THE EFFECTS OF A WEB-BASED TOOL WITH READING AND COGNITIVE PROCEDURAL SCAFFOLDS ON ALGEBRA LEARNING AMONG LOW-AND-HIGH-ACHIEVING READERS AND ITS EVALUATION FROM TEACHERS' PERSPECTIVES

A Dissertation

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ABSTRACT

The purpose of this study was to, (a) analyze the differences in the effectiveness of different computer-based scaffolds on students' math learning, (b) examine how their effectiveness on mathematics achievements can differ based on students' different reading abilities, and (c) evaluate the usefulness of the computer-based reading scaffolds from teachers' perspectives. We created three conditions: control condition, reading scaffolded condition (RS), and cognitive-tutor scaffolded (CS) condition with scaffolds for step-by-step problem solving. One hundred and two eighth- and ninth-grade students participated and were randomly assigned into the three conditions. Pre and post-tests and tool evaluation surveys were administered to all students. Statistical analyses used to identify causal effects included two-way ANOVA and ANCOVA.

We found that students in the RS and CS conditions had significantly improved knowledge gains compared to those in the control condition. Specifically, students in the RS condition had significantly better conceptual knowledge gains than those in the other two conditions. On the other hand, students in the CS condition had significantly better procedural knowledge gain than those in the control condition. Investigating the interaction effects of conditions and students' reading skills, students with high reading skills in the control and CS condition showed more procedural knowledge gain than those with low reading skills. However, in the RS condition, low-achieving readers had more conceptual and procedural knowledge gain than high-achieving readers.

In tool evaluation, one hundred and forty-eight secondary math teachers evaluated the web-based tool with computer-based reading scaffolds in terms of its ease of use and usefulness in teachers' instruction and students' learning. Teachers were also asked to share their idea on how computer-based reading scaffolds for math can be further improved. Most teachers who participated in tool evaluation responded that using the computer-based reading scaffolds in math can simultaneously increase their teaching efficiency and improve students' mathematical knowledge. Teachers also perceived that the computer-based reading scaffolds promote the math knowledge of low-achieving and self-motivated students.

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NOMENCLATURE

RS	Reading Scaffolded Condition
CS	Cognitive-tutor Scaffolded Condition
ITS	Intelligent Tutoring Systems

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CHAPTER I

INTRODUCTION

Reading problems in math have been discussed as one of the crucial predictors of math achievement, which requires that students engage in intensive reading when they study mathematics (Adams, 2003). Shanahan and Misischia (2011) found that learning math requires consistent and rigorous re-reading that allows readers to weigh all information. Fang and Schleppegrell (2010) also asserted that accuracy and precision are essential in understanding texts in mathematics because in math, every word matters.

This is because of the unique features of reading in math in which every word and symbol can convey and organize enormous amounts of information in a condensed form. The mathematics texts hold abstract concepts per word, sentence, and paragraph, so it can be difficult for students to visualize their meaning (Brennan & Dunlap, 1985; Culyer, 1988). Mathematics also requires students to be able to decode not only words but also numeric and non-numeric symbols. In other words, students need to interpret words and numeric symbols in both directions. Moreover, a mathematics text often includes diverse image information such as graphics, tables, or pictures which makes the text more complicated to understand than for the intended grade level (Barton and Heidema, 2002; Cromley et al., 2016). Therefore, it can be challenging for students to navigate complex mathematics texts.

Studies regarding the relation between reading and mathematics have revealed that reading ability is correlated with achievement in mathematics (Ní Ríordáin &

O'Donoghue, 2009; Reikerås, 2006). Concerning test items in mathematics, it has been proven that mathematics word problems assess students' reading comprehension more than the subject understanding and computation skills (Flick &Lederman, 2002; Walker & Beretvas, 2001; Shealy & Stout, 1993). Walker et al. (2008) believe that mathematics word problems are two-dimensional in that they measure both reading ability and mathematics computation skills. They also found that some students show lower performance in math not due to a lack of mathematical knowledge, but rather to a lack of being able to translate a problem presented in a written format into the correct mathematical representation. Moreover, Grimm (2008) mentioned that reading comprehension relates to a conceptual understanding of mathematics and the application of mathematics knowledge.

To deal with the reading problems in mathematics, researchers have studied how to improve students' reading ability in math. Nathan et al. (1992) proposed using computer-based tutors to help students develop their contextual understanding of algebra questions. Several studies focused on removing the unfamiliarity with the math vocabulary so that students understand mathematical texts better (Carter & Dean, 2006; Bellocchi & Ritchie, 2011). Rupley and Wilson (1997) suggested 'summary strategies', that requires students to find important information and put it in their own words, for reading in math. However, even though the literature showed that reading ability is correlated with math performance, most of the suggestions are highly dependent on teachers' experience and instructional strategies, and the effects of these suggestions on enhancing students' reading ability in mathematics have not been verified.

Statement of the Problem

Many computer-based learning environments (CBLEs), such as ASSISTments and Cognitive Tutor, have been successfully used to improve students' math learning (Heffernan & Heffernan, 2014). These systems include appropriate scaffolds (e.g., hints, computer tutoring, mastery skill map, and others) and help students master the material. However, these scaffolds are mainly focused on providing guided practice opportunities to develop upon fine-grained skillsets to boost students' ability to solve math questions, which is regarded as procedural knowledge. These computer-based scaffolds have been acknowledged to have the ability to improve procedural knowledge in math problem-solving; however, there is a lack of sufficient evidence that these scaffolds can enhance students' conceptual understanding.

Because mathematics relies heavily on student's conceptual understanding (Barton & Heidema, 2002), it is important to design and develop effective computer-based scaffolds that can assist with reading in math. However, computer-based scaffolds for reading in math have rarely been studied. Moreover, several studies have pointed out that many students, especially low-achieving students, fail to learn the target knowledge (e.g., Land, 2000; Mayer, 2004) and find it hard to regulate their learning process in CBLEs (Azevedo & Hadwin, 2005; Segedy et al., 2011). Furthermore, there is a lack of research analyzing the effects of CBLEs according to students' different knowledge levels.

Thus, this study designed a web-based tool with computer-based scaffolds to teach reading in math and to advance students' conceptual and procedural knowledge. This scaffolding approach was expected to help not only high achievers but also low achievers who usually need more assistance in learning via CBLEs. The purpose of this study was to (a) determine whether computer-based reading scaffolds in mathematics can improve students' math performance, (b) determine whether the effects of different computer-based scaffolds can vary based on students' reading levels, and (c) evaluate the ease of use and usefulness of the CBLE tool.

Research Questions and Hypotheses

This study has two dimensions: 1) an empirical experiment to analyze the tool's effectiveness on students' learning in math and 2) an evaluation of the tool from the teachers' perspectives. Three different conditions were considered: the control condition, the reading scaffolded condition, and the cognitive-tutor scaffolded condition. Detailed explanations of the three conditions are provided in Chapter 3 where the computer-based tool design is reviewed.

Tool Effectiveness Experiment

The primary interests of the tool effectiveness experiment were, first, how effective the created computer-based reading scaffolds were and second, how the effect of computer-based reading scaffolds differ based on students' reading ability. For this we established four research questions:

R1. How does the effect of three different scaffolded conditions (control, treatment 1, and treatment 2) vary students' knowledge gain?

R2. How does the effect of three different scaffolded conditions (control, treatment 1, and treatment 2) vary students' conceptual knowledge learning gain?

R3. How does the effect of three different scaffolded conditions (control, treatment 1, and treatment 2) vary students' procedural knowledge learning gain?

R4. Does the effect of each condition on knowledge gain differ between low- and high- reading level students?

According to primary interests and research questions above, the null hypotheses tested include:

H1. There is no difference in the average knowledge gain of three scaffolded conditions.

H2. There is no difference in the conceptual knowledge gain of three scaffolded conditions.

H3. There is no difference in procedural knowledge gain of three scaffolded conditions.

H4. There is no difference in the effect of each condition among students with different levels of reading ability.

Tool Evaluation

Educational software/technology needs to be evaluated by teachers regarding its potential benefits in both teaching and learning. The potential benefits of this tool include both teaching and learning math. According to Bucktleiner (1999), the evaluation of educational software should be studied in terms of its intended purpose, the developmental level of the target audience, and comparison with other alternatives. The research questions regarding tool evaluation are as follows:

R5. How did teachers perceive the effects of the web-based tool with reading scaffolds on their teaching?

R6. How did teachers perceive the effect of the web-based tool with reading scaffolds on students learning in math?

Definition of Terms

- *Scaffolding*: The term is a metaphor describing how teachers (or adults) assist learners (or a child) in completing learning tasks that the learners would be unable to complete without assistance (Wood et al.,1976).
- *Computer-based scaffolding*: Computer-based agents with methods for interpreting a students' behaviors and the library of scaffolds supports his/her learning and problem solving (Segedy, 2014).
- *Procedural knowledge*: The ability to execute action sequences to solve problems, including the ability to adapt known procedures to novel problems

(the latter ability is sometimes labeled transfer; Rittle-Johnson, Siegler, & Alibali, 2001).

- *Conceptual knowledge*: An integrated and functional grasp of ideas (Kilpatrick et al., 2001). This knowledge is flexible and not tied to specific problem types and is therefore generalizable (although it may not be verbalizable).

