after experimenting to learn about these concepts. Using the verbal protocols, Klein (1999) identified cognitive and metacognitive strategies used in writing such as planning, setting goals, organizing information, reviewing text, evaluating progress towards goals, and revising. Langer and Applebee (1987) also used think aloud protocols to examine students’ reasoning and recall strategies during a writing task based on previously studied material. Analyses of verbal protocols have been useful in identifying strategies applied during writing, but have not been used to measure knowledge restructuring. Think aloud protocols also interrupt normal cognitive processes and increase cognitive load due to the demands of verbalizing strategies while writing (Hacker et al., 2009). Hacker et al. (2009) suggested the use of eye-tracking to measure real time writing processes without placing additional demands on writers. Eye-tracking data can be used to make inferences about the
use of cognitive strategies during writing, but still only produces a measure of the writing process and not the knowledge transformation that should produce learning.

Schumacher and Nash (1991) proposed the use of popular cognitive psychology methods for measuring knowledge restructuring including reaction time, priming procedures, ordered trees from recall, multidimensional scaling, hierarchical clustering analyses and weighted networks. Although research has employed these methods to examine the structure of knowledge and even differences between novices and experts (Schumacher & Nash, 1991), the findings from these studies are still incomplete. While these measurements take additional factors into account beyond the accumulation of knowledge or quality of writing, they rely on assumptions of processing. For example, decreased reaction time is considered evidence of an improved knowledge structure because participants are taking less time to search and find information. Aspects of these strategies can prove useful for examining writing-to-learn studies, but can be improved and expanded upon to produce a more thorough understanding of learning.

If the desired learning outcomes from writing require knowledge transformation and restructuring, measures that examine changes in knowledge structure are important to gauge success. Concept maps are frequently used to understand learners’ conceptual understanding and schema for a topic (Rice, Ryan, & Samson, 1998). Schumacher and Nash (1991) suggested using methods such as ordered trees to examine knowledge structures, which are similar to a restricted concept map. Concept mapping has been used to examine prior knowledge and change after an intervention (Segalas, Balas & Mulder, 2008). Rice et al.
used science instructional objectives to create scoring guides for concept maps and found scores strongly correlated with other measures of classroom performance. Concept maps can also be compared to those of experts to identify similarities and the depth of knowledge (Schumacher & Nash, 1991), which could be further used to score knowledge structures and growth. Post assessments that measure conceptual knowledge structure may be useful in measuring writing-to-learn since they provide information about the learner’s understanding and connections between concepts.

There has been a call for high quality writing research that more fully addresses the writing task and context to better understand the role of writing in learning (Ackerman, 1993; Bangert-Drowns et al., 2004; Graham & Harris, 2014; Graham & Perin, 2007; Graham et al., 2012; Langer & Applebee, 1987). As indicated through literature reviews and meta-analyses (Bangert-Drowns et al., 2004; Gunel, Hand, & Prain, 2007), the science focused writing-to-learn research is especially lacking in adequately described, well-designed studies to answer key questions about writing and learning in science.

**Writing and Learning in Science**

Written language is integral to the practices of science, allowing scientists to inform or persuade others, interpret and preserve knowledge, and even dispute claims (Moskovitz & Kellogg, 2011; Yore et al., 2003). While the dominant view of science writing is a knowledge-telling model, scientific writing does not solely transmit information to others. Science writing is actually better represented as a knowledge-transforming model in which scientists use writing to construct new understandings, reflect on the evidence and
argumentation in their research, and develop theories. While scientists most often use writing as a “means to doing science and to constructing science understandings” (Yore et al., p. 691), writing in science classrooms tends to require a superficial restatement of well known factual information without any processing demands for knowledge construction. Writing is a powerful tool and should be used as such in science classrooms (Baker et al., 2008).

Despite the known benefits of writing-to-learn, writing is inadequately used in science learning (Yore et al., 1999). Student reported data from the 2007 National Assessment of Educational Progress (NAEP) showed that only 30% of eighth grade students and 21% of twelfth grade students reported writing a paragraph or more once a week in their science class (Applebee and Langer, 2009). Additionally, most student writing in science consists of short, informational passages written solely for the teacher to evaluate students’ factual knowledge (Yore et al., 2003). As discussed by Abell (2006), “one of the most important reasons for using writing in science is to foster conceptual understanding” (pp. 60). Writing in science should be more than writing about science; students should be writing to learn science. Instead of asking students to regurgitate factual information, students’ science writing should capitalize on cognitive and metacognitive processes to transform and construct knowledge.

With the popularity of writing across the curriculum, reflective writing in journals has become an efficient method for including informal writing opportunities in the classroom (Ackerman, 1993; Klein & Yu, 2013; Rivard, 1994). Journals differ in their learning purpose, some focusing more on content and others on learning strategies. Schlichtmann et al.’s
(2013) online science notebook and Hein’s (1999) in-class portfolio both helped learners focus on the specific course content to improve learning. Glogger et al. (2012), however, asked students to write about the cognitive and metacognitive strategies they applied to learn the content, directing their attention to their learning processes in addition to the content. Writing that focuses on strategic knowledge in addition to content knowledge is beneficial in writing-to-learn tasks (Bangert-Drowns et al., 2004; Rivard, 1994) given that it helps learners reflect on and evaluate strategies.

Formal writing tasks such as laboratory reports and essays are also common in science. The Science Writing Heuristic (SWH) is a writing strategy that scaffolds students to build arguments using evidence and support from inquiry experiences (Klein & Yu, 2013; Nam, Choi, & Hand, 2010). Compared to students with no writing support, students using the SWH have increased content knowledge, awareness of cognitive and metacognitive processes, and understanding of inquiry processes (Hand, Wallace, & Yang, 2004). The proper instructional supports for learning, whether conceptual, cognitive, or metacognitive, must be provided to help learners benefit from writing activities (Rivard, 1994). The SWH helps learners engage in knowledge transformation processes during writing tasks, which may not occur without the provided support.

Some non-traditional writing-to-learn activities have also been used in science learning. Chen et al. (2013), for example, examined elementary students’ conceptual understanding in physics by writing letters to older peers. In this study, eleventh grade students wrote letters to fourth graders posing a physics conceptual question that they would
be studying and the fourth graders responded with evidence-based explanations to the questions. A second set of letters were exchanged between the high school and elementary school students in which the high school students provided feedback and asked for elaborated ideas and additional evidence. The elementary students were able to revise their initial response, improving upon their argument and gaining a deeper conceptual understanding. In addition to significantly outperforming the control group knowledge on a pre/post assessment, the study also identified some key features of writing to learn tasks such as the use of multiple modal representations, the quality of evidence at students’ disposal for supporting claims, and the role of audience in writing.

The process of writing allows scientists to create an argument for their research and assess the validity of this argument. In contrast, most students’ science writing products are only useful to the teacher for assessment purposes. If students need only look in the textbook to copy answers to the teacher’s questions writing does not improve learning. Writing tasks can be designed to improve students’ learning. Science writing assignments that emphasize the writing process support the development of students’ conceptual understanding. It is also important for the central focus of the writing task to be the science content in order for students to actively construct new knowledge (Connolly, 1989; Yore, Hand, & Prain, 1999). Another way to improve learning from writing is to provide students with audiences beyond the teacher. Requiring students to write for different audiences forces them to translate their factual knowledge into understandable information and examples (Chen et al., 2013; Connolly, 1989). Students also need sufficient pre-writing time to collect evidence and
supporting information from multiple sources in order to build an understanding of the concept (Klein & Yu, 2013). The appropriate instructional support helps students to organize and synthesize their knowledge, while immediate feedback can identify areas that need clarified (Chen et al.; Hein, 1999). Young students also benefit from a series of writing tasks that help guide them through the knowledge transformation process (Hand, Prain, & Yore, 2001).

**Creative Writing in Science Learning**

Narrative and creative writing tasks are not well represented in writing-to-learn studies, potentially because they are not considered knowledge-transforming tasks. Additionally, creativity is underutilized in science classes, as many teachers do not see its role in a fact-based field (Kaufman & Sternberg, 2010). Contrary to this belief, creativity is actually an important factor in many scientific discoveries, and creative writing tasks can potentially support science knowledge construction (Park & Seung, 2008). Unfortunately, very little literature currently exists in this area and most reports are anecdotal.

It is true that many creative writing tasks in science (i.e. write a poem about a scientist, create a radio interview about a scientist) do not encourage knowledge transformation and instead allow the restatement of factual knowledge (Harris & Cote, 2008; Weiss-Magasic, 2012). Tasks that require the reorganization of ideas, translation of information to more common language, and the creation of examples encourage learning during the writing process (Gunel et al., 2007; Gunstone, 1995; Sutton, 1992). Creative writing tasks can address these needs while also including audiences beyond the teacher. Finally, creative...
writing tasks may be more motivating for students, especially young students, than more traditional science writing tasks.

In one example of a creative writing task that encouraged knowledge transformation, Nicholas and Ng (2008) asked gifted students to write a script for a play about electricity. This writing-to-learn activity required students to creatively apply their science knowledge and then perform the play for an audience. Concepts in electricity curriculums tend to be abstract, often making it difficult for students to learn the material on a deeper level. Writing the play pushed students to process their science knowledge on multiple levels and create physical representations of the concepts to build a new understanding of electricity. These kinds of creative writing-to-learn tasks can motivate students and help them learn in the process.

**Metacognition**

Metacognition has been loosely defined as thinking about thinking or knowledge of one’s own cognitive processes (Flavell, 1979; McCormick, 2003). Metacognition consists of two major components: knowledge of cognition and regulation of cognition (Brown, 1987; McCormick, 2003; Schraw & Moshman, 1995). Knowledge of cognition can be separated into declarative, procedural and conditional knowledge about one’s thinking. While declarative knowledge refers to knowledge about the factors that influence performance, procedural knowledge describes knowledge about how to actually perform certain procedures. Conditional knowledge is knowledge of when and why to apply various
strategies and procedures. It is crucial for learners to have adequate declarative, procedural and conditional knowledge in order to independently select, apply, and switch strategies as needed.

The second major component of metacognition, regulation of cognition, includes key skills such as planning, monitoring and evaluation (Schraw & Moshman, 1995). During planning, learners select the appropriate strategies for their learning goals and allocate the needed resources. While engaged in a task, learners must simultaneously monitor their progress towards their goals to make adjustments and shift strategies as needed. Evaluating the cognitive processes applied and the results of the task is helpful for improving learning as well as the metacognitive knowledge that can be applied in future learning events.

Metacognitive knowledge and skills are important for learning (Hacker et al., 2009; Hartman, 2001; Schraw, 2001; Pressley & Gaskins, 2006). Higher levels of metacognition have been linked to higher levels of reading comprehension (Pressley & Gaskins; Thiede, Anderson & Therriault, 2003; Williams & Atkins, 2009), improved writing (Hacker et al.), improved problem solving (Bernardi-Coletta, 1995; Fortunato et al., 1991; King, 1991; Swanson, 1990), and overall higher achievement (Hartman, 2001). Metacognition is also an important component of critical thinking (Ku & Ho, 2010) and is necessary for students to learn from inquiry (White, Frederiksen, & Collins, 2009). Metacognitive knowledge can be improved with explicit modeling of strategies including information on how, when, and why to use them (Schraw, 2001). A regulatory checklist can assist students in improving their
regulation of cognition by focusing their attention on planning, monitoring, and evaluation while performing a task.

**Developing Metacognition in Children**

Evidence of metacognition appears in young children and develops through adolescence and beyond (Schraw & Moshman, 1995). Children as young as three years old are able to differentiate between their thoughts and actual perceptions, showing evidence of their knowledge of thinking (Kuhn, 2000). At this age, children also show evidence of monitoring their thinking (Lyons & Ghetti, 2010). When answering questions three year olds refrain from answering questions when they are not confident of the answer and respond when their confidence is high (Lyons & Ghetti, 2010). Young children are also aware of the sources of their knowledge and that other people have different thoughts that may not align with their thinking (Kuhn, 2000). However, while these young children show evidence of metacognitive knowledge, they are not able to express this knowledge (Schraw & Moshman, 1995). Therefore, much of the resultant research into metacognition has focused on children nine years and older given that these children are able to articulate their thoughts.

Developmental processes differ for metacognitive knowledge and metacognitive control processes (Neuenhaus et al., 2011). Metacognitive knowledge steadily increases with age, but metacognitive control processes do not have a clear relationship with age (Schneider, 2008). Roebers, Schmid, and Roderer (2009) found that by the age of nine children monitor their knowledge by accurately distinguishing between correct and incorrect answers. However, it isn’t until ages 11 to 12 that children are able to apply more challenging
control processes. Children as young as six can differentiate between difficult and easy questions, but it is not until age 10 that children can appropriately allocate their study time to spend more time learning difficult material. Schneider et al. (2000) found that children’s ability to monitor their learning by making immediate and delayed judgments of learning develops as they get older. While children are not as accurate as adults, both children and adults show the same patterns in their global and item level judgments related to their performance on cognitive tasks.

Metacognitive knowledge, particularly strategic knowledge, increases once children enter school (Neuenhaus et al., 2011). Classroom instruction often includes metacognitive components, specifically declarative knowledge of strategies (Schnieder, 2008). However, children do not readily transfer these strategies to new domains and contexts (Lyons & Ghetti, 2010), but this ability can be improved with the proper instruction focusing on conditional knowledge (Neuenhaus et al., 2011). Improving children’s metacognitive regulation relies on instruction, modeling, and practice.

**Metacognition in Problem Solving**

Currently, problem solving in schools is largely restricted to well-structured as opposed to ill-structured problems. Students are generally successful at retaining and applying these algorithms, but they struggle when asked to transfer strategies to non-routine problems (Mayer, 2001). Metacognitive knowledge and regulation processes play an important role in problem solving and strategy transfer. Swanson (1990) found that students high in metacognitive knowledge outperformed students who were low in metacognitive
knowledge on puzzle problems, regardless of aptitude. Rozencwajg’s (2003) research into physics problem solving also showed that learners with low metacognitive monitoring applied low-level problem-solving strategies, decreasing their performance.