CHAPTER II

LITERATURE REVIEW

The first part of this review describes a reading problem in mathematics found in literature and discusses how reading components are related to each problem-solving stage. The second part of the review summarizes studies explaining how humans learn from new information and how scaffolding can help this process. The third part describes how scaffolding can assist students in achieving their intrinsic learning goals. The last part of this review illustrates the origin of the term ‘scaffolding’, its expansion and development with technology in the teaching and learning process, and contemporary research of computer-based scaffolds in the science, technology, engineering and mathematics (STEM) area.

Disciplinary literacy in mathematics

There has been a growing body of work on issues of reading, particularly in relation to the very dense nature of the written mathematics register (Halliday, 1978; Pimm, 1987), as well as the increasing symbolic interpretative load students have to bear as they progress through school mathematics. George Polya (1945) explained that the problem-solving process starts with reading and understanding the problem. According to his four-stage problem-solving process, the first phase ‘read the problem’ involves the student reading the problem entirely. In the second phase ‘understand the problem’, the student should attend to vocabulary, context/setting, the question of the problem, needed information, and extraneous information. In many instances, students may have to return to the first process, reading the problem, in order to support this second process. In the third stage, ‘solve the problem’, students must select and use appropriate strategies to respond to the problem. Again, the student may need to return to either of the first two phases to be successful in this phase. In the last stage ‘Look back’, students can find errors in understanding the problem, the procedures, or even in the recording of the solution by viewing the solution in the context of the problem. In addition, looking back lets students engage in discussions about the problem-solving process to further enhance their reasoning skills, and abilities to explain and justify solutions. Each stage needs students’ active and repetitive reading for solving math problems.

Adams (2003) also insisted that doing mathematics requires reading mathematics, and he elaborated on factors related to reading words in mathematics. According to his work, words in mathematics have specific features. First, in reading mathematics, mathematics vocabulary can have multiple meanings. For example, the word ‘graduated’ means ‘received an academic degree’ in everyday life but means ‘marked with degrees of measurement’ in mathematics. Second, words in mathematics involve homophones and similar-sounding words, such as ‘one’ and ‘won’, ‘whole’ and ‘hole’, ‘sum’ and ‘some’, ‘weight’, and ‘wait’ and others. Lastly, students need to read mathematics within the context. This requires students to recognize not only the meaning of individual words, but also the relationships among those concepts to understand the passage.

Therefore, Garbe (1985) suggested several ways to promote students' learning by creating a list of mathematics vocabulary for each such subject area (e.g., geometry), assessing students' knowledge of mathematics vocabulary periodically (e.g., end of a passage, lesson, or unit), investigating students' previous knowledge level, and providing students with additional resources based on their knowledge. Adams (2003) also recommended that teachers instruct students to specify the vocabulary they do not understand, discuss these words in small groups, and make and use a mathematics dictionary. Other strategies were also discussed such as interactive read-alouds (Marra, 2014; Bortnem, 2008), self-summary strategies, and peer discussion about key terms (Carlisle, 2010).

Most of the experimental studies about mathematics interventions focusing on students reading have been conducted with students who have reading or learning disabilities in the special education area. Kurz and Elliott (2012) contended that low performance of students with learning disabilities in mathematics can be related to skill-focused instruction, and these students need to receive more fundamental instruction of conceptual knowledge and problem-solving. Maccini et al. (2007) reviewed cognitive interventions to promote students' mathematics knowledge by assisting their reading skills. These included cognitive strategies such as mnemonic instruction about how students can recall particular algorithm, visual representations of words or numerical equations, development of mental structures about word problems, and self-monitoring strategies on problem-solving.

Several researchers in the special education field also designed and studied the effects of computer-based learning environments with aids for students' reading in mathematics (Montague et al., 2011; Iseman & Naglieri, 2011). For instance, the Solve It! intervention embedded both cognitive and metacognitive strategies to teach students with learning disabilities to solve word problems (Montague et al., 2014; Krawec et al., 2013). It included think-aloud practices, immediate and corrective feedback, visualization strategy, and teacher-directed demonstration and modeling. Strickland and Maccini (2013) developed the concrete-representational-abstract (CRA) strategy to improve the performance of students with learning disabilities on word problem-solving. This strategy showed students how to solve math problems by using visual representations before they solved problems with numerical equations. Teachers demonstrated how to link different math concepts using CRA sequence and helped students to solve questions independently. While solving problems, students were required to explain and justify answers using math concepts. These intervention studies yielded large effects on students' math posttest scores (Cohen's d=.54 - .67). However, even though these interventions used computer-based learning environments, most of the suggestions are highly dependent on teachers' experience and skills, and there are few studies verifying the effects of these suggestions on mathematical knowledge improvements of students without reading or learning disabilities.

How scaffolding can enhance students' knowledge acquisition

Failing to provide enough reading scaffolds in math disenables students from acquiring knowledge for successful problem-solving. Providing adequate scaffolds that can support students' reading of the mathematical text and facilitate the transfer of knowledge requires a deep understanding of how students learn and process new information in terms of cognitive theory. Among various theories in cognitive science, we discuss how cognitive load theory can enhance students' learning through scaffolding.

Cognitive load theory has developed cognitively effective and efficient instructional procedures. Cognitive load refers to the total working memory resources needed to perform a learning task (Kirschner et al., 2018). It assumes that human memory can be divided into two forms: working memory and long-term memory (Sweller, 1998). Working memory, in which all conscious cognitive processing occurs, can handle only a very limited number of interacting elements. Cowan (2010) argues that the working memory can handle about four elements at the same time. Miller (1956) insists that seven elements can be processed in working memory. This number is far below the number of interacting elements that occurs in most substantive areas of human intellectual activity. These limitations are irrelevant when the needed information can be retrieved from long-term memory. Long-term memory provides humans with the ability to expand this processing because it can store numerous schemas—cognitive constructs that incorporate multiple elements of information into a single element with a specific function.

Many researchers have correlated working memory with reading comprehension and reasoning skills (Clark et al., 2012). In cognitive load theory, when we encounter new information, three types of cognitive load are imposed on working memory: intrinsic, extraneous, and germane loads (Sweller, 2010). Intrinsic load is directly associated with the number of elements in the instructional material and the degree of element interactivity that have to be processed. An element can be defined as "anything that needs to be or has been learned, such as concept or procedure" (Sweller, 2010, p. 124). Kester et al. (2006) describe that solving the problem yields intrinsic cognitive load. If a problem needs to process a small number of elements at a time (low element interactivity), then it requires a low intrinsic cognitive load. On the other hand, if a problem needs to process several elements simultaneously in working memory to solve a problem, then it requires a high intrinsic cognitive load.

As well as element interactivity, the manner in which information is presented to learners and the learning activities required of learners can also impose a cognitive load. When mental resources are devoted to elements that are unnecessary and do not contribute to learning and schema acquisition and automation, it is referred to as an extraneous or ineffective cognitive load (Debue & Van De Leempt, 2014). It is mainly found in information presentation and the instructional format and increases students' overall cognitive load without enhancing learning. Many conventional instructional procedures impose extraneous cognitive load because most instructional procedures were developed without any consideration or knowledge of the structure of information or cognitive architecture.

Germane load denotes mental resources which devoted to acquiring and automating schemata in long-term memory. Sweller et al. (1998) discovered that some instructional formats could increase cognitive load and learning as well. Unlike extraneous load, germane load engages a learner in schema acquisition and automation that are beneficial for learning (Van Gerven et al., 2002). In general, a well-designed learning environment should properly manage intrinsic load, minimize extraneous load, and optimize germane load within the boundaries of working memory capacity.

Considering three different kinds of cognitive load, Van Gerven et al. (2002) suggest two forms of scaffolding that can adjust cognitive load which occur with learning. One is the scaffold learning material of simple-to-complex sequencing, which mitigates the intrinsic cognitive load. The other is providing the substantial scaffolding of worked examples in the early stage. The 'worked example' is regarded as the best-known cognitive load reducing technique (Paas et al., 2003), which allows a student to study with examples which can be more effective in building schemas and improving performance than solving similar problems repeatedly. The effect occurs because element interactivity is reduced by studying examples compared to problem solving (Sorden, 2005). When solving problems, learners must search for appropriate moves while considering all interrelated elements. This causes students to overwhelm their working memory load far above their limits. In contrast, when studying an example, each step can be learned without considering alternative options because an appropriate move has been provided. Element interactivity and extraneous loads on working memory are reduced with the use of examples. Students are expected to increase problem-solving ability with less burden on cognitive load by studying examples.

Scaffolding Students' Intrinsic Motivation to Achieve Mastery Learning

Intrinsically motivated learning indicated learning based on the satisfaction, pleasure of the activity of learning itself, and self-confidence (Deci & Ryanl, 2000). The motivation of learners is one of the key factors which influence an active attitude toward learning (Martens, et al., 2004; Renninger et al., 2011). Intrinsically motivated students are curious, desiring to gain an understanding about a topic or particular interest (Deci, 1992). Students with intrinsic motivation show a strong desire for mastery of content through learning activities. In the light of its importance to motivation in learning, we would navigate theoretical backgrounds explaining how students' intrinsic motivation facilitates their mastery learning and how scaffolding can support this process.

Mastery Motivation Theory

Mastery motivation can be defined as "a psychological force that stimulates a student to attempt independently to solve a problem or master a skill or task which is at least moderately challenging for him or her" (Morgan et al., 1990, p. 319). The word 'Mastery' implies to become competent at doing something and achieve a goal. Thus, Mastery motivation is related to the motivation to accomplish mastery of a skill or task. According to Morgan et al. (1990), mastery motivation in young children is assumed to be intrinsic and be determined by a combination of genetic and environmental factors. It is also assumed to explain individual differences and to vary from one domain to another.

Morgan et al. (1990) discussed key features of mastery motivation. First, the core of mastery motivation does not directly result in the successful completion of a task. This means that the important part of mastery motivation is “attempting or trying” to solve a problem, rather than whether a child can perfectly solve the problem. We can find an important distinction between motivation and competence from this point. A competence describes that the child knows how to do the target task and actually can do. A mastery motivation emphasizes the process and effort, such as a child’s focus and persistence, when the child is working on developing skills and competencies.

Second, mastery motivation deals with a child’s independent attempts to master when the child is using his or her resources and working unassisted (Morgan et al.,1990). Third, learning behaviors should reflect the features of mastery motivation. Persistence at tasks is the key measure of mastery motivation, which implies focused time and effort for obtaining a mastery of skill sets. The motivation should be involved with persistence toward a goal that is not yet mastered or at least moderately challenging relative to a child’s current developmental level. If the task or problem is too easy or involved in something that a student already has the skill to do, it is not what we mean by mastery motivation.

Achievement Goal Theory

Achievement goal theory (Ames, 1992; Ames & Archer, 1988; Hulleman, Schrager et al., 2010) also provides a useful framework for understanding students' motivation which is related to success and failure in learning (Duffy & Azevedo, 2015). Achievement goals are considered a sort of motivation in that they provide a purpose or focus for the task. It leads students to show positive learning behaviors and reach the standards of success (Elliot & Murayama, 2008; Linnenbrink & Pintrich, 2001). According to this framework, there are two achievement goals toward learning; mastery goal and performance goal. Students who adopt a mastery goal focus on developing competence and skills, whereas students with a performance goal concentrate on outperforming their peers (Elliot & McGregor, 2001; Elliot & Murayama, 2008).

Students with mastery goals endeavor to understand new material and develop skills and competence. Mastery goals are associated with the use of effective learning strategies and intensive learning (Ames, 1992). For example, mastery motivated children tend to expend more effort, are more persistent, show a preference for challenging tasks, and use instrumental help-seeking strategies (Newman, 1990). On the other hand, students with performance goals are focused on gaining favorable recognitions by demonstrating their knowledge or skills. Students with performance goals prefer to being judged by how well they perform compared to others (Elliot, 1988). In general, performance goals are associated with less effective strategies and consequently shallow learning (Elliot, 1988) since performance-motivated students are highly likely to do tasks that they can complete without challenge or help.

According to Wolters (2004), more recent studies developed these two broad achievement goals into four principal goal orientations (Elliot & McGregor, 2001; Pintrich, 1999), adding mastery-avoidance and performance-avoidance orientations. Unlike students with mastery goal orientation who are focused on learning and increasing their level of competence, those who have mastery avoidance orientation tend to study to avoid a lack of mastery or a failure to learn. Students with performance-avoidance goal orientation want to avoid looking incompetent or less able compared to their peers, as opposed to students with a performance-approach goal orientation who want to demonstrate their ability or worth relative to others.

Achievement goal theory also emphasized how a learning environment or setting presents the achievement goal because it affects students' motivation, cognitive engagement, and achievement within that setting (Ames & Archer, 1988). The type of achievement goal can be influenced by the dominant instructional practices and policies within a classroom, school, or other learning environments. The structure of achievement goals can be forged with the types of tasks assigned, the grading procedures, the degree of autonomy students have, and whether students foster approach or avoidance goals (Ames, 1992; Kaplan et al., 2002; Urdan, 1997).

Theories explaining students' intrinsic motivation toward learning have influenced the research on how students' help-seeking strategies can be affected by their metacognitive abilities. Several research studies have indicated that students' learning patterns can strongly depend on their intrinsic motivation toward learning. For example, some students do not always request help even though they cannot solve the given problems by themselves, while other students wisely seek help from teachers or peers and learn how to solve the problems. The type of help students want can also vary based on their motivation toward task completion and can include help for understanding the task, helpful hints, and/or help for locating resources to solve the task.

Scaffold STEM learning in computer-based learning environments

The Origin of Scaffolding

Wood et al. (1976) introduced the term 'scaffolding', describing how a baby learns language through early parent-child interaction. They defined a scaffolding process by which a child can solve a problem or achieve a goal that would not be able to reach without assisted efforts. In Wood et al.'s work, scaffolding is the key to fill the gap between students' current abilities and the knowledge which is needed to complete the task. According to their theory, scaffolding encompassed three key characteristics: contingency, intersubjectivity, and transfer of responsibility. Contingency indicated that teachers dynamically assessed students' current abilities and provided just the right amount of support (Wood et al., 1976). Intersubjectivity meant that students needed to be able to determine a successful solution to the problem and transfer of responsibility meant that successful scaffolding would lead students to learn how to complete the tasks independently (Wood et al., 1976).

Vygotsky's zone of proximal development (ZPD) theory (1978) conceptualized the notion of the scaffolding of Wood et al.'s work sociohistorically. Vygotsky (1978) proposed that a child is constructing his/her own world constantly via social communication and interaction with others. He defined the zone of proximal development as “the distance between a child’s actual developmental level of independent problem solving and the higher mental functioning level which can be obtained with adult guidance or in collaboration with more able peers” (p. 86). This theory emphasized that learning promoted internal developmental processes that needed a child to actively interact with people and peers.

For decades after Wood et al.’s work (1976) and Vygotsky’s ZPD theory, Collins et al. (1988) developed the cognitive apprenticeship approach in which students can acquire a set of cognitive skills through observation and scaffolded practice. In the cognitive apprenticeship environment, students can learn how to solve complex tasks in a structured manner with the guidance of teachers. Cognitive apprenticeship focuses on four dimensions: content, method, sequencing, and sociology (Collins et al., 1991). According to Collins et al.’s work, content includes specific domain knowledge, heuristic strategies for accomplishing tasks, control strategies for directing one’s solution process, and learning strategies about how to learn new knowledge. Content in the cognitive apprenticeship combined cognitive knowledge in a specific domain and metacognitive strategies that are related to learners’ control of learning. The method means ways that teachers can promote learners’ cognitive development. This includes modeling, coaching, scaffolding, articulation, reflection, and exploration. In cognitive apprenticeship, coaching is used as a broader concept, which includes observing students and offering hints, challenges, scaffolding, feedback, modeling, and new tasks, to make their performance close to expert performance. Scaffolding refers more narrowly to the supports that a teacher provides to help the student carry out the specific task. Sequencing indicates ways to order learning activities. Teachers are encouraged to place tasks gradually increasing in difficulty and variety. The last dimension is sociology, illustrating the social characteristics of learning environments such as realistic tasks, communication, intrinsic motivation, and cooperation.

Several scholars enriched research regarding scaffolding instructions. Hannafin et al. (1999) organized scaffolding types into four categories based on its functionalities: conceptual, strategic, metacognitive, and motivation scaffolding. Conceptual scaffolding is for assisting to solve a problem. Metacognitive scaffolds support students to self-regulate when they solve the problems. Strategic scaffolds provide students with different solutions on the task. Motivation scaffolding is related to students' self-efficacy, autonomy, connectedness, mastery goals, and perceptions of the value of the task. Yelland and Masters (2007) focused on the cognitive scaffolding and clarified it as the tools or techniques which support learners' conceptual and procedural knowledge.

Computer-based Scaffolds and their Effectiveness

Numerous literatures argue for the importance of timely and effective feedback in motivating and assisting students' performance (Wiggins, 2012; Rolliston, 2005; Murzyn & Hughes, 2015). Feedback for learning may be defined as information obtained by students regarding the correctness of their performance in a learning task (Kozma, 1991). In the traditional classroom, a teacher is the one who is mainly responsible for providing timely and constructive feedback to each student. Teachers need to spend time observing and reflecting students' comprehension of the content to provide the necessary feedback which supports students in learning. The culture of the classroom and management style of the teacher also affect the quality of the feedback that students receive in the traditional classroom. If students feel comfortable in the classroom and their teachers carefully pay attention to them what they need to understand about the materials, it is likely for them to engage in-class activities and actively express their needs (White, 2009).

However, even though providing proper scaffolds is deeply related to the learners' development, the process can be demanding for teachers who have to deal with the multiple zones of proximal development at the same time. This is because every student has different prior knowledge, background, and preferred learning styles. Therefore, it would be challenging for a teacher to provide timely and effective feedback to all students in the classroom.

As technology advances, computer-based scaffolds received great attention as the complement or alternative of traditional interactions between a teacher and a learner. The integration of class and computer-based scaffolds encompass providing software tools that can realize the computer-based learning environment and functionality and resources that enhance the learning experience (Guzdial 1994; de Jong & Njoo 1992; de Jong & Van Joolingen 1998; Sherin et al. 2004).