The importance of metacognitive knowledge is increased when solving non-routine and ill-structured problems because it facilitates the transfer of skills between problems (Ge & Land, 2004; Mayer, 2001). Improving childrens’ problem solving requires students to evaluate the strategies they are applying and subsequently to make adjustments to their problem-solving approach. Delclos and Harrington (1991) examined problem solving in Rocky’s Boots, a computer-based problem-solving game, and found that students who monitored and reflected upon their problem-solving process had improved problem-solving performance. Additionally, these students were more likely to transfer their newly learned problem-solving strategies to new problems. If students are not taught to monitor and control their problem-solving processes they will likely not transfer skills to new areas, a primary goal of strategy instruction (Pressley & Harris, 2006).

solvers find and assess solutions to the problem. Additionally, the scaffolding requires the problem solver to access metacognitive knowledge from previous problems and build additional knowledge for future problems.

Research has shown that experts are better problem solvers in their domains due to strategic knowledge rather than simply content knowledge (Schunn, McGregor, & Saner, 2005). Experts’ conditional metacognitive knowledge of strategies helps them easily select and apply the most appropriate strategy to reach a problem solution. Metacognitive skills are quite useful because children do not always have the necessary background knowledge to solve ill-structured problems. For instance, Chen and Bradshaw (2007) used metacognitive scaffolds to promote knowledge integration during ill-structured problem solving. The scaffolds reminded participants to reflect on their related prior knowledge in order to build a better problem representation. This scaffolding can help children search for useful strategies from other domains and apply them to the new problem. Engaging in this practice can also create a disposition in children to transfer strategies in future non-routine or ill-structured problem-solving scenarios.

Metacognitive Prompting to Improve Metacognition and Learning

Children’s metacognitive knowledge and regulation of cognition can be improved with instruction focusing on strategies and the development of conditional knowledge for each strategy (Pressley & Gaskins, 2006; Schraw, 2001). Explicitly focusing on conditional knowledge helps learners generalize strategies and apply them in new situations. A student reflection sheet can be used during cognitive skill instruction to assist students’ reflection on
the essential pieces of conditional knowledge for each strategy (how, when, and why to use each strategy) and a regulatory checklist can remind students to plan, monitor, and evaluate their strategies while learning (Schraw, 2001). Engaging in these regulatory processes prompts students to access previously learned material and strategies and to transfer their use to new situations while simultaneously increasing their metacognitive knowledge (Bransford et al, 1986; Hartman, 2001).

As noted, metacognitive scaffolding aids students in developing the necessary conditional knowledge during cognitive skill instruction (Bransford et al., 1986; Schraw, 2001). Developing the proper conditional knowledge can prevent students from learning inert strategies by illustrating how strategies can be generalized to new situations. Scaffolding prompts can lead students to reflect on the how, when, and why of strategies while simultaneously applying them in a learning situation. Metacognitive scaffolding also provides a model of the processes learners should engage in during learning. By providing this model and leading students through the metacognitive processes, students hopefully internalize these processes and improve their metacognition (Hoffman & Spatariu, 2008).

Instructional strategies often include question prompts to scaffold learners by directing their focus to important information and asking them to reflect on their metacognitive processes (Bulu & Pederson, 2010; Chen & Bradshaw, 2007; Delclos & Harrington, 1991; Kauffman, 2004; King, 1991; King & Rosenshine, 1993). Aligning with Vygotsky’s social learning theory, the scaffolding provides support similar to that provided by the more knowledgeable other, helping students advance to the next level. While teachers
generally embed metacognitive knowledge and cues for applying this knowledge in their lessons, scaffolding prompts in computer-based learning environments (CBLE) can serve a similar purpose by providing students with cognitive tools, instructional scaffolds, and feedback to improve their learning and metacognition (Bulu & Pederson, 2010; Chen & Bradshaw, 2007; Delclos & Harrington, 1991).

Numerous studies have combined metacognitive scaffolding with CBLEs to improve content learning, cognitive skill learning, and general metacognitive knowledge and processes (Desoete, Roeyers, & De Clercq, 2003; Ge & Land, 2003; Hoffman & Spatariu, 2008). Delclos and Harrington (1991), for instance, examined the use of metacognitive prompts with fifth and sixth grade students playing a computer-based problem-solving game. The students who completed the prompts before, during, and after each game solved more complex problems in less time than students without the metacognitive prompts. Chen and Bradshaw (2007) also found that college students solving real-world, ill-structured problems performed better when presented with prompts to reflect on and integrate their prior knowledge. These metacognitive prompts facilitated intentional reflection to construct integrated problem representations and identify superior problem solutions. Bulu and Pederson (2010) also found that domain-general (metacognitive) prompts lead to improved monitoring and evaluation, and facilitated students’ transfer problem-solving skills when prompts were faded.

Computer programs can be designed to provide immediate feedback to students while learning to help them adjust and correct their learning and strategies. Roll et al. (2011)
provided immediate metacognitive feedback to geometry students studying in a computer-based program. The feedback was designed to help students evaluate their help-seeking strategies (asking the program for hints while solving problems) while working in the program. Each problem contained several hints that became consecutively more specific until the final, or bottom-out hint, provided the exact directions for solving the problem. Students were able to ask for as many hints as needed while solving the problem. Results showed that metacognitive feedback lead to fewer bottom-out hints during problem solving. Saadwi et al. (2010) also found that immediate performance feedback in a medical tutoring program led to higher metacognitive performance as measured by the accuracy of participants’ judgments of learning. However, once the feedback was removed, the improved performance was not maintained. Comparing the provided feedback in these two studies, it appears that Saadawi et al.’s feedback did not lead participants to reflect on their processes, but was instead a crutch that only temporarily helped students learning. Computer provided feedback, while convenient, must also be designed to force reflection in learners to assist in the development of metacognitive knowledge.

CBLE’s can promote more accurate metacognitive monitoring by asking students to make frequent judgments of their performance or perceived ability (Winne & Nesbit, 2009). Requiring students to make metacognitive judgments encourages reflection, an important regulatory process. Reflection helps students judge their learning progress and strategies, providing an opportunity to make adjustments and improve performance. With regular practice, students can adopt monitoring processes to improve their metacognition. The VisA,
discussed earlier, also requires learners to provide explanations for their judgments (Jacobse & Harskamp; 2012). These explanations may cause learners to identify the cause of their judgment to improve their metacognitive knowledge.

In order to improve metacognition, computer-based interventions must engage learners in meaningful processes rather than superficial activities. Winne & Nesbit (2009) noted that computer programs can facilitate metacomprehension, but only if learners self-assess their understanding and strategies throughout the learning experience. As discussed above, some computer-based metacognitive supports do not help students. It is important that the instructional supports within the computer program are aligned with the specific metacognitive processes targeted by the intervention. It is also critical that interventions explicitly model the metacognitive processes and provide students with opportunities to practice and reflect on the skills.

Some CBLE’s such as MetaTutor (Azevedo et al., 2010) and gStudy (Perry & Winne, 2006) have been designed to provide more intelligent, personalized, and adaptive scaffolding to support metacognition and learning. Azevedo et al. (2012) developed pedagogical agents within MetaTutor, a hypermedia learning environment, that prompt users to apply different metacognitive processes and provide immediate feedback on their use of the strategy. Participants receiving prompts and feedback learned more efficiently than those receiving only prompts or no prompts. Intelligent, adaptive tutors, like those in MetaTutor, are able to provide instructive, just-in-time help to learners, and fade away as learners acquire metacognitive skills and apply them independently. This kind of individualized support is
quite expensive and time intensive to create, which is why relatively few programs are currently using these supports in their programs.

**Metacognition and Writing**

The role of metacognition in writing is well established in the literature (Glynn & Muth, 1994; Klein, 1999; Rivard, 1994; Scardamalia & Bereiter, 1984) and considered an essential component of writing (Bangert-Drowns et al., 2004; Hacker et al, 2009; Pugalee, 2004; Scardamalia, Bereiter, & Steinbach, 1984). Writing requires the translation of thoughts to an organized, clear representation that accurately represents the writers’ knowledge and goals. Throughout this recursive process, the writer plans, monitors progress, rereads, revises, and reflects on the products’ alignment with their writing goals (McCormick, 2003). As the writer metacognitively monitors their own understanding and the representation of this understanding in their writing, they transform their knowledge to develop a deeper understanding (Hacker et al., 2009).

Writing-to-learn activities rely on high-level metacognitive processes to regulate the writing process and products (Bereiter & Scardamalia, 1987; Rivard, 1994; Scardamalia & Bereiter, 1984). The act of writing about a topic engages cognitive and metacognitive processes that may not have been used otherwise to aid learning. Pugalee (2004), for instance, compared written and verbal descriptions of ninth grade students’ algebra problem solving and discovered that students who wrote about their problem-solving processes were significantly more successful at problem solving than those who verbalized their processes. Examination of the verbal and written descriptions indicated more comprehension strategies,
problem assessment, and problem representation in the group who wrote about their problem solving. These individuals also spent more time monitoring and assessing their problem-solving success while writing. The act of writing about problem solving rather than simply verbalizing seems to help learners engage in more metacognitive processes while solving the problems, which improves success.

Writing is similar to an ill-structured problem because of the vague goals and lack of a specific path to reach the goal state. However, just like problem solving, writing can be improved with explicit instruction that includes cognitive and metacognitive skills (McCormick, 2003). Well-established writing instructional programs, such as self-regulated strategy development (SRSD), include metacognitive instruction to develop learners’ strategic knowledge and monitoring during writing (Graham, Harris, & Mason, 2005; Harris, Graham, & Mason, 2006). SRSD uses explicit cognitive-focused writing instruction to improve skills, strategic behavior, knowledge, and motivation in writing, all key pieces for students’ success.

The inclusion of metacognitive monitoring and evaluation prompts during writing can improve writing-to-learn outcomes (Bangert-Drowns, 2004; Glynn & Muth, 1994; Scardamalia, Bereiter, & Steinbach, 1984). Questions that direct students’ thinking to include additional details and clarify ideas are beneficial while writing. Writing prompts can also help students identify connections between fragmented pieces of knowledge to build a cohesive understanding of the content. These prompts are especially helpful to younger children who have not fully developed their own metacognitive knowledge and processes. In
Chen et al.’s (2013) study, high school students asked elementary students to clarify their ideas and provide more information in their responses to physics questions. These prompts helped students revise their writing and improve their understanding of the content. Metacognitive prompts also help students improve their own metacognitive monitoring, which will improve their future writing.

**Overview of Current Study**

Engaging students in complex physics problem solving can improve students’ content knowledge (Sinatra & Taasoobshirazi, 2011), encourage them to address misconceptions (Mayer, 2013), and increase their problem-solving skills (Hartman, 2001b). Integrating complex ill-structured problems into the physics curriculum provides students with opportunities to solve meaningful, real-world problems that encourage the application of knowledge rather than the memorization of facts. Integrative lessons also allow teachers to meet the goals of the Common Core and Next Generation Science Standards to improve problem solving and critical thinking by addressing multiple skills while teaching the science curriculum (National Governors Assn., 2010; NGSS, 2013). Further, complex, ill-structured problem-solving experiences provide important opportunities for students to use writing for learning. A variety of authentic writing tasks can be incorporated into problem-solving experiences to help students improve their understanding of the physics content and problem-solving process.
The current study examines the impact of narrative writing and problem-solving prompt writing on seventh grade students’ physics content learning and problem-solving skill acquisition during ill-structured physics problem solving. While the new Common Core Standards (2010) emphasize informational text reading and writing, current research suggests that middle school students may not benefit from the traditional informational writing-to-learn tasks (Bangert-Drowns et al., 2004). In order to provide middle school students with valuable writing-to-learn opportunities while solving ill-structured problems, non-traditional writing-to-learn tasks must be explored. Gunel et al. (2007) found science writing tasks that require students to re-represent and apply their knowledge, such as writing tasks with a design or problem-solving focus, lead to increased performance on content assessments. Gunstone (1995) and Sutton (1992) also suggested that science writing should include opportunities for students to translate technical science language into everyday language and to explain, elaborate, and integrate their knowledge of science concepts. Further, studies have shown that non-traditional writing tasks, such as writing a letter or play, can improve learning of challenging science topics and increase student motivation (Chen et al., 2013; Nicholas & Ng, 2008). While narrative writing tasks are generally excluded from the writing-to-learn literature (Newell, 2006), carefully designed narrative writing tasks can meet all of the requirements for science learning to occur during writing. Narrative writing tasks may also be easier and more appealing for middle school students, allowing them to learn from their writing.
In this study, the narrative writing tasks are designed to assist students in applying knowledge gathered from research and experimentation to real world scenarios. Students solve six ill-structured physics problems in a computer-based problem-solving intervention, Solve It!. Solve It! has two main goals, to improve conceptual physics knowledge and teach students general problem-solving strategies that can be applied to new problems in the future. Both of these goals are achieved through writing activities in the program that are designed to foster content learning and problem-solving skill acquisition. Solve It! introduces students to real-world, ill-structured physics problems that are embedded in short stories. Once the problems are introduced, the story stops and students are asked to solve the problem and finish writing the story. The program scaffolds students through a five-step general problem-solving process using metacognitive problem-solving prompts to help students identify relevant physics knowledge and apply the knowledge to the problem solution. Students write their responses to each of the prompts as they move through the program, which is more representative of traditional writing-to-learn activities. Once students have identified a problem solution, they use this information to finish writing the story. While writing the story, students make connections between the science concepts and the real world problem. The application of science knowledge and translation of that knowledge to common language and examples encourages deep learning and conceptual understanding. Students also use their own research and experimentation as the basis for their writing, which helps them evaluate the processes they used while solving the problem.
Seventh grade science students were randomly assigned to one of four conditions (Write Prompt + Write Story, Think Prompt + Write Story, Write Prompt + No Story, Think Prompt + No Story) while solving ill-structured physics problems in *Solve It!*. A sequential explanatory (QUAN+qual) mixed methods design was utilized to determine the impact of the two writing tasks (writing prompt responses and writing the story) on learning (Creswell & Clark, 2011). A mixed methods design was selected because both quantitative and qualitative data are essential to answer the research questions. Quantitative analyses were used to answer the main research questions and qualitative data were collected to help explain the results. The diagram in Appendix A shows the study design, data collection, and data analysis overview.