Pea (2004) presented that there are two primary axes for organizing the theoretical contributions of supports in learning. One is interactive responsiveness that is dependent on the learner's need and providing resources, and the other is technologically designed artifacts. The social conception of human scaffolding for learning can be explained further by the former components such as social practices in parenting. More recently, the latter has become increasingly used for describing scaffolding in the educational process due to the advance of technology. As Vygotsky (1978) emphasized the importance of cultural tools in mediating human action (Polman & Pea, 2006), the initial symbolizing technologies such as written language and number system are regarded as the product of the most significant cultural achievements. Pea (1993) expanded this ‘tool’ metaphor and indicated that intelligence can be distributed in social arrangements and activities that support human learning through guided participation (Polman & Pea, 2001). This can be facilitated by the integral use of cognitive tools such as software.

Then, how can these tools provide effective scaffolding? Reiser (2004) considered two critical notions in scaffolding. One is that learners should be able to receive assistance when otherwise the task is too difficult, and the other is that learners’ skills or knowledge should be improved on that process. He proposed two mechanisms of scaffolding with software tools – structuring the task of problem solving and problematizing subject matter - based on these notions. In structuring the task, a software tool can help a learner decompose complex tasks and keep track of small steps to complete tasks. This tool interface can assist learners to focus on resources in productive ways and make it easy to monitor learners’ progress explicitly. In terms of the second software-mediated scaffolding mechanism, the software makes students’ work more problematic by increasing the utility of the problem-solving experience

(Hiebert et al., 1996). Problematizing in a learning situation consists generally of several characteristics: focusing students' attention on a situation which needs to be solved, provoking students to solve the problem with full of commitment, generating interest in the problem (Reiser, 2004).

Quintana et al. (2004) also articulated a systematic guideline for software-based scaffolding of learning in science according to three primary science inquiry elements: sense-making, process management, and articulation and reflection. The *sense-making* processes require scaffolds to help students identify relevant variables, build hypotheses, collect data, and verify those hypotheses and arguments based on the data. The *process management* scaffolds aid students to plan how to complete an inquiry task and monitor the planned steps systematically so that they can manage the process handling complex and ill-structured nature of the inquiry. Finally, *reflection and articulation* scaffolds facilitate sense-making and process management phases by decomposing complex tasks, highlighting relevant information, and helping students construct their ideas.

Kim and Hannafin (2010) articulated how CBLEs can offer different scaffolds on each phase of problem-solving. They differentiated problem-solving stages into five phases: identification & engagement, exploration, reconstruction, presentation & communication, and reflection & negotiation. They proposed different computer-based scaffolds on each phase, such as providing authentic situated contexts and visualizations in the identification & engagement phase, taking over lower-order tasks in the exploration phase, helping students diagnose their misconceptions, and providing procedural assistance in the reconstruction phase, providing multiple perspectives in the presentation & communication phase, and lastly, promoting metacognitive assistance in the reflection & negotiation phase.

In terms of the effectiveness of computer-based scaffolds, Belland et al. (2017) synthesized the results of the studies regarding computer-based scaffolding in STEM education by analyzing 144 experimental outcomes. Their research focus was to gain an overall impact on cognitive outcomes of computer-based scaffolding in STEM education. It also evaluated how the effect size estimates can differ depending on learner characteristics (education level/ population), the context of scaffolding, assessment level, scaffolding characteristics (scaffolding change, logic, scope, and intervention), and study quality.

Results indicate that there is a significantly positive effect of computer-based scaffolds on students' STEM learning ($\bar{g} = 0.46$), suggesting that students with computer-based scaffolding had better learning outcomes in cognitive tests than students without scaffolds. The effect size estimates of computer-based scaffolds showed consistently statistically significant and also positive across different education levels, various context of scaffolding use (case/design/inquiry/modeling/problem-solving/project-based learning), diverse assessment level (concept, principle, application), scaffolding characteristics, and study design (quasi-experimental, group random, and random). However, the effect size for low-income learners is relatively large, but that for underperforming learners was significantly lower than a traditional student group.

Contemporary research on computer-based scaffolds in STEM learning

As discussed above, central to student success is scaffolding and computer-based scaffolding plays an essential role in improving students' participation and high-order skills in STEM education. Among various computer-based learning environments using virtual reality, gaming, hypermedia, and others, this section will review intelligent tutoring systems and open-ended learning environments that are most widely used for STEM learning.

Intelligent Tutoring Systems

Computer-based tutoring is traditionally categorized into two different types (VanLehn, 2011). The first type of computer tutoring provides students with immediate feedback and hints on what they answered. Students can instantly receive feedback on whether their answers are correct or wrong when they enter the value. This type of tutoring system has been called in many names including Computer-Aided Instruction (CAI), Computer-Aided Learning, and Computer-Based Learning. The second type of computer tutoring equips other user interfaces such as electronic form, natural language dialogues, or simulations that allow students to follow the steps required for solving the problem. For instance, if a computer tutoring systems proceed based on a dialogue with an agent, the student may select questions to ask or answer what the agent asks following the dialogue. This process waits until students solve the given steps and discuss each step with the student unlike the first type of tutoring systems which gives feedback for every step. Such tutoring systems are usually referred to as Intelligent Tutoring Systems (VanLehn, 2011).

Intelligent tutoring systems (ITSs) are computer-assisted learning environments which incorporate Artificial Intelligence (AI) techniques to provide intelligent tutors. ‘Intelligent’ indicates that AI attempts to produce computerized behavior corresponding to human behavior (Nwana, 1990). ‘Intelligent tutor’ can generate computer behavior which analogous to good teaching (Elsom-Cook, 1987). Providing such an intelligent system necessitates four components: the expert knowledge module, the student model module, the tutoring module, and the user interface module.

The expert knowledge module includes the facts and rules of the content that should be taught. In order to embody the knowledge of the expert, intangible knowledge, skills, or experience needs to be represented or codified explicitly. The expert knowledge module serves as the source of knowledge to be presented to the students and the standard for evaluating students’ performance. This module is also used to identify any gap between students’ knowledge and that of experts so that ITSs can have sensible and intermediate steps for students.

The student model module indicates the ‘dynamic representation of the emerging knowledge and skill of the student’ (Nwana, 1990). ITSs should reflect students’ behaviors and how they develop their knowledge through learning tasks. Self (1988) analyzed twenty different uses of student models in ITSs including corrective (find and eradicate mistakes), elaborative (correct incomplete knowledge), and evaluative (assess student performance). Overall, the student model provides information about students and represent what they know.

The third component is the tutoring module which involves with instructional interactions between tutor and a student in ITSs. This module can be paralleled to the instruction strategy embracing how to present the knowledge, learning objectives, and support based on the student model (Self, 1988). Thus, the tutoring module is described as a combination of all kinds of pedagogic interventions. If a student gets stuck or lost, ITSs monitor the students' activity and adapting their tutoring actions to the students' responses based on strategies which are embedded in them.

The last module is the user interface module, which controls the interaction between the students and the system itself (Nwana, 1990). Assorted user interfaces are employed in ITSs such as text, pictures, graphics, or natural language via computer speech recognition. Given that the effect and power of interaction are influenced by the user interface, it needs to be clear and understandable to students.

Intelligent tutoring systems have been developed for many STEM areas, such as mathematics, science, engineering, statistics, and others (Cognitive Tutor: Anderson, Corbett et al., 1995; Koedinger et al., 1997). The use of ITS in the education field has increased considerably throughout U.S. schools. Cognitive Tutor by Carnegie Mellon University, which is regarded as one of the most popular and successful ITS in STEM learning, was used in over 2,600 schools in the United States as of 2010 (What Works Clearinghouse, 2010). Its name, Cognitive Tutor, originated from the approach of using a cognitive model in a tutoring system (Anderson et al., 1990). Koedinger et al. (1997)

found that students tutored by Cognitive Tutor showed extremely high learning gains in algebra compared with students who learned algebra through regular classroom instruction. However, recent meta-analysis papers about the effects of ITS on students' learning presented that ITS had no significant improvement when students lacked prior knowledge in math and reading (Al-Aqbi, 2017). Indeed, several studies reported that ITS cannot help students without basic understanding of target concepts and even showed negative effects on those students' learning (Grubišić et al. 2009; Pane et al., 2010).

Open-ended Learning Environments

Open-ended learning environments (OELEs) are a sort of CBLEs, which focus on supporting students to engage in authentic problem solving and learner-centered understanding and knowledge construction (Clarebout & Elen 2008; Land 2000; Azevedo et al. 2010; Conati et al. 2006). Students can learn complex and abstract concepts in STEM areas by information seeking, inquiry, and modeling in OELEs (Gordin & Pea, 1995). According to Land's (2000) work, OELEs embed technologies to visualize or manipulate complex phenomena, provide authentic contexts to foster connections between formal knowledge and everyday experience, and realize resource-rich environments to support learner-centered inquiry.

Land and Hannafin (1996) suggested a theory-building model to explain the process how students' understanding evolves when they use OELEs. Open-ended learning environments assume that students develop their understanding with a 'theory-in-action' (Land & Hannafin, 1996, p. 38.), by which students generate intuitive theory and develop it with repeated modifications and reflections. Open-ended learning environments provide resources and support that students can experience challenges of their intuitive theory by letting them explore, observe, and experiment with their intuitive notions. The theory-in-action development process consists of five components: leaner and system context, system affordances, intention-action cycle, system responses/feedback, and learner processing.