Three primary research questions were addressed in this study. *What is the impact of narrative and prompt response writing on seventh grade students’ physics knowledge, problem solving strategies, and self-efficacy?* It was predicted that students who wrote both the problem-solving prompt responses and the narrative writing task would outperform students in the other three conditions on physics knowledge, problem-solving strategies, and self-efficacy for science and writing. Research has shown that young students’ learning benefits from a series of writing tasks that contribute to the final writing task (Chen et al., 2013). By writing responses to the problem-solving prompts and writing the end of the narrative problem-solving scenario, it was expected that students would develop higher levels of physics knowledge, problem-solving strategies, efficacy, and confidence than students in other conditions. Students who wrote either the problem-solving prompts or the narrative
were expected to outperform students who did not write during the intervention. Significant differences were not expected between students who wrote either the problem-solving prompts or the narrative because both of these writing tasks provide students with opportunities to develop content knowledge.

*Is there a significant interaction between condition and prior knowledge, writing ability, or writing effort with respect to final physics knowledge or final problem solving knowledge?* Prior knowledge, writing ability, and writing effort were expected to impact the relationships between condition and final physics knowledge and condition and final problem-solving knowledge. A significant interaction was expected between experimental condition and prior physics knowledge for final physics knowledge, since prior knowledge plays an important role in ill-structured problem-solving solutions (Larkin et al., 1980; Voss et al., 1991). It was expected that students who began with higher levels of prior physics knowledge would end with higher levels of physics knowledge in all conditions. Further, students beginning with low prior knowledge in the WP + WS condition were expected to experience more growth in knowledge than students with high prior knowledge. The program scaffolds would be especially beneficial for low prior knowledge students because they force students to make connections between the research, experimentation, and real-world problem. Writing the end of the story would help to further enforce the knowledge and connections created while responding to the prompts in the WP + WS condition. This interaction was not expected in the other conditions.
A significant interaction was also expected between prior problem-solving knowledge and condition for final problem-solving knowledge. Students with low levels of problem-solving knowledge in the WP + WS and WP + NS conditions were expected to have higher levels of final problem-solving knowledge than students in the TP + WS and TP + NS conditions. This is because students in the WP + WS and WP + NS conditions spent time writing about each of their problem-solving steps during the program, which should improve their final problem-solving knowledge.

Writing ability can impact whether students’ benefit from the writing tasks (Bangert-Drowns et al., 2004), therefore it was expected that students with higher levels of writing ability would display higher levels of physics and problem-solving knowledge in the three conditions that include writing tasks (WP + WS, WP + NS, and TP + WS). Students with low levels of writing ability were not expected to show increased benefits from the writing activities because of the cognitive demands associated with writing. Story writing effort was also expected to play a large role in final physics and problem-solving knowledge. Students with higher levels of effort were expected to display higher levels of final physics and problem-solving knowledge in the two story writing conditions (WP + WS and TP + WS). Students with low effort in the story writing conditions were not expected to benefit from the story-writing task.

*How do students feel about learning from the problem-solving program?* It is important to understand what factors contributed to students’ learning outcomes in this study. Interview data from random sample of student across all four conditions will be used to
understand how students perceive the writing tasks in the program. Additionally, students will be asked to describe their learning outcomes from the study.
CHAPTER THREE

Methods

Participants

Recruitment. Seventh grade science teachers were recruited by email to use the problem-solving intervention, Solve It! with their students. Teachers from two middle schools in the Southeast, US agreed to participate in the study. The first school \( n = 105 \) was a public school with 40.57% of students qualifying for free and reduced lunch. The second school \( n = 12 \) was a small charter school with 83.59% of students qualifying for free and reduced lunch. Seventh grade students were recruited from participating teachers’ classrooms by requesting parental consent. All students in participating teachers’ classrooms had access to the program and materials, but students’ data was only used if their parents consented (105/116 in first school and 12/12 in second school).

Sample. A total of 117 seventh grade students (Boys \( n = 56 \); Girls \( n = 61 \)) participated in this study. The racial and ethnic composition of the sample was: Asian/Asian American 4.3%, Black/African American 16.2%, Hispanic/Latino 24.8%, and White 54.7%. Students ranged in age from 12 to 15 \( (M = 12.66) \). Individual students were randomly assigned to one of four conditions: Write Prompts + Write Story, Think Prompts + Write Story, Write Prompts + No Story, or Think Prompts + No Story.
Time Frame and Conditions

This study took place over nine consecutive days of science instruction prior to students beginning their physics curriculum. Teachers implemented the intervention during the early spring of the 2014-2015 school year. On the first two days of the study, students completed demographic questionnaires and pre-assessments on an online survey program. On days three through eight, students participated in the intervention using the computer based program Solve It!. During these days students used the program once each day for approximately 65 minutes. On the ninth day, students completed the post assessments in the online survey program.

*Note: Due to an error in the intervention program, the sixth story did not follow the condition specific guidelines. The story six data and related content questions were dropped from analyses.

The intervention consisted of four conditions:

1. **Write Prompts + Write Story (WP + WS):** Students in this condition wrote their responses to metacognitive problem-solving prompts in the problem-solving program. After completing the problem-solving steps, students finished writing the end of the story.

2. **Think Prompts + Write Story (TP + WS):** Students in this condition were presented with metacognitive problem-solving prompts, but did not provide written responses. Instead, they were asked to think about each step in the problem-solving process.
before moving to the next step. After thinking about all of the problem-solving steps, students finished writing the story ending.

3. Write Prompts + No Story (WP + NS): Students in this condition wrote their responses to metacognitive problem-solving prompts in the problem-solving program. However, students did not write the end of the stories during the intervention. Instead, students were asked to think about each story ending.

4. Think Prompts + No Story (TP + NS): Students in this condition were presented with metacognitive problem-solving prompts, but did not write their responses. Students were asked to think about each step in the problem-solving process before moving to the next step. In addition, students did not write the end of the stories during the intervention but were instead asked to think about each story ending.

Measures and Materials

Pre and Post Assessments (Appendix B)

Demographic questionnaire. Participants completed a three-item measure to identify age, gender, and ethnicity.

Test of Written Language (TOWL-4). Participants completed the spontaneous writing portion of the TOWL-4 (Hammill & Larsen, 2009) during the pre-assessments to measure writing conventions and story composition. The TOWL-4 is a measure of written language ability that has been normed with subjects ranging in age from nine years old to seventeen years and eleven months old. It is well suited to research studies because of its high reliability and validity. The spontaneous writing portion of the TOWL-4 assessment
requires participants to write a story about a provided image. Participants are provided with five minutes to plan their writing and fifteen minutes to write their story. Responses are scored using two rubrics, one for writing conventions and one for story composition. Two trained raters scored the samples. The first rater scored all of the samples. A second rater scored 20% of the samples and scores were compared. The Pearson moment correlation coefficient between the two raters’ scores was .93 for the writing conventions and .87 for the story composition.

**Force and motion content knowledge.** Participants completed a fifteen-item multiple-choice pre ($\alpha = .56$) and post ($\alpha = .60$) assessment of physics content knowledge. The assessment items were based on the Force Concept Inventory (Halloun & Hestenes, 1985) and the conceptual physics assessment used by Shute et al. (2013). The assessment focused on the major force and motion concepts addressed in the first five stories. The internal reliability was most likely low due to the varied topics on the assessment.

**Self-efficacy.** Participants completed a measure of physics self-efficacy and writing self-efficacy during both the pre and post assessments. The physics self-efficacy inventory was adapted from the Educational Psychology Self-Efficacy Inventory used by Nietfeld, Cao, and Osborne (2006). The survey consisted of eight items answered on a five-point Likert scale. The internal reliability was high for both the pre ($\alpha = .78$) and post administration ($\alpha = .82$).

The writing self-efficacy inventory was adapted from three self-efficacy inventories (Bruning et al., 2013; Nietfeld et al., 2006; Sanders-Reio, 2010). The survey consisted of 22
items on a five-point Likert scale. The items were grouped into five sub-scales: Ideation (pre $\alpha = .90$; post $\alpha = .89$), Audience (pre $\alpha = .85$; post $\alpha = .85$), Learning (pre $\alpha = .88$; post $\alpha = .89$), Interest (pre $\alpha = .82$; post $\alpha = .83$), and Self-Efficacy (pre $\alpha = .77$; post $\alpha = .74$).

**Problem-solving questionnaire.** Participants completed a problem-solving strategy questionnaire adapted from Fortunato (1991) who originally used the scale as a post problem-solving reflection. In this study the items have been adapted to reflect general problem-solving strategy use and was administered as both a pre and post survey. The questionnaire consists of 23 items on a five-point Likert scale that are grouped into four subscales: Before Problem Solving (pre $\alpha = .73$; post $\alpha = .84$), During Problem Solving (pre $\alpha = .81$; post $\alpha = .85$), After Problem Solving (pre $\alpha = .84$; post $\alpha = .86$), and Frequency (pre $\alpha = .08$; post $\alpha = .10$). Due to the extremely low internal reliability, the Frequency subscale was not used in further analysis.

**Problem-solving strategies.** Participants were asked to write a short description of how they would solve an ill-structured problem presented in a short scenario. Two different scenarios were used for pre and post assessments. Students’ descriptions were scored with a problem-solving rubric by two raters. The six-point rubric was based on the five problem-solving steps used in the program. Two raters worked together to score 20% of the pre and post assessments. Scores were compared and differences discussed at three points for each assessment. The Pearson moment correlation coefficient between the two raters’ scores was .92 for the pre assessment and .87 for the post assessment. A single rater scored the remaining scenarios.
**Jr. Metacognitive Awareness Inventory (Jr. MAI).** Students completed the Jr. MAI as a pre (α = .73) and post (α = .75) assessment of general metacognitive awareness (Sperling, Howard, Miller, & Murphy, 2002). The measure consists of 12-items answered on a 3-point Likert scale.

**Intervention Data**

**Solve It! data.** Log file data was collected from the problem-solving program including students’ responses to the prompts, students’ written story endings, and time spent per screen. This data was used to calculate word count scores and problem-solving time for analyses.

**Story effort.** Story writing effort scores were calculated for participants in the WP + WS and TP + WS conditions. An effort score was created for each story using the time spent writing the story and the length (word count) of the story. To calculate the score, Z-scores for writing time and writing length were combined. A mean story effort score was calculated across the five stories.

**Intervention Materials (Appendix C)**

**Intervention program.** The intervention took place in *Solve It!*, a computer-based metacognitive problem-solving program (Appendix C). The program consisted of six ill-structured story problems, each presenting a physics-based (force and motion) problem. After each story was read, the program used metacognitive problem-solving prompts to scaffold students through the problem-solving process. All participant responses to prompts and all
story writing were completed in the program. The program recorded participant responses to all questions and log file data of movement in the program and time spent on each screen.

**Instructional videos.** Four brief instructional videos were created using a video screen capture program with voice-over recording. The videos modeled how to use *Solve It!* and expectations for writing responses to questions and writing story endings. Students watched one video before beginning the program, and the second video before finishing the story. Students in the Think Prompt and Write Prompt conditions viewed slightly different videos altering the directions for writing or thinking about each prompt. Students in the Think Story and Write Story conditions viewed slightly different videos, which altered the directions for writing or thinking about the rest of the story. The videos were included in each of the six stories.

**Ill-structured story problems.** The intervention utilized six short stories, created for the purpose of this study, with embedded ill-structured problems (See Appendix D for example story). Each story addressed a different topic from the force and motion unit (Newton’s 1st Law of Motion, friction, balanced and unbalanced forces, forces of flight, and simple machines) and all topics were aligned with the North Carolina Standard Course of Study for seventh grade science. The stories were written from the student perspective and contain everyday force and motion problems (Flesch Kincaid Readability ranges from 2.3 to 3.5). Stories were written at a lower grade level both to meet a range of students’ reading levels as well as provide simpler expectations for finishing the story. Each story employs a narrative approach to introduce the problem and then ends by prompting the reader to help
provide a solution and finish the story. Problem scenarios were presented in the same order for all students and students had to complete each story before moving on to the next.

**Filler activity.** Participants were allowed to work at their own pace throughout the problem-solving program, with the general expectation that they finish one story per class. If participants finished the day’s story before class was over, they were provided with filler activities to make sure they spent the same amount of time working during each class. These activities involved online science (non-physics) passages to read with corresponding comprehension questions. Filler activities were provided to students from any condition if they finished before class was over.

**Intervention fidelity.** Teachers completed a daily checklist during the study to record attendance and participation in the intervention activities. Teachers were asked to record any issues that arose during the study for individual students. Teachers also immediately contacted the researcher if any problems with the technology occurred during the program. Students who did not complete the problem-solving intervention were removed from the data analysis.

**Qualitative Data**

**Interviews.** A subset of 14 students were randomly selected for interviews. Students were interviewed using a short (5-7 minutes) semi-structured protocol (See Appendix E) that asked them to reflect on their learning during the intervention. Students were interviewed individually in a quiet location throughout the school day and interviews were recorded for transcription.
Procedures

Student consent and identification. Participating teachers sent home IRB approved consent letters for parents to sign and return to school. All students had access to the program, but data was only used from participants whose parents returned the signed consent form. Students received an identification number that was used to enter the intervention program. All student data was stored with the identification numbers.

Pre-intervention. Participants completed two days of pre-assessments using online Qualtrics links immediately before beginning the intervention. Participants completed the demographic questionnaire, TOWL-4 spontaneous writing subtest, and the problem-solving strategies scenario on the first day. On the second day participants completed the science and writing self-efficacy surveys, the problem-solving questionnaire, the Jr. MAI, and the force and motion conceptual knowledge assessment.