In terms of the first component, leaner, and system context, students advance their knowledge by active interactions with OELEs. Thus, learners' prior knowledge and experience and context, interpret the goals of the system, elaborate them based on personal knowledge and experience, and even redefine the system's goals. The individual then explores and refines a theory using the tools and resources afforded by the system. Affordances represent ways in which tools and resources of the system are designed to promote learning, not necessarily how they are actually used. At this stage, knowledge, and experience are continually cross-referenced with the problem context to determine what action should be taken. Action may take the form of simple browsing, with little or no intent to test a theory, or be "thought-based" and mediated by the individual intentions to test understanding. The system provides feedback, based on the actions of the individual, which are subsequently processed according to the individual's intentions. As intentions and actions are increasingly linked with the feedback and subsequent processing, the theory-in-action is examined critically. Problem contexts continue to evolve, and based upon deepened processing, intentions and actions become more calculated and differentiated. Over time, the theory-in-action evolves based upon progressively refined interactions in the OELE, which allow the individual to further speculate, test, and observe.

Thus, OELEs are regarded to provide students with great opportunities that can practice and advance their metacognitive regulation in the context of authentic and complex problem-solving tasks. Metacognitive regulation refers to how students can create plans, monitor and manage the effectiveness of those plans, and then reflect on the outcome using their metacognitive knowledge, which is an individual's understanding of their own cognition and strategies for managing that cognition (Young & Fry, 2008; Flavell et al., 1985; Schraw et al., 2006; Whitebread et al., 2009).

Betty's Brain (Leelawong & Biswas, 2008) is one of the well-known open-ended learning environments that supports middle school students in learning science. In Betty's Brain, students need to read about science concepts or phenomena and teach Betty, a virtual agent, by identifying causal relationships among those concepts. Students can examine Betty's understanding by asking her to take a quiz. Betty solves quiz problems using the causal model that students created. If her answer and explanation match the expert model then it can be regarded for students to understand given science phenomena and generate the correct causal model. If her answer is wrong, the system lets students know where are missing or incorrect links in their models. Betty's Brain is recognized as a successful science learning environment that can improve students' learning in science and reasoning ability simultaneously (Biswas et al., 2005).

Summary and the Current Study

The current study is aiming to develop the computer-based reading scaffolds to solve the reading problem in math and analyze their effects on students' math performance. Drawn upon a literature review of relevant studies, it is inferred that we should take cognitive processes and intrinsic motivation into account when designing scaffolds. Literature of Cognitive Load Theory has highlighted the importance of reducing cognitive load by scaffolding learning material with worked examples. Both the Mastery Motivation Theory and Achievement Goal Theory emphasize the importance of students' intrinsic motivation in learning and obtaining desirable competence. Emotional scaffolding such as direct encouragement can enhance intrinsic motivation when working alone on a challenging task or activity. Sophisticated assistance regarding how to do a task can also relieve students' frustration and contribute to their learning given material. Students often tend to hesitate to ask for help because they do not want to seem needy or incompetent. Thus, it is required to design learning environments that include not only proper types of achievement goals and appropriate scaffolding strategies so that we can encourage students to pursue learning goals.

Regarding prevalent computer-based learning environments for STEM learning, ITSs and OELEs, we found that much of the research on computer-based feedback design focused on feedback for step-by-step problem-solving in domains such as algebra, geometry, and computer programming. These scaffolds are mainly organized as successive hints that eventually provide the answer to the current problem step (e.g., Koedinger & Aleven, 2007; Mendicino et al., 2009; VanLehn, 2006). Many studies found that these scaffolds could enhance procedural knowledge of each domain. However, several studies have shown that many students fail to gain a conceptual understanding of target knowledge with these scaffolds (e.g., Land, 2000; Mayer, 2004). Moreover, some students often fail to regulate their learning process in CBLEs or fail to know how to learn using resources in CBLEs (Azevedo, 2005; Segedy et al., 2011). These limitations might be able to explain why underperforming students who are likely to have less prior knowledge or lower metacognition showed significantly lower achievement when using computer-based scaffolds compared to other student groups in Belland et al's work.

CHAPTER III

METHODS

This chapter delineates the research methods and provides a rationale for the research design approach. Tool designs and measures are presented with their associated validity and reliability. The chapter also describes the research procedures and data analysis for both tool effectiveness experiment and tool evaluation.

Research Approach and Rationale

Tool Effectiveness Experiment

This study is grounded in the experimental research tradition. The research design, data analysis, and interpretation of the study are quantitative, and this study can be identified as a quasi-representative design with respect to population and ecological validity (Snow, 1974). According to Snow (1974), a "thorough description of participant characteristics" (p. 270) is required to generalize the research result. This research would be conducted in the experimental setting that is natural and congruent with participants' daily life. Thus, we would not be able to rule out all threats or population characteristics that might affect the result of this experiment. However, this research design considered some possible covariates using participants' reading ability, math pretest scores, and random assignment.

The specific research design is a two-way design shown in table 1. The first factor was three different conditions: control, reading scaffolded, and cognitive-tutor scaffolded.

Table 1

Research Design

Computer-based scaffold conditions		Students' reading ability		Math Achievement	
		Low	High	pre	post
Control	control condition				
Treatment	Reading scaffolded				
	Cognitive-tutor scaffolded				

The second factor was students' reading ability, which was measured by a reading pretest. The outcome variables were knowledge gains, which were differences between students' mathematics posttest scores and pretest scores. This approach also can be interpreted as using an experimental strategy for one factor (scaffold conditions), which was manipulated independent variable, and a quasi-experimental strategy for another factor (student's reading ability), which is non-manipulated. This design enables researchers to investigate two factors simultaneously and cost-efficiently by involving all participants in both analyses (Montgomery et al., 2003). Moreover, it is possible to estimate the interaction effect of two factors.

Tool evaluation survey

A mixed methods research design was used to collect and analyze tool evaluation data. Quantitative data about the perceived ease of use and the tool's advantages in teaching and learning were measured with the Technology Acceptance Model (TAM) questionnaire (Davis, 1989). Qualitative data such as the perceived effects of this tool on teaching and learning were obtained by open-ended questions for teachers and students.

Measures

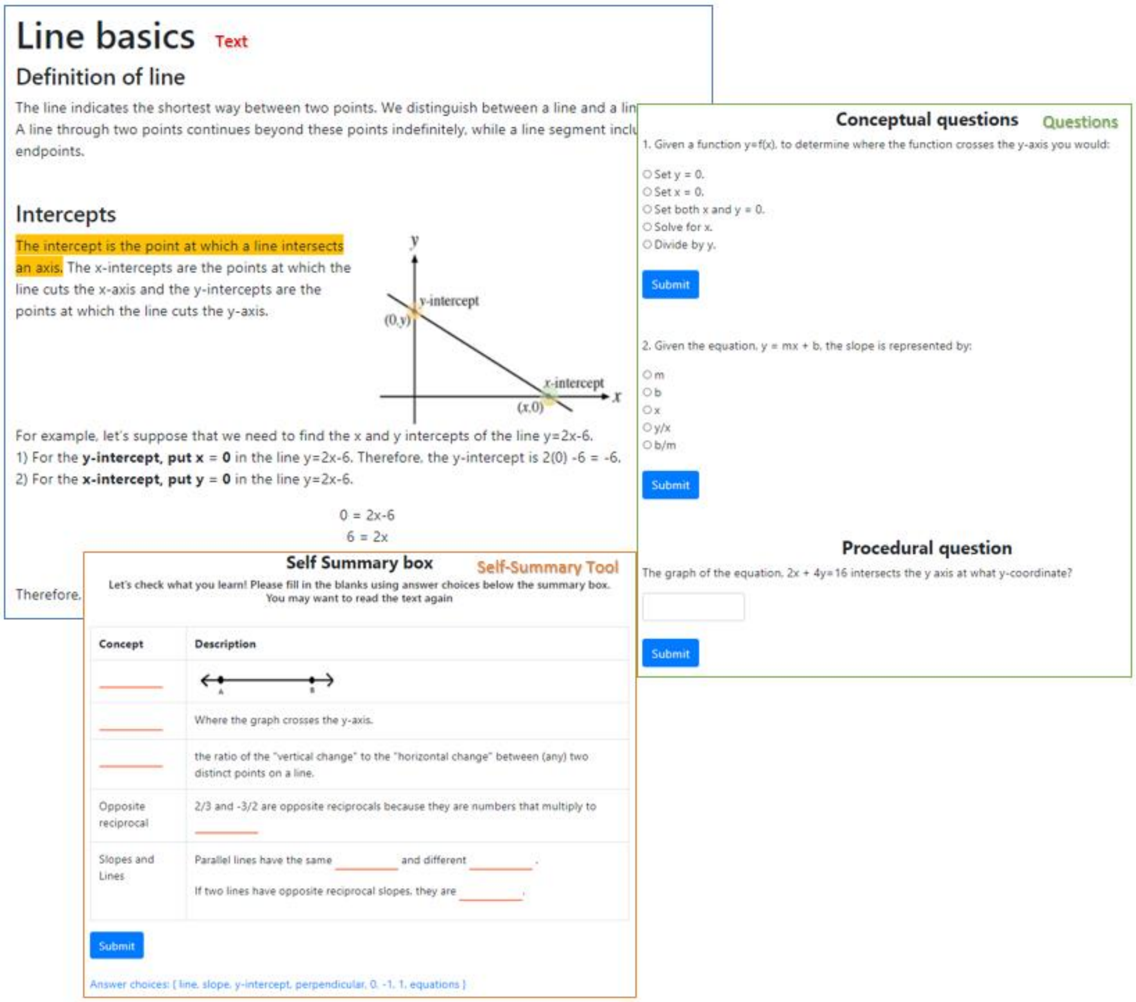
Computer-Based Tool Design

Control *Condition*

The basic structure of this tool shown in figure 1 includes an Algebra 1 coordinate geometry section skill set. The content for this study consisted of three chapters: line basics, writing the equation of a line, and systems of linear equations. Each chapter had text paragraphs, images, a problem set, and a self-summary box. The text paragraphs and questions were developed by a high school math teacher and reviewed by two graduate students who also worked as secondary math teachers. A problem set included at least a conceptual question and a procedural question. The self-summary box lets students engage in active reading and summarize key mathematics concepts and their characteristics (Meyer & Ray, 2017). Students should fill the self-summary box for each chapter before they solve the questions. The content in the experimental treatment material is designed to be simple and readable so that we can focus on the effectiveness of different tool designs. The Flesch-Kincaid grade level of content in three conditions is 6.0. Its Flesch reading ease score is 78.6.

Figure 1

Tool Design of the Control Condition



Reading-Scaffolded Condition (Treatment 1)

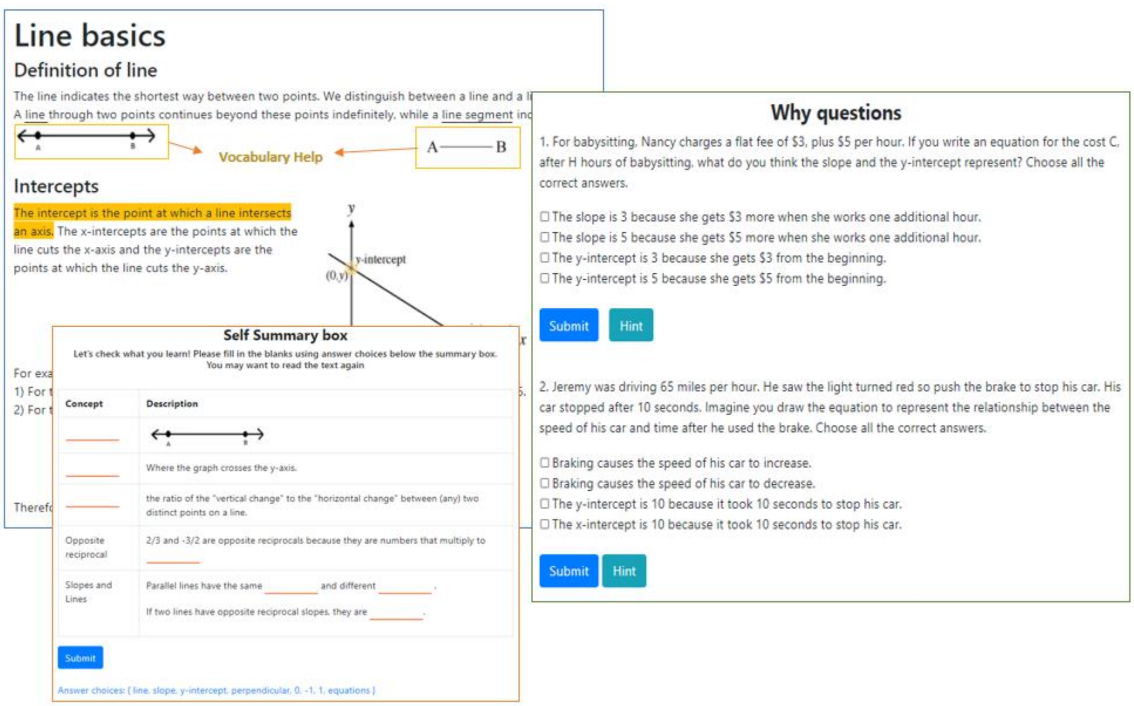
In order to provide support in reading in math, we designed the reading-scaffolded condition (RS) by embedding diverse learning strategies in the control condition. Figure 2 shows the structure of the RS condition. First, students can see the resources with images of the mathematical word when they hover their cursor. Because many studies emphasized increasing the familiarity with math vocabulary, we expect that students can comprehend the math concept better with this vocabulary help. Moreover, we highlighted key terms in the text so that students can recognize the important concepts.

Another instructional method applied was the 'worked example effect' that allows a learner to study with examples, which can be more effective in building schemas and improving performance than solving similar problems repeatedly (Paas et al., 2003). Many examples regarding math concepts and problem-solving steps are included in the texts in the RS condition. When solving problems, learners often overwhelm their working memory load when searching for appropriate moves. when studying an example, each step can be learned without considering alternative options because an appropriate move has been provided (Sorden, 2005). Thus, students are expected to increase problem-solving ability with less burden on cognitive load by studying examples (Sweller, 2011).

Lastly, 'why' questions were added. Why questions encourage students to connect the cause-and-effect relationships among math concepts. Magliano et al. (2007) found that students can retrieve diverse textual information when they can link the causal relationships among different text constituents. Several other studies also discussed that identifying causal connections between different events in a text is regarded as the core of the reading comprehension process. (Mcnamara & Kendeou, 2011; Wijekumar et al., 2017). Ozuru et al. (2009) also analyzed that low achievers can benefit from textual cohesion including causal relationships, by which they can obtain the necessary knowledge to generate inferences. Thus, the inclusion of 'why' questions asking students to think logically and provide causal reasoning about different math concepts in the given text. Each 'why' question has hints that students can use. Students should fill the self-summary box and work on 'why' questions for each chapter before they solve the question set.

Figure 2.

Tool Design of the Reading Scaffoded Condition

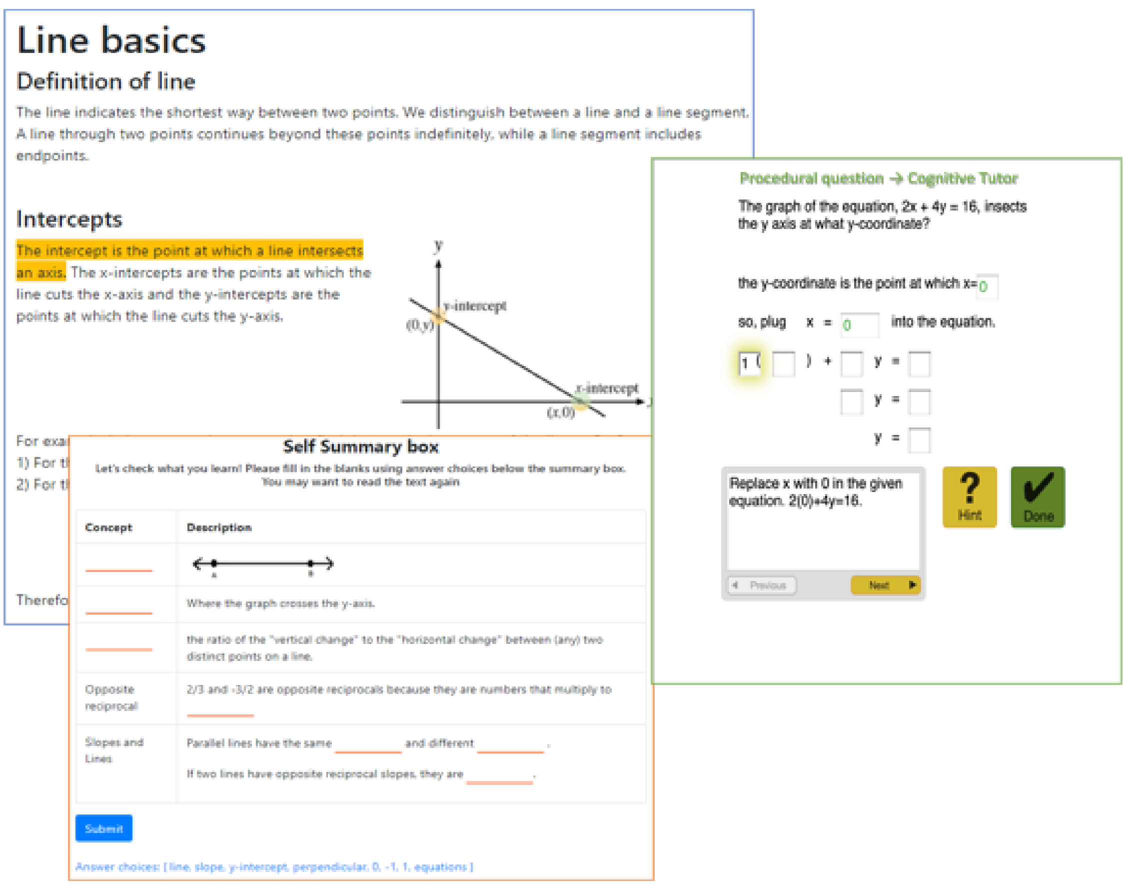


Cognitive-tutor Scaffolded model (Treatment 2)

Cognitive-tutor Scaffolded condition (CS) integrated Cognitive Tutor to the control condition. In the control condition, both conceptual and procedural questions were presented in the same multiple-choice question format. However, in the CS condition, procedural questions are provided as Cognitive Tutors (CT) that students can exercise each step of problem-solving and receive multilevel hint messages if they present a wrong answer. Figure 3 shows the structure of the CS condition.