Intervention. Participants begin Solve It! by watching a short 3-minute instructional video that explains how to use the program and the five metacognitive problem-solving steps included in the program (Identify the Problem, Show the Problem, Brainstorm and Plan, Execute, Check your Solution). Participants were required to watch the video the first time they began the program, but it was optional on all successive uses. After watching the instructional video, participants were presented with the first story. Once they finished reading the story they were asked to rate their confidence for finding a solution to the problem using a sliding scale (0% to 100%) and saw a brief reminder about the problem-solving steps. The program used prompts to scaffold participants through the five problem-
solving steps, as shown in Table 3.1. At the end of these steps the participants rated how confident they were that they accurately solved the problem using a sliding scale from 0% to 100%. The intervention lasted six consecutive days, with participants completing one story each day. Teachers maintained intervention fidelity checklists throughout each stage of the intervention.
### Table 3.1

**Intervention scaffolding prompts**

<table>
<thead>
<tr>
<th>Problem Solving Steps</th>
<th>Example Scaffolding for Story 1</th>
<th>Question Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Identify the Problem</td>
<td>What is Alex's problem in the story?</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(2) Show the Problem</td>
<td>One way to show the problem is to draw a picture of what happened. Imagine what happens in the story. Use the images below to make a picture of what happened. There may be extra pictures. Explain what is happening in your picture: How did imagining and drawing the picture help me understand what happened in the story?</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(3) Brainstorm and Plan</td>
<td>Brainstorm: Ask yourself these questions when planning your solution: Have I solved a problem like this before? Is there a math formula that will answer this question? Can I research a topic to answer this question? Can I plan an experiment to answer this question?</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(3) Brainstorm and Plan</td>
<td>One way to solve a problem is to recreate it or try to make it happen again. We can't use a real car and milkshake, but we can use a model. Use the wooden car and a penny to represent the milkshake. You can use a book to make the car stop suddenly. Gather the materials you will need to do this in the next step. Plan: Explain what you will do in the experiment.</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(4) Execute</td>
<td>Complete your experiment. Describe what you did and what happened below. How did I have to adjust my strategies during the experiment?</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(3) Brainstorm and Plan</td>
<td>Another way to solve the problem is to research the problem. This will help you learn what other people know about the problem. Alex remembered writing a paper about scientists for school. You can read his paper to see if it has useful information. Plan: What keywords will you look for when reading Alex's paper?</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(4) Execute</td>
<td>Research: Read Alex's paper. Take notes on this topic as you read. Do you have enough information to solve the problem? If NO-where can I find more information?</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>(5) Check Your Solution</td>
<td>What is the solution to Alex's problem? How do I make sure other people will understand this solution?</td>
<td>Problem Solving</td>
</tr>
</tbody>
</table>

### Condition Specific Procedures
**Write Prompts + Write Story (WP + WS).** Students in this condition were asked to write responses to the metacognitive problem-solving prompts and write a solution to the dilemma presented in each story.

- The instructional video at the beginning of the intervention demonstrated the use of the program. The video modeled prompt responses for students using an example story.
- Students read the story.
- Students rated their confidence for finding a solution to the problem using a sliding scale (0% to 100%).
- Students followed the program’s metacognitive problem-solving scaffolding and wrote a response to each prompt (Table 3.3). All questions in the program were forced response, therefore students had to respond before moving to the next question. Step two, show the problem, required the generation of a problem representation and step three, brainstorm and plan, was composed of four yes/no closed response questions.
- Students rated how confident they were that they accurately solved the problem using a sliding scale (0% to 100%).
- Students watched a short 1-minute instructional video that modeled expectations for writing the end of the story. Students were reminded to focus on the problem-solving steps, how the character in the story thinks about solving the problem, and the final solution.
- Students were prompted to provide a written conclusion to the story, describing how the character solved the problem and the solution to the problem. While at this stage, participants could access their responses to all of the previous questions on the right half of the screen, while writing on the left half of the screen.
• In order to control the time spent working and content encountered during class between the conditions, if students completed the program before class ended they were provided with the filler activities.

**Think Prompts + Write Story (TP + WS).** Students in this condition were presented with each of the metacognitive problem-solving prompts, but did not provide written responses. Instead, they were prompted to think about each step in the problem-solving process. Students finished writing the stories in the intervention.

• The instructional video at the beginning of the intervention demonstrated the use of the program. The video modeled thinking about each prompt. The verbal thinking examples were identical to the written responses in the WP+WS condition.
• Students read the story.
• Students rated their confidence for finding a solution to the problem using a sliding scale (0% to 100%).
• Students followed the program’s metacognitive problem-solving scaffolding by thinking about each prompt. Students saw all of the same prompts as the WP+WS condition. Beside each question was a check box. Students checked the box to signify that they were done with the step. Step two, show the problem, required the generation of a problem representation. Students in this condition were asked to create a mental image of the problem. In step three, brainstorm and plan, students checked yes or no for each of the four closed response questions because this did not require a written response.
• Students rated how confident they were that they accurately solved the problem using a sliding scale (0% to 100%).
• Students watched a short 1-minute instructional video that modeled expectations for writing the end of the story. Students were reminded to focus on the problem-solving steps, how the character thinks about solving the problem, and the final solution.
• Students were prompted to write the rest of the story, describing how the character in the story solved the problem and the solution to the problem. While at this stage, participants could access all of the question prompts on the right half of the screen, while writing on the left half of the screen. They were able to see their yes/no responses from the brainstorm and plan step.

• In order to control the time spent working and content encountered during class between the conditions, if students completed the program before class ended they were provided with the filler activities.

**Write Prompts + Think Story (WP + TS).** Students in this condition were asked to write their responses to the metacognitive problem-solving prompts in the problem-solving program. However, students did not provide a written solution for the story.

• The instructional video at the beginning of the intervention demonstrated the use of the program. The video modeled prompt responses for students using an example story.

• Students read the story.

• Students rated their confidence for finding a solution to the problem using a sliding scale (0% to 100%).

• Students followed the program’s metacognitive problem-solving scaffolding and wrote a response to each prompt (Table 3.3). All questions in the program were forced response, therefore students had to respond before moving to the next question. Step two, show the problem, required the generation of a problem representation and step three, brainstorm and plan, was composed of four yes/no closed response questions.

• Students rated how confident they were that they accurately solved the problem using a sliding scale (0% to 100%).
• Students watched a short 1-minute instructional video that modeled expectations for thinking about the end of the story. Students were reminded to focus on the problem-solving steps, how the character thinks about solving the problem, and the final solution.

• Students were prompted to think about the rest of the story and to consider how the character provided a solution to the problem. While at this stage, participants could access all of the question prompts on the right half of the screen. The left half of the screen displayed the thinking directions.

• In order to control the time spent working and content encountered during class between the conditions, if students completed the program before class ended they were provided with the filler activities.

**Think Prompts + Think Story (TP + TS).** Students in this condition will see all of the metacognitive problem-solving prompts, but will not write their responses. Instead, they will be prompted to think about each step in the problem-solving process. Students will not provide a written solution for the story, but will be prompted to think about how the character in the story would provide a solution.

• The instructional video at the beginning of the intervention demonstrated the use of the program. The video modeled thinking about each prompt. The verbal thinking examples were identical to the written responses in the WP+WS condition.

• Students read the story.

• Students rated their confidence for finding a solution to the problem using a sliding scale (0% to 100%).

• Students followed the program’s metacognitive problem-solving scaffolding by thinking about each prompt. Students saw all of the same prompts as the WP+WS condition. Beside each question was a check box. Students checked the box to signify
they were done with the step. Step two, show the problem, required the generation of a problem representation. Students in this condition were asked to create a mental image of the problem. In step three, brainstorm and plan, students checked yes or no for each of the four closed response questions because this did not require writing.

- Students rated how confident they were that they accurately solved the problem using a sliding scale (0% to 100%).
- Students watched a short 1-minute instructional video that modeled expectations for thinking about the end of the story. Students were reminded to focus on the problem-solving steps, how the character thinks about solving the problem, and the final solution.
- Students were prompted to think about the rest of the story, describing how the character solved the problem and the solution to the problem. While at this stage, participants could access all of the question prompts on the right half of the screen. The left half of the screen displayed the thinking directions.
- In order to control the time spent working and content encountered during class between the conditions, if students completed the program before class ended they were provided with the filler activities.

**Post intervention:** Participants completed one day of post assessments immediately following the last day of the intervention. The physics conceptual knowledge assessment, science and writing self-efficacy surveys, the problem-solving questionnaire and the post problem-solving scenario were all completed on the same day.

**Interviews:** A subset of students were sampled from each condition and interviewed about using *Solve It!* Students were randomly selected due to the non-significant findings in the quantitative data (TP + TS $n = 2$; WP + TS $n = 2$; TP + WS $n = 5$; WP + WS $n = 5$). The interviews were conducted approximately one week following the post assessments. Student
interviews were conducted individually during the school day and recorded for transcription. The interview data was used to identify possible reasons for the non-significant findings.
CHAPTER FOUR

Results

This study employed four conditions to examine the impact of two writing to learn activities on seventh grade students’ conceptual understanding of force and motion knowledge, efficacy for learning science and writing, and problem-solving strategies. Study data was analyzed using Analysis of Variance (ANOVA), Multivariate Analysis of Variance (MANOVA), Repeated-Measures Analysis of Variance (RM-ANOVA), and Analysis of Covariance (ANCOVA). This section contains descriptive statistics and analyses for the study’s primary research questions.

Intervention fidelity checklists from teachers were used to remove participant data if they did not complete the intervention (due to absences or progress) or did not follow study procedures (off-task behavior, inappropriate use of program, multiple issues with saving data, missing data). Additionally, log file data from the intervention program was used to identify and remove extreme cases (+ or − 3 standard deviations) based on time spent in the problem-solving portion of the program. A one-way ANOVA of mean problem-solving time across the five stories did reveal significant differences between conditions (\(F[3, 103] = 10.89, p < .001\)). Tukey post-hoc comparisons showed that students in the Think Prompt conditions (TP + TS, \(M = 8.54 \ SD = 6.57\), and TP + WS, \(M = 8.06 \ SD = 6.18\)) spent significantly less time completing the problem-solving steps than students in the Write Prompt conditions (WP +
TS, $M = 14.60\ SD = 5.03$ and WP + WS, $M = 14.02\ SD = 4.00$). This difference was expected due to the increased time for writing responses.

### Table 4.1

Means and standard deviations for pre and post assessments by condition.

<table>
<thead>
<tr>
<th></th>
<th>TP + TS</th>
<th>WP + TS</th>
<th>TP + WS</th>
<th>WP + WS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 23</td>
<td>n = 31</td>
<td>n = 30</td>
<td>n = 33</td>
</tr>
<tr>
<td>Pre Physics Knowledge</td>
<td>5.39 (2.82)</td>
<td>5.87 (2.72)</td>
<td>5.52 (2.23)</td>
<td>6.22 (2.72)</td>
</tr>
<tr>
<td>Post Physics Knowledge</td>
<td>6.18 (2.79)</td>
<td>7.03 (2.98)</td>
<td>6.93 (2.62)</td>
<td>7.63 (2.76)</td>
</tr>
<tr>
<td>Pre Problem Scenario</td>
<td>1.45 (.92)</td>
<td>1.29 (1.04)</td>
<td>1.25 (.80)</td>
<td>1.48 (1.24)</td>
</tr>
<tr>
<td>Post Problem Scenario</td>
<td>2.00 (1.02)</td>
<td>2.00 (.90)</td>
<td>2.18 (1.06)</td>
<td>2.23 (1.10)</td>
</tr>
<tr>
<td>Conventions</td>
<td>15.17 (7.32)</td>
<td>14.90 (5.57)</td>
<td>15.17 (8.26)</td>
<td>17.27 (6.67)</td>
</tr>
<tr>
<td>TOWL Story</td>
<td>7.78 (5.20)</td>
<td>8.90 (4.27)</td>
<td>8.07 (4.88)</td>
<td>9.24 (4.89)</td>
</tr>
<tr>
<td>Pre Before PS</td>
<td>20.17 (4.17)</td>
<td>21.97 (3.85)</td>
<td>19.55 (3.78)</td>
<td>20.50 (4.54)</td>
</tr>
<tr>
<td>Post Before PS</td>
<td>21.36 (2.80)</td>
<td>20.77 (3.92)</td>
<td>19.96 (4.76)</td>
<td>20.37 (5.32)</td>
</tr>
<tr>
<td>Pre During PS</td>
<td>16.74 (3.41)</td>
<td>17.77 (3.32)</td>
<td>16.03 (3.28)</td>
<td>18.06 (3.87)</td>
</tr>
<tr>
<td>Post During PS</td>
<td>17.73 (2.88)</td>
<td>16.47 (3.54)</td>
<td>17.32 (3.61)</td>
<td>17.33 (4.67)</td>
</tr>
<tr>
<td>Pre After PS</td>
<td>17.00 (3.46)</td>
<td>17.73 (4.17)</td>
<td>15.83 (3.92)</td>
<td>17.59 (4.11)</td>
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<tr>
<td>Post After PS</td>
<td>17.18 (2.72)</td>
<td>16.97 (3.52)</td>
<td>16.93 (4.27)</td>
<td>17.77 (3.88)</td>
</tr>
<tr>
<td>Pre Physics Efficacy</td>
<td>27.00 (5.44)</td>
<td>29.20 (5.34)</td>
<td>26.52 (5.40)</td>
<td>28.41 (5.96)</td>
</tr>
<tr>
<td>Post Physics Efficacy</td>
<td>26.63 (6.14)</td>
<td>26.97 (5.82)</td>
<td>27.29 (5.79)</td>
<td>27.60 (4.97)</td>
</tr>
<tr>
<td>Pre Writing Ideation</td>
<td>17.57 (2.89)</td>
<td>18.03 (4.87)</td>
<td>16.90 (4.27)</td>
<td>16.59 (5.61)</td>
</tr>
<tr>
<td>Post Writing Ideation</td>
<td>17.55 (4.00)</td>
<td>17.17 (4.58)</td>
<td>16.36 (4.24)</td>
<td>16.43 (5.05)</td>
</tr>
<tr>
<td>Pre Writing Like</td>
<td>11.04 (2.67)</td>
<td>10.93 (3.08)</td>
<td>10.21 (2.84)</td>
<td>10.31 (3.56)</td>
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<td>Post Writing Like</td>
<td>11.09 (2.76)</td>
<td>10.53 (3.18)</td>
<td>10.43 (2.80)</td>
<td>10.43 (3.28)</td>
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<td>Pre Writing Audience</td>
<td>21.43 (4.96)</td>
<td>22.27 (4.92)</td>
<td>22.66 (4.24)</td>
<td>23.59 (3.89)</td>
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<tr>
<td>Post Writing Audience</td>
<td>21.82 (4.47)</td>
<td>21.80 (3.82)</td>
<td>22.50 (4.16)</td>
<td>23.57 (3.49)</td>
</tr>
<tr>
<td>Pre Writing Learn</td>
<td>13.39 (3.55)</td>
<td>13.00 (4.16)</td>
<td>13.76 (3.10)</td>
<td>13.44 (4.97)</td>
</tr>
<tr>
<td>Post Writing Learn</td>
<td>13.82 (3.79)</td>
<td>13.50 (3.44)</td>
<td>13.21 (3.14)</td>
<td>12.77 (4.21)</td>
</tr>
<tr>
<td>Pre Writing Efficacy</td>
<td>14.00 (3.19)</td>
<td>13.80 (2.92)</td>
<td>13.93 (3.41)</td>
<td>14.41 (3.53)</td>
</tr>
<tr>
<td>Post Writing Efficacy</td>
<td>13.73 (3.06)</td>
<td>13.60 (2.82)</td>
<td>13.86 (2.99)</td>
<td>13.57 (3.59)</td>
</tr>
<tr>
<td>Pre Jr MAI</td>
<td>27.78 (3.27)</td>
<td>28.03 (3.04)</td>
<td>26.69 (3.27)</td>
<td>27.91 (3.72)</td>
</tr>
<tr>
<td>Post Jr MAI</td>
<td>27.77 (2.72)</td>
<td>28.07 (3.00)</td>
<td>27.71 (3.30)</td>
<td>28.17 (4.00)</td>
</tr>
</tbody>
</table>

*Note. TP + TS = Think Prompt + Think Story, WP + TS = Write Prompt + Think Story, TP + WS = Think Prompt + Write Story, WP + WS = Write Prompt + Think Story, PS = problem solving.*
What is the impact of narrative and prompt response writing on seventh grade students’ physics knowledge, problem-solving strategies, self-efficacy, and metacognition?

In order to evaluate the impact of narrative and prompt response writing tasks on students’ physics knowledge, a 2x4 repeated-measures ANOVA was conducted to compare pre and post physics knowledge assessments. The within subject factor was time (pretest, posttest) and the between subjects factor was condition (WR+WS, TP+WS, WP+NS, TP+NS). The Box-M test \(F[9,97748.064] = 1.16, p > .05\) and Levene’s tests were both non-significant, indicating that the assumptions of homogeneity of variance and covariance were met. There was a significant effect for time, \(F(1,103) = 26.84, p < .001\) partial \(n^2 = .21\), but there was not a significant interaction between time and condition, \(F(3, 103) = .55, p = .65\), partial \(n^2 = .02\). While participants across conditions showed a significant increase in physics knowledge, this growth did not vary by condition. The observed power for this analysis was only .16, indicating that the sample size was insufficient.

A 2x4 repeated-measures ANOVA was used to examine changes in problem-solving strategies measured with the pre and post problem solving scenarios. Again, the within subject factor was time (pretest, posttest) and the between subjects factor was condition (WR+WS, TP+WS, WP+NS, TP+NS). The Box-M test \(F[9,88642.01] = 1.00, p > .05\) and Levene’s tests were both non-significant, indicating that the assumptions of homogeneity of variance and covariance were met. The results indicated a significant increase in strategies
over time, $F(1,99) = 33.53$, $p < .001$ partial $n^2 = .25$, but no significant interaction between time and condition, $F (3,99) = .44$, $p = .73$ partial $n^2 = .01$.

Before analyzing the subscales of the problem-solving questionnaire, Pearson correlations were conducted to verify that the subscales were significantly correlated (Table 4.2). A 2x4 RM-MANOVA was performed to identify changes in self-reported problem-solving strategies over time and whether these differences varied by experimental condition. The within-subjects factors were time (pretest, posttest) and subscale (Before Problem Solving, During Problem Solving, After Problem Solving). The between-subjects factor was condition (WR+WS, TP+WS, WP+NS, TP+NS). The sphericity assumption was violated for the subscales, as indicated by Mauchly’s test. However, since the sample size was sufficient, multivariate tests are reported. The Box-M test was not significant ($F[63,22516.736] = .96$, $p > .05$). The three-way interaction between time, subscale, and condition was not significant, $F(6,204) = 1.09$, $p = .37$ partial $n^2 = .03$.

Table 4.2

<table>
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<tr>
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<td>1. Pre Before Problem solving</td>
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<td>.67**</td>
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<td>.51**</td>
<td>.48**</td>
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<td>.54**</td>
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<td>4. Post Before Problem solving</td>
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<td>.71**</td>
<td>.66**</td>
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<tr>
<td>5. Post During Problem solving</td>
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</table>

Note: ** = $p < .01$
A 2x4 repeated-measures ANOVA was conducted to examine the impact of the experimental condition on participants’ physics efficacy. The within subject factor was time (pretest, posttest) and the between subjects factor was condition (WR+WS, TP+WS, WP+NS, TP+NS). There was a significant interaction between time and condition, \( F(3, 103) = 2.86, p < .05, \text{partial } n^2 = .08 \). Follow-up univariate statistics with Bonferroni corrections indicated no significant differences in pre to post physics efficacy for the TP + TS, TP + WS, or WP + WS conditions. There was a significant decrease in physics efficacy in the WP + TS condition from the pre (\( M = 29.69, SD = 1.00 \)) to post assessment (\( M = 27.21, SD = 1.05 \)).

Pearson correlations were conducted on the subscales of the writing efficacy survey to ensure the measures were related before conducting a 2x4 repeated-measures MANOVA (see Table 4.3). The within subject factors were time (pre and post) and subscale (Ideation, Like, Audience, Like, Efficacy). The between subjects factor was condition (WR+WS, TP+WS, WP+NS, TP+NS). The sphericity assumption was violated for the subscales and interaction between time and subscale, as indicated by Mauchly’s tests. However, since the sample size was sufficient, multivariate tests are reported. The Box-M test was not significant (\( F[165,20872.498] = 1.00, p > .05 \)). The three-way interaction between time, subscale, and condition was not significant (\( F[12,264.87] = 1.25, p = .25, \text{partial } n^2 = .05 \)). Additionally, there was not a significant interaction between time and subscale (\( F[4.100] = 1.25, p = .29, \text{partial } n^2 = .05 \)), indicating that participants’ writing efficacy did not change from the pre to post assessments.
Table 4.3

**Pearson correlations for measures of writing efficacy.**

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<td>.69**</td>
<td>.69**</td>
<td>.77**</td>
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<td>.59**</td>
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<td>3. Pre Writing Audience</td>
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<td>.31**</td>
<td>.43**</td>
<td>.41**</td>
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<td>.63**</td>
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<td>4. Pre Writing Learn</td>
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<td>7. Post Writing Like</td>
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</tr>
<tr>
<td>8. Post Writing Audience</td>
<td>1</td>
<td>.51**</td>
<td>.27**</td>
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<tr>
<td>9. Post Writing Learn</td>
<td>1</td>
<td>.58**</td>
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<td></td>
</tr>
</tbody>
</table>

Note: * = p < .05, ** = p < .01

Changes in metacognitive awareness from the pre to post assessment by conditions were examined using a 2x4 repeated-measures ANOVA. The within subject factor was time (pretest, posttest) and the between subjects factor was condition (WR+WS, TP+WS, WP+NS, TP+NS). The assumption of equity of variance-covariance was not violated (Box-M test, $F[9,97748.064] = .56, p = .83$) and Levene’s tests were both non-significant. Both the interaction between time and condition ($F[3,103] = .54, p = .66$ partial $n^2 = .02$) and the main effect for time ($F[1,103] = .33, p = .57$ partial $n^2 = .01$) were not significant.

Is there a significant interaction between condition and prior knowledge, writing ability, or writing effort with respect to final knowledge or final problem-solving knowledge?

Final Physics Knowledge
Physics prior knowledge. In order to examine the interaction between experimental conditions and physics prior knowledge, a high physics prior knowledge group and a low physics prior knowledge group were created. Due to the small sample size, a median split was used to create the high and low groups rather than tertiles. The mean score ($M = 5.78$ rounded to 6.00) was identified for the physics knowledge pretest and participants falling below this score were placed in the low prior knowledge group ($n = 51, M = 3.49, SD = 1.45$) and participants scoring above this score were grouped into the high prior knowledge group ($n = 41, M = 8.51, SD = 1.52$). Participants whose score was equal to the mean score ($n = 22$) were removed from this analysis. The high and low physics prior knowledge groups were significantly different from one another ($t(90) = -16.18, p < .001$, Cohen’s $d = 3.38$). Means and standard deviations for high and low physics prior knowledge by condition are displayed in Table 4.4.

A 2x4 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (4: WR+WS, TP+WS, WP+NS, TP+NS) and prior knowledge (2: low, high) with respect to final content knowledge, controlling for prior knowledge. There was a significant interaction between condition and prior knowledge, $F(3,78) = 2.93, p < .05$, partial $n^2 = .10$. As shown in Figure 4.1, having high or low prior knowledge did not impact final knowledge in the TP + TS, WP + TS, or WP + WS conditions. However, in the TP + WS condition, participants with low prior knowledge had significantly higher final knowledge outcomes than those with high prior knowledge.
Figure 4.1. Estimated marginal means of final physics knowledge for high and low prior knowledge groups controlling for prior physics knowledge.

Writing ability. High writing ability and low writing ability groups were created by identifying the mean writing conventions score ($M = 15.69$ rounded to 16.00). Participants with scores below the mean were grouped into the low writing ability group ($n = 52, M = 9.38, SD = 3.97$) and participants with scores above the mean were grouped into the high writing ability group ($n = 58, M = 21.31, SD = 4.04$). Participants whose score was equal to the mean score ($n = 16$) were removed from this analysis. The high and low writing ability groups were significantly different from one another ($t(108) = -15.58, p < .001, Cohen’s d = 2.98$).
A 2x4 complete between ANCOVA was conducted to determine if there was a significant interaction between condition (4: WR+WS, TP+WS, WP+NS, TP+NS) and writing ability (2: low, high) with respect to final content knowledge controlling for prior knowledge. The interaction was not significant, $F(3,91) = .11, p = .96$, partial $n^2 = .01$.

A second set of writing ability groups were created using the story writing subscale of the TOWL-4. The mean score for the story writing subscale was 8.56, which was rounded to 9.00. Participants were grouped into the low story writing group ($n = 50, M = 4.06, SD = 2.47$) if their scores were below the mean and participants were grouped into the high story writing group ($n = 57, M = 12.44, SD = 2.90$) if their scores were above the mean. Participants whose score was equal to the mean score ($n = 10$) were removed from this analysis. The high and low story writing groups were significantly different from one another ($t(105) = -15.96, p < .001$, Cohen’s $d = 3.11$).

A 2x4 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (4: WR+WS, TP+WS, WP+NS, TP+NS) and story writing (2: low, high) with respect to final content knowledge controlling for prior knowledge. The interaction was not significant, $F(3,88) = 2.54, p = .06$, partial $n^2 = .08$, although it was approaching significance. Although conclusions can not be drawn from this non significant finding, it is worth noting that participants with higher story writing ability had significantly higher final physics knowledge than participants with low story writing ability in the TP + WS condition.
**Story effort.** High and low story effort groups were created by identifying the mean story effort score ($M = .04$). Participants with scores below the mean were grouped into the low story effort group ($n = 29, M = -1.37, SD = .51$) and participants with scores above the mean were grouped into the high story effort group ($n = 25, M = 1.67, SD = 1.46$). Participants whose score was equal to the mean score ($n = 1$) were removed from this analysis. The high and low writing ability groups were significantly different from one another ($t(52) = -10.50, p < .001$, Cohen’s $d = 2.78$).

A 2x2 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (2: TP + WS, WP + WS) and story effort (2: low, high) with respect to final content knowledge, controlling for prior knowledge. The interaction was not significant, $F(1,48) = 2.10, p = .15$, partial $\eta^2 = .04$. 
Table 4.4

Means, standard deviations and cell sizes for final physics knowledge by condition and group

<table>
<thead>
<tr>
<th></th>
<th>TP + TS</th>
<th>WP + TS</th>
<th>TP + WS</th>
<th>WP + WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Prior Physics</td>
<td>5.00 (1.58)</td>
<td>5.92 (1.69)</td>
<td>6.85 (2.88)</td>
<td>6.11 (2.03)</td>
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<td>n = 13</td>
<td>n = 14</td>
<td>n = 13</td>
<td>n = 9</td>
</tr>
<tr>
<td>High Prior Physics</td>
<td>7.86 (3.67)</td>
<td>9.60 (2.80)</td>
<td>6.11 (1.96)</td>
<td>9.42 (2.11)</td>
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<td>n = 7</td>
<td>n = 10</td>
<td>n = 9</td>
<td>n = 12</td>
</tr>
<tr>
<td>Low Writing Ability</td>
<td>5.91 (3.08)</td>
<td>5.61 (2.84)</td>
<td>6.13 (2.39)</td>
<td>6.00 (3.32)</td>
</tr>
<tr>
<td></td>
<td>n = 11</td>
<td>n = 13</td>
<td>n = 15</td>
<td>n = 7</td>
</tr>
<tr>
<td>High Writing Ability</td>
<td>6.45 (2.58)</td>
<td>8.00 (2.83)</td>
<td>8.00 (2.73)</td>
<td>8.00 (2.40)</td>
</tr>
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<td></td>
<td>n = 11</td>
<td>n = 15</td>
<td>n = 12</td>
<td>n = 19</td>
</tr>
<tr>
<td>Low Story Writing</td>
<td>6.00 (3.22)</td>
<td>7.67 (3.50)</td>
<td>5.93 (1.86)</td>
<td>6.40 (3.17)</td>
</tr>
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<td>n = 9</td>
<td>n = 14</td>
<td>n = 10</td>
</tr>
<tr>
<td>High Story Writing</td>
<td>6.40 (2.55)</td>
<td>6.71 (1.90)</td>
<td>8.45 (3.14)</td>
<td>8.00 (2.33)</td>
</tr>
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<td>n = 10</td>
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<td>n = 11</td>
<td>n = 18</td>
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<tr>
<td>Low Story Effort</td>
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<td></td>
<td>6.00 (1.90)</td>
<td>7.47 (2.35)</td>
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<tr>
<td></td>
<td>n = 11</td>
<td>n = 17</td>
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<td></td>
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<tr>
<td>High Story Effort</td>
<td></td>
<td></td>
<td>7.87 (2.90)</td>
<td>7.33 (2.18)</td>
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<td></td>
<td>n = 15</td>
<td>n = 9</td>
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</table>

**Final Problem-Solving Strategies (Scenario)**

**Prior problem-solving strategies.** In order to examine the interaction between experimental conditions and prior problem-solving strategies, a high pre problem-solving strategy group and a low pre problem-solving strategy group were created. The mean score ($M = 1.37$) was identified for the pre problem-solving strategy scenario and participants falling below this score were placed in the low pre problem-solving group ($n = 71, M = .73, SD = .45$) and participants scoring above this score were grouped into the high pre problem-solving group ($n = 41, M = 2.46, SD = .75$). The high and low pre problem-solving strategy
groups were significantly different from one another ($t(110) = -15.40$, $p < .001$, Cohen’s $d = 2.80$).