Figure 3.

Tool Design of the Cognitive-tutor Scaffolded Condition



Pre- and Post-tests

Both reading and mathematics tests consisted of State of Texas Assessments of Academic Readiness (STAAR) questionnaires. We used English 1 and Algebra 1 End-of-Course exams for ninth-grade students. The reading pretest was comprised of a set of seven questions extracted from the 2018 STAAR English 1 questionnaire. The researcher classified students who scored 1-4 out of seven questions as low-reading level, and students who had 5-7 as high-reading level. The outcome variables were knowledge gains, which were differences between students' mathematics posttest scores and pretest scores. The mathematics pretest and posttest were composed of eight questions each, which were selected from the STAAR 2013-2018 Algebra 1 questions. The reported Cronbach's alphas of all tests were greater than 0.8, meaning that they had good internal consistency as shown in table 2. The reliabilities calculated using participants responses were between 0.66 and 0.76, which were acceptable internal consistency (Goforth, 2015).

Table 2

Reliability of Measures

Measure	Reported Reliability (Cronbach's alpha)	Sample Reliability (Cronbach's alpha)
Reading pretest	0.81	0.70
Math pretest	0.82	0.67
Math posttest	0.85	0.77

The questions were classified into three categories using the KLI theory (Koedinger et al., 2012): Constant-Constant, Variable-Constant, Variable-Variable

(Table 3). Constant-Constant problems or Variable-Constant problems were regarded as conceptual questions, and Variable-Variable problems were considered as procedural questions. Both pretest and posttest include 4 conceptual questions and 4 procedural questions. Each test took 10 minutes. The Flesch-Kincaid grade level of both tests is 6.9 and Flesch Reading Ease is around 73.

Table 3

Problem Classification Criteria

Knowledge	Category (Condition - Response)	Definition
Conceptual Knowledge	Constant -Constant	If the problem is asking students to recall math concepts (or definitions) which are constant and the answer would be also constant, then it can be classified as Constant-Constant.
	Variable -Constant	If the problem is asking students to recall math concepts (or definitions) that are constant and variables can change randomly, then it can be classified as Variable-Constant.
Procedural knowledge	Variable -Variable	If the problem consists of variables and conditions that can change values and the answer would vary depends on variables, then it can be classified as Variable-Variable.

Tool Evaluation Survey

The measures for the tool evaluation survey are created by modifying the TAM questionnaire (Davis, 1989; Teo & Van Schalk, 2009). It includes four questions about perceived ease of use, five questions for perceived usefulness for teaching, and three questions about perceived usefulness for learning. In addition to TAM, we also adopt a scale for computer attitudes from Thompsonet et al. (1991) to check teachers' attitudes toward computer use in daily teaching practices and how this characteristic influences the web-based tool evaluation. The questionnaire also contains several open-ended questions for collecting qualitative data from teachers. Table 4 specifies questions for the tool evaluation survey for teachers.

Table 4

Survey Questions for Teachers and their Reliabilities

Category	Cronbach alpha	Statement
Affect toward Computer use (CA)	0.81	CA1. Computers make my teaching work more interesting. CA2. Working with computers is fun. CA3. I like using computers. CA4. I look forward to those aspects of my job that require me to use computers.
Perceived ease of use (PE)	0.73	PE1. My interaction with this tool is clear and understandable. PE2. I find it easy to get this tool to do what I want it to do. PE3. Interacting with this tool does not require a lot of mental effort. PE4. I find this tool easy to use.
Perceived usefulness for teaching (PUT)	0.75	PUT1. Using this tool will improve my overall teaching practices. PUT2. Using this tool will help me deliver the given content effectively. PUT3. Using this tool will help me prepare to teach the given content before the class. PUT4. Using this tool will help me teach mathematical concepts effectively. PUT5. Using this tool will help me teach how to solve math problems effectively.
Perceived usefulness for students' learning (PUS)	0.71	PUS1. Using this tool will improve students' learning outcomes. PUS2. Using this tool will help students learn mathematical concepts effectively. PUS3. Using this tool will help students learn effectively how to solve math problems related to the given content.
Open-ended questions		OE1. If you have any further ideas about how this tool will affect your teaching, please let us know. OE2. What students can benefit from using this tool? OE3. If you have any strategies to improve students' math literacy, please let us know.

Students were also be asked to respond to the tool evaluation survey after the post-test on the second day. The tool evaluation survey questions for students are shown in table 5.

Table 5.

Survey Questions for Students and their Reliabilities

Category	Cronbach alpha	Statement
Perceived ease of use	0.72	Q. When I read the text of each chapter (1~3) in the tool, 1) I could understand the mathematical text in the chapter 1 (Line basics) 2) I could understand the mathematical text in the chapter 2 (Writing the equation of a line) 3) I could understand the mathematical text in the chapter 3 (Systems of Linear equation) 4) When I read the text of each chapter (1~3) in the tool, - I could understand math concepts better by reading the text in this tool than reading paper math textbooks. *Reading scaffolded condition only 5) The word images were helpful for understanding the corresponding words 6) The word images were helpful for understanding the math concepts in the text.
Perceived usefulness for learning	0.75	Q. When I was solving questions below each chapter, 1) The examples of how to solve problems in the text were helpful 2) Filling the summary box was helpful *Reading scaffolded condition only 3) Solving 'Why questions' were helpful
Perceived difficulty level	0.85	Q. How difficult was each section? 1) pre-test 2) Ch1. Line basics 3) Ch2. Writing linear equations 4) Ch3. Systems of linear equations 5) post-test

Procedure

This section describes the detailed procedures that were employed to support the design rationale and ensure the integrity of the study. The timeline of the whole procedure is shown in table 6.

Table 6

Timeline of the Whole Data Collection Procedure

	Jan	Feb	Mar	Apr	May	Jun	Jul
Tool development							
IRB approval							
Pilot study							
Tool improvement							
Tool effectiveness experiment							
Tool evaluation							

A pilot study for tool effectiveness experiment

A pilot study was conducted with 11 students (7 ninth grade, 4 eighth grade) to check if there is any malfunction or anything that students could not understand in the three conditions. All study sessions were undertaken online individually to protect students' privacy. All pilot study participants were randomly assigned to one of three conditions. Students participated in two sessions and each session took 50 minutes. They were asked to take a reading pre-test (10 minutes) and mathematics pre-test (10 minutes), study coordinate geometry using the assigned condition, take a mathematics post-test (10 minutes), and respond to a tool evaluation survey (5 minutes).

Tool effectiveness experiment

Since the content in the three conditions addresses the Algebra 1 coordinate geometry section, we recruited eighth or ninth-grade students in Central Texas. One hundred and two students (fifty boys and fifty-two girls) were individually randomized into the three conditions (Table 7).

Table 7

The Number of Students According to their Different Reading Levels and Conditions Outlined

Conditions	Low reading level (n)	High reading level (n)
Control	17	17
Reading Scaffolded	15	19
Cognitive-tutor scaffolded	15	19

The study procedures were the same as the one for the pilot study. Students participated in two sessions, and each session took 50 minutes. They were asked to take a reading pre-test (10 minutes) and a mathematics pre-test (10 minutes), study coordinate geometry using the assigned condition, take a mathematics post-test (10 minutes), and respond to a tool evaluation survey (5 minutes).

Tool evaluation survey

148 middle or high school math teachers in the United States (129 middle school, 19 high school) participated in the tool evaluation to assess the preliminary usability and usefulness of the tool. We recruited teacher participants from various sources, including teaching associations (at both the state and national levels) and teachers who are enrolled as graduate students at the College of Education and Human Development at Texas A&M University. Participants were asked to examine the tool and respond to the evaluation survey. All evaluation was conducted online. Teachers reviewed the tool with computer-based reading scaffolds for around 20-30 minutes and responded to the survey questions for 15-20 minutes.

Data analyses

Tool effectiveness experiment

First, 3 (conditions) * 2 (reading level) analysis of variance (ANOVA) was conducted in order to analyze our research questions. The first factor was the three different conditions for scaffolds: control condition, RS, and CS. The second factor was the students' reading level, which was measured by a reading pretest. The outcome variables were knowledge gains, which were differences between students' mathematics posttest scores and pretest scores.

In addition to ANOVA, we further analyzed the interaction effects between the predetermined conditions and students' reading abilities using a two-way analysis of covariance (ANCOVA), which can test the significance of differences among group means by removing the confounding variables' effects on the dependent variable. The dependent variables, which were knowledge gains, were the same as those used in the ANOVA. The independent variables were the conditions, and students' reading pre-test scores were used as the continuous covariate variables. STATA version 16.1 was used for all necessary analysis to determine tool effectiveness.

Tool evaluation survey

The analysis of tool evaluation data was comprised of three stages. The first stage analyzed the descriptive statistics of the measurement items to figure out teachers' perceived easiness of use and usefulness of the tool. In the second stage, each teacher's responses to the open-ended questions were coded separately by the researcher. Table 8 shows identified themes and subthemes for coding.