A 2x4 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (4: WR+WS, TP+WS, WP+NS, TP+NS) and pre problem-solving strategies (2: low, high) with respect to final problem-solving strategies, controlling for initial problem-solving strategies. The interaction between condition and pre problem-solving strategies was not significant ($F[3,94] = 1.29$, $p = .29$, partial $n^2 = .04$).

Writing ability. A 2x4 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (4: WR+WS, TP+WS, WP+NS, TP+NS) and writing ability (2: low, high) with respect to final problem-solving strategies, controlling for initial problem-solving strategies. The interaction between condition and pre problem-solving strategies was not significant ($F[3,88] = 1.46$, $p = .23$, partial $n^2 = .05$).

Story writing. A 2x4 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (4: WR+WS, TP+WS, WP+NS, TP+NS) and story writing (2: low, high) with respect to final problem-solving strategies, controlling for initial problem-solving strategies. The interaction between condition and pre problem-solving strategies was not significant ($F[3,84] = .92$, $p = .43$, partial $n^2 = .03$).

Story effort. A 2x4 completely between ANCOVA was conducted to determine if there was a significant interaction between condition (2: TP+WS, WP+WS) and story effort (2: low, high) with respect to final problem-solving strategies, controlling for initial problem-
solving strategies. The interaction between condition and story effort was not significant

\(F[1,44] = 1.22, p = .28, \text{ partial } n^2 = .03\).

Table 4.5

Means, standard deviations and cell sizes for final problem-solving strategies by condition and group

<table>
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<tr>
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<th>TP + TS</th>
<th>WP + TS</th>
<th>TP + WS</th>
<th>WP + WS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Problem Solving</strong></td>
<td>2.17 (.12)</td>
<td>1.71 (.69)</td>
<td>2.13 (.99)</td>
<td>2.25 (1.25)</td>
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<tr>
<td><strong>High Problem Solving</strong></td>
<td>1.89 (.93)</td>
<td>2.45 (1.04)</td>
<td>2.45 (1.13)</td>
<td>2.25 (.71)</td>
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<td>n = 11</td>
<td>n = 8</td>
<td></td>
</tr>
<tr>
<td><strong>Low Writing Ability</strong></td>
<td>1.60 (.84)</td>
<td>1.73 (.65)</td>
<td>2.00 (1.00)</td>
<td>1.29 (.76)</td>
</tr>
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<td>n = 11</td>
<td>n = 13</td>
<td>n = 7</td>
<td></td>
</tr>
<tr>
<td><strong>High Writing Ability</strong></td>
<td>2.45 (1.04)</td>
<td>2.13 (1.06)</td>
<td>2.33 (.78)</td>
<td>2.61 (.98)</td>
</tr>
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<td>n = 15</td>
<td>n = 12</td>
<td>n = 18</td>
<td></td>
</tr>
<tr>
<td><strong>Low Story Writing</strong></td>
<td>1.80 (1.14)</td>
<td>1.88 (.84)</td>
<td>2.00 (1.00)</td>
<td>1.50 (.71)</td>
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<td>n = 8</td>
<td>n = 13</td>
<td>n = 10</td>
<td></td>
</tr>
<tr>
<td><strong>High Story Writing</strong></td>
<td>2.30 (.95)</td>
<td>2.13 (1.03)</td>
<td>2.60 (1.08)</td>
<td>2.69 (1.14)</td>
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<td>n = 10</td>
<td>n = 16</td>
<td></td>
</tr>
<tr>
<td><strong>Low Story Effort</strong></td>
<td>1.80 (.92)</td>
<td>2.43 (.85)</td>
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<tr>
<td><strong>High Story Effort</strong></td>
<td>2.25 (1.13)</td>
<td>2.22 (1.09)</td>
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<td>n = 16</td>
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</table>

*Additional Analysis*

Story data (TP + WS and WP + WS conditions only) from the first day of the intervention was reviewed and responses were scored as either appropriate (followed directions, story addresses content and problem solving) or inappropriate (single sentence, no content or problem solving). Descriptive statistics are presented in Table 4.6 for physics
knowledge and problem solving knowledge by category. Two 2x2 completely between ANCOVAs were conducted to compare final physics knowledge and final problem-solving strategies between students with appropriate and inappropriate story responses, controlling for prior knowledge in both instances. The between factors were condition (2: TP+WS, WP+WS) and appropriate response (2: appropriate, inappropriate). While there was no significant difference between students with appropriate and inappropriate responses on final content knowledge ($F[1,53] = 2.18, p = .15, \text{ partial } n^2 = .04$), there was a significant difference in final problem-solving strategies ($F[1,51] = 8.43, p < .01, \text{ partial } n^2 = .14$).

Table 4.6

Means and standard deviations for final physics and problem-solving knowledge by story 1 task score.

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<tr>
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<th>Appropriate</th>
<th>Inappropriate</th>
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<tr>
<td>$n$</td>
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</tr>
<tr>
<td>$M (SD)$</td>
<td>8.00 (2.69)</td>
<td>6.81 (2.35)</td>
</tr>
<tr>
<td>Post Physics Knowledge</td>
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<tr>
<td>Post Problem Solving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario</td>
<td>2.62 (1.02)</td>
<td>1.84 (.99)</td>
</tr>
</tbody>
</table>

Interview Data

An inductive approach was used to analyze the transcribed student interviews. To begin, interviews were grouped by condition. Each group of condition specific interviews was read and reread to identify themes throughout the interviews. Codes were then generated and applied to the interviews to reduce the data. Coded interview data was then organized
into a table by question, code, and condition. Further data from interviewees’ pre and post physics knowledge and TOWL-4 scores were added to the table to help group student responses. Student names were removed from the data and qualitative data was used to explain the quantitative results.

**How do students feel about learning from the problem-solving program?**

Overall, students across all conditions enjoyed using *Solve It!*. One student from the TP + WS condition said, “I actually felt pretty good about it. As I read it taught me something and it helped me to understand more about physics and how it worked.” Another student in the WP + WS condition said, “I liked it actually. I felt like I got a lot of work done and I learned a lot of new things.” Students were excited about solving the problems independently as well. A student from the WP + WS condition found the process challenging, but a good learning experience, “It was hard for me. But I think that the challenge helped me understand better.” One participant from the WP + TS condition said she was often frustrated when her teachers gave her independent work without a lot of support for completing the assignment. However, she enjoyed the program because “The program was kind of different, it was independent work that was just handed to me but it had very detailed instructions and the instructions were clear. It was easy to understand and that helped me.”

Students also enjoyed the stories used to introduce the problems and found them interesting. A student from the TP + TS condition said, “It had interesting stories and that
really catches my attention.” Another student from the WP + TS condition said, “The stories are ok, they keep you entertained.” Throughout the interviews, students also described the characters and events from the stories. The stories provided students with interesting contexts for the physics problems and helped them remember the learning experience. Further, students in the WP conditions enjoyed writing the stories as a part of the program. A student from the WP + WS condition said, “I wrote really long endings cause I got really into the stories.” A student from the TP + WS condition said he struggled remembering information because he wasn’t able to write his responses to the prompts, however, “I got better when I started writing the stories because it helped me process that a lot easier.”

Students were generally positive about writing during the program, but some students in the WP + WS condition did feel overwhelmed by the amount of writing. One student said, “It was long for me to complete everything… cause I finished like one day in two days.” However, this student did find writing the story useful, “…once I had written the story it came back to me that I remembered everything that happened in the story and what caused it and that helped me write the story.” Another student in the WP + WS condition found the writing assignments helpful, even though he normally didn’t enjoy writing, “I think that having more writing assignments for me will help me get better and make like writing more.” Overall, the writing tasks provided students with important learning opportunities throughout the program. Students enjoyed writing the story, and even though the prompt responses felt overwhelming, students in the TP conditions said they would have liked to write their responses to help them remember information. A student from the TP + TS condition said, “I
think it would have helped me if I had got to type because I didn’t get to type.” Another student from the TP + TS condition also wanted to write during the program, “I think it would have helped me if I was able to write… I really like writing and I think it would have helped me more. I think it would have helped me to write a story at the end.” Overall, students found the writing tasks useful, and not being able to write was seen as a negative aspect of the program.

Qualitative interview data were also reviewed to explain some of the quantitative findings from the study.

**Lack of Content Knowledge Differences Between Experimental Conditions**

Differences in final physics knowledge and problem-solving strategies were expected between conditions, but were not observed in this experiment. Student interviews across conditions revealed several possible explanations for this. First, there was contamination between experimental conditions. Because students were randomly assigned to conditions, students from all four conditions were present in the same classrooms. There were opportunities during the intervention to talk to neighbors while working on the computer program and conducting the hands-on experiments. Eight of the fourteen students interviewed mentioned that they asked their peers questions both while using the program and while conducting the experiment. While discussing the experiments, students noted that they discussed their problem solutions with their peers. One student in the TP + WS condition said, “Yeah, I talked to some of my neighbors, usually to ask if they understood it or if I got the answer to like check with them.” Another student in the same condition said,
“Yeah, I would talk to [student] beside me and we would talk about some of it and it would help me get a better understanding of some of it.”

The dense intervention schedule was another potential factor in the content knowledge outcomes. In order to fit teachers’ schedules, the intervention was compressed into nine consecutive days. Each day students tackled a different force and motion topic, presenting them with a significant amount of information and limited time to learn the material. One student in the WP + WS condition mentioned this compressed schedule and varied topics as a problem for the final assessment.

“When I took the final test I kind of dazed out a little bit... Because the days were spanned out cause there was different stuff on everyday, so it was hard for me to take the test cause I couldn’t remember it.”

This student had clearly engaged in the study, as evidenced by the mean story length (Z-score = 3.95) and time spent working on the problem-solving steps (Z-score = 1.64). Additionally, this student described the stories, problem solutions and related physics content during the interview. It is possible that the dense schedule and varied story topics negatively impacted students’ performance on the content assessment.

**Differences in TP + WS Condition**

Quantitative results identified some interesting differences between the TP + WS condition and the other three conditions. In contrast with the other conditions, students with high story writing ability in the TP + WS condition had higher final knowledge than students with low story writing ability. One potential factor that influenced this result was the lack of
scaffolding during the story-writing component of the intervention. Expectations for the story’s content (problem solution with scientific evidence, characters’ problem-solving process and characters’ metacognitive processed) were described in the training video, but students did not receive support in the program for writing the story or including these components. One of the students from the TP + WS condition that was interviewed felt pressure to write a good story, but didn’t know how to accomplish this goal. “I had to write the story and it kind of put pressure on me.” When asked what might have helped make this process easier, the student said,

“I think with the talking [problem solving thinking prompts] thing, it kind of had steps. It said this happened first and then this happened and why this happened, and it kind of helped me understand. So it [scaffolded steps] would have helped me a little bit more.”

This student’s story writing ability score was 1 standard deviation below the mean, suggesting that story writing was difficult for the student. Students with low story writing ability may need additional support to be successful on this type of writing-to-learn task.

It was also noted that students in the TP conditions spent less time on the problem-solving steps than students in the WP conditions. One interviewee (WP + TS condition) said, “[Writing the prompt responses] definitely helped me, cause some kids were just clicking I am done thinking and they didn’t even think about it. But when I wrote it I actually thought about it.” This supports findings that students in the TP conditions ($M = 8.27$, $SD = 6.29$) spent significantly less time completing the problem-solving steps than students in the WP
conditions ($M = 14.30, SD = 4.49$), $t(105) = -5.74, p < 001$. Writing responses to the prompts may force students to engage with the process rather than skip past it. Additionally, five of the seven students interviewed from the TP conditions mentioned that they would have liked to have the option of typing during the problem-solving steps. Students felt that the inability to take notes on the experiment and research made it difficult to remember the information for the story.

**Lack of Problem-Solving Strategy Differences Between Experimental Conditions**

Quantitative results did not identify differences in post intervention problem-solving strategies by conditions as expected. During the student interviews, interviewees were asked what they learned from the using the program, and all of the students listed physics content as their learning outcomes. This could mean that students’ focused on the content more than the strategies as they went through the problem-solving process. This is not surprising since students completed this program as part of their science class. However, when interviewees were asked if they learned any new strategies for solving problems, eight of the fourteen students described metacognitive strategies they could use to solve future problems. For example, one student noted, “I learned to not just think about it and choose what comes to the top of your head, but to actually think deeply about it.” Another student said that “Instead of looking and not really thinking about it, [I learned] to read what the question was really asking.” Both of these students noted the importance of metacognitive reflection and monitoring, both components of the metacognitive problem-solving prompts used in the program.
While there were no significant differences in final problem-solving strategies (as measured by the problem-solving scenario) between the experimental conditions, there were increases in the use of problem identification strategies (frequency across all participants: pre = 4, post = 22) and planning before beginning the problem-solving steps (frequency across all participants: pre = 7, post = 37). Interviewees also mentioned the importance of clearly identifying the problem, “[I learned to] read over the problem a lot because I usually just read it once… so I will think about it more.” Another student said “it helped me when we did the picture. It helped me get a better visual of what was happening.”
CHAPTER FIVE

Discussion

Overview of Findings

Complex ill-structured problem-solving experiences can potentially be used to increase students’ science content knowledge (Sinatra & Taasoobshirazi, 2011) as well as improve their problem-solving strategies (Hartman, 2001b). Writing is a typical component of ill-structured problem solutions, allowing the problem solver to explain and support their solution through argumentation. This type of writing creates important learning opportunities for students. While current research has shown limited benefits for middle school students’ learning from writing in science (Bangert-Drowns et al., 2004), atypical narrative and creative writing assignments can potentially be used in science courses to improve students’ learning through writing (Chen et al., 2013; Nicholas & Ng, 2008). The current study evaluated the impact of prompt response and narrative story writing tasks on learning with middle school science students. Four experimental conditions were used to isolate the impact of writing prompt responses, writing stories, and writing both prompt responses and stories on learning. Pre and post assessments were used to identify changes in content knowledge, problem-solving strategies, efficacy, and metacognition. Further, differences in initial content knowledge, problem-solving strategies, writing ability, and story writing effort during the intervention were used to identify important factors for learning outcomes.
The four experimental conditions in the current study did not produce the expected between condition differences in learning outcomes for content knowledge or problem-solving strategies. However, students’ content knowledge and problem-solving strategies did increase from pre to post assessment across conditions, as evidenced by the large effect sizes. One potential explanation for the lack of between condition differences is the similarity between the four conditions. Graham and Harris (2014) described several important characteristics of high quality writing intervention studies, one of which was creating credible comparison conditions. As they noted, a potential risk with creating comparison conditions that only vary in one key aspect is the decreased chance of finding significant differences between conditions. In the current study, students in all four conditions were presented with identical metacognitive problem-solving steps, research materials, experimentation opportunities, and story completion tasks. The conditions only varied in whether students wrote or thought about their responses to the prompts and story completion task. The similarities between conditions may have impacted the between condition results in the study. Further, using four experimental conditions decreased the sample size in each condition, leading to low power for the between condition comparisons.

In spite of the lack of differences between conditions, increases in content and problem-solving knowledge across conditions provide some evidence that complex problem-solving experiences can benefit students’ learning. Increases in problem-solving strategies are seen as a positive outcome of the study given that this is a major component of the Solve It! program. While the pre/post problem-solving strategy assessment was meant to measure
gains in problem-solving strategy knowledge, it also provided some evidence of strategy transfer. When describing how they would solve a problem outside of the intervention program, students independently applied strategies they learned during the intervention. The potential for Solve It! to assist students in learning and transferring problem-solving skills is exciting since this is a major goal in education. These findings provide support for the use of Solve It! to increase students’ problem-solving strategies, but the results should be interpreted cautiously until further research has been conducted. Further, before conclusions can be drawn about the utility of this program for content learning, additional studies need to be conducted using a traditional learning classroom as a comparison group.

Unexpected differences did emerge from the TP + WS condition. Students with low prior knowledge in this condition scored significantly higher on the final physics knowledge test than students with high prior physics knowledge. This relationship was not found in the other conditions. These results suggest that writing the story endings alone benefitted students with low prior knowledge, but were detrimental to students with high prior knowledge. One potential explanation for this finding is that students low in prior knowledge felt more motivated by the narrative writing task and engaged in more thoughtful processing while writing the story. Students with high prior knowledge may not have considered the story-writing task to be useful, decreasing their engagement in the task. A second potential explanation for this finding lies in the inability to write responses to the problem solving prompts. Students with high prior knowledge may be used to taking notes while learning, but
were unable to take notes in this learning condition. Not being able to type responses to the prompts may have hurt their learning outcomes.

Interestingly, students in the WP + WS condition did not show the same relationship between prior knowledge and final knowledge as students in the TP + WS condition. Students in both conditions wrote story endings, but those in the WP + WS condition were able to write their responses to the problem-solving prompts, which has been shown to improve learning outcomes (Bangert-Drowns, 2004; Chen et al., 2013; Glynn & Muth, 1994; Scardamalia, Bereiter, & Steinbach, 1984). While high prior knowledge students’ learning may have been hindered by not being able to write their responses in the TP + WS condition, high prior knowledge students in the WP + WS may have benefitted from writing their responses. Originally, students in the WP + WS condition were expected to outperform the other three conditions on content knowledge. It is possible that the volume of writing required in the WP + WS condition was overwhelming for students in this condition. After responding to all of the prompts, these students may not have had the time or energy to engage with the story-writing task. It will be important to identify the ideal amount of writing for learning in future studies.

In addition to physics prior knowledge, final physics knowledge also relied on story writing ability in the TP + WS condition. Research has suggested that writing ability may interfere with learning outcomes from writing-to-learn tasks (Bangert-Drown et al., 2004; Rivard, 1994). In this study, students in the TP + WS condition were expect to learn from writing the story, but this learning depended on their ability to write stories. Students with
low story writing ability did not benefit from writing the story, while students with high story writing ability did benefit from writing the story. This relationship between story writing ability and final knowledge was not present in the WP + WS condition. Students in the WP + WS condition wrote responses to scaffolded prompts before writing the story, so their ability to write stories may not have had as large of an impact on their learning. Scaffolded writing prompts may assist students with low writing ability in organizing and applying their knowledge for learning to occur, as previous research has suggested (Bangert-Drowns, 2004; Chen et al., 2013). Both the story writing and prompt writing tasks appear to influence learning in this study, but further research is needed to more clearly examine their impact on learning.

In sum, the current study did not provide sufficient evidence to examine the impact of prompt and story writing tasks on learning during complex problem solving. While overall learning gains were found across conditions, the small sample size decreased the likelihood of finding effects related to the varied conditions. In addition to collecting additional data to increase the sample size, different analyses could be considered. In the current study, students’ written stories were not analyzed, but may be important sources of data for understanding the results of this study. The task appropriateness of the students’ first story was found to impact final problem-solving knowledge. Students’ varying level of engagement with the story-writing task may have impacted their learning from the program. A further analysis of each individual story for task appropriateness and content accuracy should be conducted to better understand the outcomes in this study. When a full analysis of
all five stories has been conducted, a more thorough analysis of the results will be conducted. This will also allow for the computation of calibration indices using metacognitive judgments in conjunction with scores from writing samples.

**Limitations of the Current Study**

Several limitations with the current study design may have negatively impacted the results. To begin, the small sample size was a major limiting factor in this study, as indicated by the low observed power. Weather related schedule changes altered teachers’ schedules during the intervention. This led to two teachers dropping out of the study, reducing the sample size by two-thirds. Further data will need to be collected to examine the impact of writing on learning during problem solving.

Additionally, the intervention schedule was condensed to fit with the participating teachers’ schedules. Future studies should consider the benefits of spacing the intervention out over several weeks to reduce fatigue and issues with multiple content areas being taught in a short time frame (Son, 2004). Students should also be provided with more time to write during the intervention, rather than being rushed to finish. Interview data supports the need to adjust the intervention schedule to improve learning outcomes.

Another limitation in the current study is the physics content assessment used to measure students’ pre and post knowledge. Although the assessment was tested with middle school students prior to this study, there was a floor effect on both the pre and post administrations. This assessment may have been too difficult for the students, decreasing its usefulness in the study. Previous research has indicated that multiple-choice assessments may not be the best
method for measuring learning from writing (Schumacher & Nash, 1991). Another option for measuring learning is grading the written responses from the intervention for learning (Durst, 1987; Newel, 1984). A further analysis of the current students’ written stories for content knowledge should be conducted in the future to examine differences in learning between conditions. Alternative assessments, such as open-ended assessments or concept maps could also be considered for future studies (Rice et al., 1998; Segalas et al., 2008).

As described previously, an error in the intervention program lead to the condition specific procedures not being applied consistently in the sixth day of the intervention. All data related to the sixth day was removed from the analyses. Additionally, missing data related to time spent in the program, metacognitive judgments, and errors in saved data files led to the removal of several key analysis variables including time spent writing and post-task metacognitive judgments. Program errors will need to be repaired for future studies.

The original study design included delayed post assessments to measure the lasting impact of the program on key learning outcomes. However, weather related schedule changes significantly altered study plans. Initially, teachers’ instructional schedules included a 3-week break between finishing the program and beginning the regular physics instruction. Delayed post assessments were scheduled during this window. School cancellations due to inclement weather and deadlines for District-wide science content assessments forced teachers to begin their physics unit immediately after the intervention ended. Because students would be learning the same content as was presented in the intervention, it was not appropriate to give the delayed post assessment as originally planned.
**Recommendations for Future Research**

In addition to addressing the limitations of the current study, future research should consider changes to the study design. Multiple measures of physics content knowledge should be used to identify changes and growth of knowledge. Using a combination of open response assessments, scored writing products, and traditional multiple-choice assessments may create a more thorough picture of the learning benefits associated with different types of writing. Further, a second administration of the spontaneous writing portion of the TOWL-4 using the alternative image will help identify changes in story writing ability after participating in the intervention. Future research designs should also include a comparison condition of students receiving traditional physics instruction to better understand the impact of this intervention.

The measurement of learning outcomes could also be improved if future studies included transfer tasks. The problem-solving strategy scenario used in this study was one attempt to measure transfer, but it could be improved upon to get a better picture of the problem-solving strategies, metacognitive strategies, and even the transfer of knowledge to new problems. Scenarios should prompt students to include metacognitive processes in addition to problem-solving steps. By creating scenarios that are both science and non-science based, it will be possible to look at different levels of transfer (immediate, near, far). Additionally, administering at least one of these scenarios as a delayed post assessment will help determine if the intervention lasts.
Writing-to-learn literature has stressed the importance of multiple drafts and feedback to increase learning outcomes from writing (Chen et al., 2013; Hein, 1999; Yore et al., 1999). For instance, in Chen et al.’s study (2013), fifth graders were provided with feedback and probing questions after submitting their first written product. Students were able to continue their research and rewrite their response, improving their understanding of the content as well as their written product. In the current study, students were not provided feedback and were not asked to improve upon their written products. This may have been detrimental to students’ learning and decreased the impact of the story writing intervention. The addition of feedback and multiple drafts will improve learning outcomes and products in future studies.

Additionally, the story writing portion of the intervention could be improved if metacognitive monitoring and evaluation prompts or checklists were included to help direct students’ writing (Bangert-Drowns, 2004; Glynn & Muth, 1994; Scardamalia, Bereiter, & Steinbach, 1984). This was mentioned by one of the interviewed students as a way to make writing the story easier for those who struggle. The addition of these prompts could help address the content, strategies, and story components that students should include when writing.
REFERENCES


APPENDICES
Appendix A
Study Method Diagram

**QUAN Data Collection**
N = 117 Seventh Grade Science Students  
(Days 1-2)

**Pre Assessments**
*Day 1:* Demographic Data, TOWL-4, Problem Scenario  
*Day 2:* Efficacy, Problem Questionnaire, Content Knowledge  

(Days 3-8)

**Intervention**
6 Days, 1 Story Per Day  
Four Conditions:  
1. Write Prompt + Write Story (N = 23)  
2. Think Prompt + Write Story (N = 31)  
3. Write Prompt + No Story (N = 30)  
4. Think Prompt + No Story (N = 33)  

(Day 9)

**Immediate Post Assessments**
*Day 1:* Content knowledge, Efficacy, Problem Questionnaire, Problem Scenario

**Design:** Sequential Explanatory (QUAN + qual)

**QUANTITATIVE Data Analysis**

**Case**

**qual Data Collection**

**Interviews**
Write Prompt + Write Story (N = 2)  
Think Prompt + Write Story (N = 2)  
Write Prompt + Write Story (N = 5)  
Think Prompt + Write Story (N = 5)

**Qualitative Data Analysis**

Integration of QUANTITATIVE and Qualitative Results
Appendix B
Study Measures

Demographic Data Questionnaire

How old are you?
What is your gender?
Which of the following best describes your race?

Physics Content Knowledge Assessment
1. Imagine you are riding your bike and you hit a large rock. Your bike stops completely. What most likely happens to you?
   A. You stop moving with the bike because of the rock (1)
   B. You fall backward off of your bike when it stops (2)
   C. You stop moving and fall to the side with your bike (3)
   D. You fall forward over the bike handles when it stops (4)

2. Imagine that you placed your backpack on the back seat of the car. You are riding with your parents and they stop suddenly. Your backpack slides off the backseat and lands under the front seat. What is most likely the cause of this?
   A. The backpack is moving at the same speed as the car and continues moving forward when the car stops. (1)
   B. The backpack is moving slower than the car and stops before the car causing it to slide off the seat. (2)
   C. The backpack is moving faster than the car and does not stop as quickly as the car causing it to slide off the seat. (3)
   D. The backpack stops moving but slides off of the seat because the car is still moving forward as it slows down. (4)

3. Imagine a speedboat travelling down a river. Which of the following statements is true?
   A. The passengers on the boat are not moving, the boat is moving. (1)
   B. The passengers on the boat are moving slightly slower than the boat. (2)
   C. The passengers on the boat are moving slightly faster than the boat. (3)
   D. The passengers on the boat are moving the same speed as the boat. (4)

4. Imagine you are pushing a heavy box across the floor at a constant speed. Which of the following is true?
   A. The amount of force with which you push on the box is equal to that with which the box pushes back on you. (1)
   B. The amount of force with which you push on the box is smaller than that with which the truck pushes back on you. (2)
   C. The amount of force with which you push on the box is greater than that with which the box pushes back on you. (3)
   D. The amount of force with which you push on the box and the box pushes back on you is zero. (4)
5. A ball is rolled across the ground. It eventually slows down and stops. Which of the following explanations MOST LIKELY caused the ball to stop?
A. The ball stopped because it was not rolled with enough force to keep it moving. (1)
B. The ball stopped because there was friction between the ball and ground. (2)
C. The ball stopped because the contact forces acting on it were greater than the force used to roll the ball. (3)
D. The ball stopped because gravity was pulling it towards the ground causing it to slow down. (4)

6. The resistance to motion when two surfaces are in contact is called
A. Gravity (1)
B. Reaction Force (2)
C. Inertia (3)
D. Friction (4)

7. John wants to conduct an experiment to examine the impact of friction on motion. He is rolling a toy car down an inclined plane and measuring the distance the car travels. What variable should he change in his experiment to examine the impact of friction on motion?
A. John should use cars with different masses (1)
B. John should change the slope of the inclined plane (2)
C. John should change the surfaces the car rolls on (3)
D. John should change the amount of force he uses to push the car (4)

8. A ball is rolling across the floor. What do you need to do to make the ball stop rolling?
A. Apply a force in the opposite direction that is equal in magnitude to the force of the rolling ball. (1)
B. Apply a force in the same direction that is equal in magnitude to the force of the rolling ball. (2)
C. Apply a force in the opposite direction that is greater in magnitude than the force of the rolling ball. (3)
D. Apply a force in the same direction that is greater in magnitude than the force of the rolling ball. (4)
E. Apply a force in the opposite direction that is smaller in magnitude than the force of the rolling ball. (5)
F. Apply a force in the same direction that is smaller in magnitude than the force of the rolling ball.

9. A ball is rolling across the floor. What do you need to do to make the ball roll in the opposite direction?
A. Apply a force in the opposite direction that is equal in magnitude to the force of the rolling ball. (1)
B. Apply a force in the same direction that is equal in magnitude to the force of the rolling ball. (2)
C. Apply a force in the opposite direction that is greater in magnitude than the force of the rolling ball. (3)
D. Apply a force in the same direction that is greater in magnitude than the force of the rolling ball. (4)
E. Apply a force in the opposite direction that is smaller in magnitude than the force of the rolling ball. (5)
F. Apply a force in the same direction that is smaller in magnitude than the force of the rolling ball.

10. Which of the following statements is true?
A. Unbalanced forces are equal in magnitude and occur in opposite directions (1)
B. Unbalanced forces are unequal in magnitude and occur in the same direction (2)
C. Balanced forces are equal in magnitude and occur in the same direction (3)
D. Balanced forces are equal in magnitude and occur in opposite directions (4)

11. An object moving along a surface suddenly increases speed. What can cause this to happen?
A. It is moved by balanced forces (1)
B. It is moved by a force without direction (2)
C. It is moved by a low magnitude force (3)
D. It is moved by unbalanced forces (4)

12. Which simple machine is commonly used to hold things together?
A. wheel and axle (1)
B. clamp (2)
C. pulley (3)
D. screw (4)

13. A knife is an example of which simple machine?
A. Wedge (1)
B. Lever (2)
C. Inclined plane (3)
D. It is not an example of a simple machine (4)

14. Airplane wings were designed to allow planes to fly. According to the principles of flight, the wind on the top of the wing is moving faster so it is exerting ______________ the wind under the wings.
A. more force than (1)
B. equal force as (2)
C. less force than (3)
D. more pressure than (4)

15. A student throws a paper airplane and it falls to the ground. What is most likely the reason for this?
A. The plane’s drag was too low. (1)
B. The plane’s lift was too low. (2)
C. The plane’s momentum was too low. (3)
D. The plane’s weight was too low. (4)
**Physics Self-Efficacy**

This questionnaire is designed to help us gain a better understanding of the kinds of things that create problems for students in physics classes. Physics is the study of the nature and properties of matter and energy. You will be learning specifically about forces and motion in this unit. Please indicate your opinion about each of the statements below. Remember to think of your physics class when you answer these questions. Your answers are confidential and will not be identified by name.

The following statement is ______ like me.

1. I am sure that I can learn physics.
2. I can get a good grade in the physics portion of science class.
3. I am sure I could do advanced work in physics during science class.
4. I have a lot of self-confidence when it comes to physics.
5. I am not the type to do well in physics.
6. It takes me a long time to catch on to new topics in physics.
7. Even before I begin a new topic in physics, I feel confident I'll be able to understand it.
8. I think I have good skills and strategies to learn physics.
Writing Self-Efficacy

This questionnaire is designed to help us gain a better understanding of the kinds of things that create problems for students in writing classes. Please indicate your opinion about each of the statements below. Remember to think of your writing experiences when you answer these questions. Your answers are confidential and will not be identified by name.

The following statement is _______ like me.

1. I have a lot of self-confidence when it comes to writing.
2. I am not the type to do well in writing.
3. It takes me a long time to write a story.
4. I think I have good skills and strategies for writing.
5. Writing helps me understand better what I’m thinking about.
6. Writing helps me see the complexity of ideas.
7. My thoughts and ideas become more clear to me as I write and rewrite.
8. Writing helps new ideas emerge.
9. Good writers make complicated information clear.
10. Good writers are sensitive to their readers.
11. Good writers support their ideas effectively.
12. Good writers adapt their message to their readers.
13. Good writers thoroughly explain their opinions and findings.
14. Good writers are reader friendly.
15. I can think of many ideas for my writing.
16. I can put my ideas into writing.
17. I can think of many words to describe my ideas.
18. I can think of a lot of original ideas.
19. I know exactly where to place my ideas in my writing.
20. I am a good story writer.
22. I think writing is an important part of learning.
Jr. MAI

We are interested in what learners do when they study. Please read the following sentences and circle the answer that relates to you and the way you are when you are doing school work or home work. Please answer as honestly as possible.

1. I know when I understand something. (1)
2. I can make myself learn when I need to. (2)
3. I try to use ways of studying that have worked for me before. (3)
4. I know what the teacher expects me to learn. (4)
5. I learn best when I already know something about the topic. (5)
6. I draw pictures or diagrams to help me understand while learning. (6)
7. When I am done with my schoolwork, I ask myself if I learned what I wanted to learn. (7)
8. I think of several ways to solve a problem and then choose the best one. (8)
9. I think about what I need to learn before I start working. (9)
10. I ask myself how well I am doing while I am learning something new. (10)
11. I really pay attention to important information. (11)
12. I learn more when I am interested in the topic. (12)

**Problem Solving Questionnaire (Fortunato, 1990)**

Before you begin solving a problem, how often do you do the following: (Likert Scale 1-5)

1. I read the problem more than once (1)
2. I ask myself, "Do I understand what the problem is asking me?" (2)
3. I put the problem into my own words (3)
4. I try to remember if I have solved a problem like this one before (4)
5. I think about what information I need to solve the problem (5)
6. I ask myself if there is information in the problem that I don't need (6)

While you are solving a problem, how often do you do the following:

1. I think about all the steps I am taking as I solve the problem (1)
2. I look back at the problem after I finish each step (2)
3. I stop and re-think a step, even if I already finished it (3)
4. I check my work step by step as I solve the problem (4)
5. If I do something wrong, I go back and re-do my steps (5)
AFTER you finish solving a problem, how often do you do the following:

1. I look back to make sure I used the correct procedures (1)
2. I check to see if any calculations were correct (2)
3. I go back and check my work again (3)
4. I look back at the problem to make sure my answer makes sense (4)
5. I think about a different way to solve the problem (5)

How often do you do the following when solving a problem:

1. I draw a picture to help me understand the problem (1)
2. I use "guess and check" (2)
3. I write down important information (3)
4. I feel confused and can't decide what to do (4)
5. I start working without planning how to solve the problem (5)
6. I make mistakes and have to start again (6)
7. I make mistakes but decide NOT to start again (7)

Problem Solving Strategy Scenario

**Pre:**

Lots of people drop their cell phones in water, which can damage or break them. This is a very common problem that can cost a lot of money to fix or replace the phone.

Pretend you have been hired by a company to create a NEW way to either prevent or fix water damaged phones. They want to make sure this is a new idea so they are able to make money. They do not want to rely on existing methods.

**How would you go about finding a solution to this problem? Please carefully describe the steps you would take to solve the problem.**
Post:

Two students are discussing what happens when a piece of paper and a heavy rock are dropped at the same time. Student A thinks that both the paper and rock will land on the floor at the same time because of gravity. Student B thinks that the rock will reach the floor first because it is heavier.

What steps should the students take to find the solution to this problem? Please carefully describe the steps you think they should take to solve the problem.

Rubric:

1 Point for each of the following steps:

- Identification of Problem (identifies problem and/or relevant knowledge)
- Problem Representation (draw, model, diagram problem)
- Planning (preparing for research and experimentation, organizing procedures/steps)
- Research (researching related topics and problem solutions)
- Experimentation (evidence of experimentation or testing of solution)
- Solution (present solution, or evidence for solution)
Appendix C
Solve It! Screen Shots

Metacognitive Problem Solving Program Screen Shots

Step 1 - Identify the Problem

What is the problem that Kelly and Chris need to solve?

Step 2 - Show the Problem

One way to show the problem is to make a picture of what happened. Imagine what happened in the story. Use the images on the left to make a picture of what happened by dragging them into the space on the right. There may be extra pictures and you can use the same picture more than once. You can remove an image from your picture by dragging it off the "canvas".

Writing the Story

Write your conclusion to the story with a solution to Alex’s problem in the space below. When you write your story, include all of the steps you used to solve the problem. Use the “Click for Resources” menu to review and update your work. In your story, include the kinds of things you were thinking while solving the problem. This will make the story more interesting and will also help people reading the story understand how you solved the problem.

One way to show the problem is to make a picture of what happened. Imagine what happened in the story. Use the icons on the left to make a picture of what happened by dragging them into the space on the right. There may be extra pictures and you can use the same picture more than once. You can remove an image from your picture by dragging it off the “canvas.”
Appendix D
Example Problem Story 1

Ill-Structured Story Problem Example: Alex’s Story (Story 1)

Alex stared at the clock. He was so excited for school to end. Just one more minute and his weekend would begin!

He was surprised when he heard his name being whispered. Alex looked over and saw Beth smiling at him.

“Alex, what are you doing this weekend?”

Alex struggled to respond. He always got nervous when he talked to Beth. He had a crush on her from the moment he met her and was usually too shy to talk to her.

“Oh, tomorrow is my birthday so I am going to get a new-” The school bell rang and cut off his sentence.

“I’m sorry Alex, a new what?” Beth asked.

“A new skateboard. My mom is taking to get a new skateboard.” Alex was slightly embarrassed and hoped Beth thought skateboards were cool.

“That sounds great! I love to skateboard!” Beth responded excitedly. “But I am not very good. Maybe you could help me get better?”

Alex started to blush as he said “Yeah, that would be fun.” Luckily his friend Tom interrupted them and told Alex they needed to start walking home. Beth waved goodbye as they walked out of school.

“What were you two talking about?” Tom asked in a high pitched voice as he smiled and winked at Alex.

“We were talking about skateboarding. She asked me to teach her—” Alex started to respond, but Tom began dancing around and teasing Alex. “Whatever Tom, at least a girl is talking to me.”

“I doubt BETH is talking to you because she likes you. She was just bored.” Tom responded.

“I don’t think so.” Alex was nervous though. What if Beth was just bored and trying to be nice? “Anyways, it doesn’t matter. Tomorrow is my birthday and I am getting my new skateboard. Do you want to go to the park when I get home?”

“Sure,” Tom said, as they stopped in front of Alex’s house. “I’ll see you tomorrow. Hopefully Beth can make it!” Tom shouted as he walked down the street towards his house.

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Alex was very pleased with his choice as he and his mom stood in line to pay for his new skateboard.

“Are you sure this is the one you want?” Alex’s mom asked.

“This is it!” Alex said excitedly. “I can’t wait to go to the park with Tom. A girl from school, Beth, asked me to teach her how to skateboard too, but I don’t know if I want to.”

“Why not?” Asked Alex’s mom.
“Because she is a girl. What if she is no good? Plus Tom was teasing me...” Alex trailed off.

“I wouldn’t worry about Tom. I am sure he wouldn’t mind if you brought Beth to the park. It is nice to help your friends. Let’s get lunch before we go home, it is your birthday.” Alex’s mom said. They paid for the skateboard and then stopped to eat lunch. His mom even bought him a milkshake before they headed home.

Alex’s hands were full as he walked to the car. He set his milkshake on the roof of the car and carefully loaded his new skateboard into the back seat. He was so excited to get home and go to the park with Tom and, hopefully, Beth.

Alex’s mom backed the car out of the space and began to drive through the parking lot. Up ahead Alex saw Beth and her mother walking to their car. Beth was holding a small bag from the same store where Alex bought his skateboard. Could she have bought a present for Alex?

Suddenly a little girl ran into the parking lot and Alex’s mom stopped very quickly. Alex felt his body jerk forward as the car came to a stop. The seatbelt caught him and held him in place. He looked up and was frozen. There was Beth, covered in strawberry milkshake. He looked down. Where was his milkshake? He looked up again and saw his empty milkshake cup roll along the ground. Beth was staring at him. She looked upset. Her mother was also wearing some of the strawberry milkshake.

Alex’s mom jumped out of the car. “Oh no, what happened?” she asked Beth and her mother.

They all looked at Alex. “Did you throw your milkshake at them?” Alex’s mother demanded.

“No!” Alex said as he jumped out of the car.

“Then where is your milkshake? The strawberry milkshake I just bought you?” Alex’s mom demanded. Beth was just standing there waiting for Alex to respond.

“Alex, did you throw your milkshake at me?” Beth asked. She looked like she was going to cry.

Alex felt horrible. He didn’t know what to say. He did not have his milkshake. He must have left it on the roof of the car. He didn’t know what had happened. He tried to say something, but couldn’t.

“Alex, this is unacceptable behavior! You are certainly not going to the park today and I am going to keep the skateboard until you can prove to me that you deserve it.”

“But Mom, I didn’t throw my milkshake at them!” Alex said as he tried to figure out what happened. Beth and her mother began to walk back into the store to clean the milkshake off of their clothes.

Alex was so upset. His mom was mad at him. Beth was mad at him. He was grounded and he lost his skateboard. But he didn’t do it! What could he do to prove to his mom and Beth that it was an accident?

When they returned home Alex was sent to his room while his mother and father discussed what had happened. Alex sat at his desk. What had actually happened? How could he prove to his mom and Beth that he was innocent?

His science teacher always said it was important to use logic when solving problems. Alex knew he was going to need a lot of logic for this one.
Suddenly he remembered learning about some famous scientists, one who even studies moving things. He had written a paper on them. He needed to find that paper!
Appendix E
Interview Questions

1. How did you feel about using the problem-solving program?
2. Did you learn while using the program? Physics content? Problem Solving?
3. The program required you to learn on your own. How do you feel about learning on your own?
4. Do you learn from experiments? Do you learn from research/reading?
5. What would have helped you learn more while using the program?
6. Did writing responses to the problem solving questions help you understand the problems? Why or why not?
7. Did you like writing the story endings? Did writing the story endings help you understand the problems? Why or why not?
8. Which writing did you prefer- answering the questions or writing the story? Why?
9. What would you change about the problem-solving program?