Table 8

Themes and Subthemes Identified from Teachers' Responses

Theme/ Category	Subthemes
Effect on teaching (OE1)	Increase teaching efficiency Improve students' learning Improve students' motivation Need improvements
Target students (OE2)	Students with different skill levels Self-motivated Learners
Strategies about how to improve students' disciplinary literacy in math (OE3)	Encouraging students to actively engage in reading mathematical texts Identify key concepts and words Providing additional resources Arousing students' interests and curiosity

In addition to the qualitative coding, we used lexical-based text mining methods to analyze teachers' open-ended answers to each question and to support the qualitative coding results. Lexical-based methods focused on text-level word counts so that we could measure the construct of interest and sentiment that could help us grasp teachers' opinions on tool effectiveness. Before applying text-mining techniques, we preprocessed the data using tokenization, which separated the text into pieces of words and deleted stop words such as “a,” “an,” or “the.” For the sentiment analysis, two well-known lexicons, bing (Ding et al., 2008) and NRC (Mohammad & Turney, 2013), were employed to classify words into different emotional classes. The bing lexicon model classifies sentiments into a binary category of positive or negative. On the other hand, the NRC lexicon categorizes sentiment into diverse emotional states including anger, anticipation, disgust, fear, joy, sadness, surprise, and trust. Moreover, we tokenize the text into two consecutive sequences of words, bigrams, removed stop words, and visualized the relationships between connected words. All data cleaning work, analysis, and visualization were conducted using the dplyr, tidytext, tidyr, widyr, gggraph, and ggplot2 packages.

CHAPTER IV

RESULTS

Tool Effectiveness Experiment

The descriptive statistics of the mathematics pre- and post-test scores were calculated as shown in Table 9. Students in three conditions had similar average math and reading pre-tests scores, meaning that there was no huge difference among students' math and reading skills before the interventions.

Table 9

Descriptive Statistics for Pretests and Posttests

	Control		RS		CS	
	M	SD	M	SD	M	SD
Math pretest	4.85	2.32	4.15	1.97	4.35	2.23
Math posttest	5.21	2.56	6.21	2.03	5.91	2.04
Reading pretest	4.21	2.19	4.29	1.98	4.32	2.03

**RS = Reading scaffolded condition, CS= Cognitive-tutor scaffoldded condition*

Before running ANOVA and ANCOVA, assumptions were checked. The data satisfied the normality assumption based on skewness (.55) and kurtosis (3.11). We conducted the Breusch–Pagan/Cook–Weisberg test for heteroskedasticity to examine the homogeneous variance assumption. The null hypothesis of constant residual variance failed to be rejected; $x^2(1, 102) = 0.60$, $p = .438$. Thus, the collected data seemed to be reasonable for ANOVA and ANCOVA.

Tool Effectiveness on Students' Knowledge Gains

Conducting ANOVA to analyze the effect of conditions and reading levels on students' knowledge gain, Table 10 shows that the main effect of the conditions on students' knowledge gain was statistically significant [$F(2, 96) = 9.75$, $p<.001$]. The main effect of the reading level on knowledge gain was also significant [$F(1, 96) = 4.13$, $p=.045$]. However, the interaction effect between conditions and reading levels was not statistically significant ($p=.569$). In group mean comparisons, Tukey's HSD test (Table 11) indicated that the mean score for the RS condition students was 1.70 higher than students in the control condition ($p<.001$), and the mean score for the CS condition students was 1.14 higher than students in the control condition ($p=.012$). There was no significant difference between the RS and CS condition students ($p=.355$). Comparing average knowledge gain between low and high reading level groups, high reading level group students had 0.65 better knowledge gain than low reading level group students ($p=0.045$).

Table 10

ANOVA Results (Total Knowledge Gain)

Variable	df	MS	F	p	η^2
Condition	2	24.84	9.75	<0.001	0.17
Reading level	1	10.51	4.13	0.045	0.04
Condition*reading level	2	1.44	0.57	0.569	0.01
residual	96	2.55			

Table 11

Tukey Post Hoc Comparisons (Total Knowledge Gain)

	Comparison		Mean difference	SE	t	p	95% C.I.	
Conditions	RS	Control	1.70	0.38	4.32	<0.001	0.75	2.60
	CS	Control	1.14	0.38	2.93	0.012	0.22	2.07
	CS	RS	-0.54	0.39	-1.38	0.355	-1.47	0.39
Reading Levels	High	Low	0.65	0.32	2.03	0.045	0.01	1.28

Furthermore, we divided the knowledge gain into two parts, conceptual knowledge gain and procedural knowledge gain, and conducted separate ANOVA to analyze if students in the three conditions showed different knowledge gain in each part. For conceptual knowledge gain, Table 12 shows that the both main effects of conditions [$F(2,96)=13.74$, $p<.001$] and reading level [$F(1,96)=5.31$, $p=.0023$] were significant. However, there was no significant interaction effect between conditions and reading levels on students' conceptual knowledge gains ($p=.99$). In the post hoc analysis for comparing conditions (Table 13), the average conceptual knowledge gain of the RS condition students was 1.24 higher than the control condition students ($p<.001$) and 1.03 higher than the CS condition students ($p<.001$).

Table 12

ANOVA Results (Conceptual Knowledge Gain)

Variable	df	MS	F	p	η^2
Condition	2	14.83	13.74	<0.001	0.22
Reading level	1	5.73	5.31	0.023	0.05
Condition*reading level	2	0.01	0.01	0.99	0.0001
residual	96	1.08			

Table 13

Tukey Post Hoc Comparisons (Conceptual Knowledge Gain)

	Comparisons		Mean difference	SE	t	p	95% C.I.	
Conditions	RS	Control	1.24	0.25	4.90	<0.001	0.64	1.84
	CS	Control	0.21	0.25	0.81	0.697	-0.39	0.81
	CS	RS	-1.03	0.25	-4.07	<0.001	-1.64	-0.43
Reading Levels	High	Low	0.48	0.21	2.30	0.023	0.07	0.89

In terms of procedural knowledge gain (Table 14), the main effect of the condition was significant [F(2,96)=5.07, *p*=.008]. However, the main effect of reading levels (*p*=.48) and the interaction effect between conditions and reading levels were not statistically significant (*p*=.43). Tukey's HSD test showed that the average procedural knowledge gain of the CS condition students was 0.93 higher than those in the control condition (*p*=.006) (Table 15).

Table 14

ANOVA Results (Procedural Knowledge Gain)

Variable	df	MS	F	p	η^2
Condition	2	7.38	5.07	0.0081	0.10
Reading level	1	0.72	0.49	0.4834	0.005
Condition*reading level	2	1.25	0.86	0.4275	0.018
residual	96	1.46			

Table 15

Tukey Post Hoc Comparisons (Procedural Knowledge Gain)

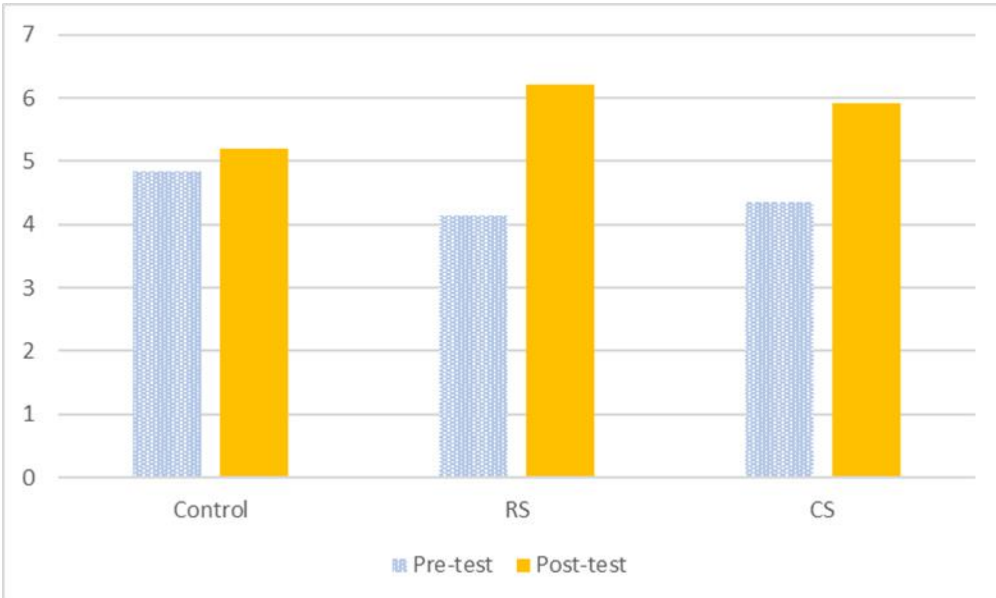
	Comparisons		Mean difference	SE	t	p	95% C.I.	
Conditions	RS	Control	0.44	0.29	1.50	0.296	-0.26	1.14
	CS	Control	0.93	0.29	3.18	0.006	0.24	1.63
	CS	RS	0.49	0.29	1.68	0.219	-0.21	1.20
Reading levels	High	Low	0.17	0.24	0.70	0.483	-0.31	0.65

Interaction Effects of Conditions and Reading Skills on Knowledge Gains

Following the original research plan, which divides students into two reading level groups, and conducting ANOVA, we could not find any significant interaction effects between the predetermined conditions and reading levels on students' knowledge gain. However, as Figure 4 shows, there are noticeable differences in mathematical knowledge gains across the three conditions when comparing average math pre-test and post-test scores. Thus, further analysis was conducted to analyze any hidden relationships among the effects of conditions, students' prior knowledge, and reading skills.

Figure 4

Average Math Pre-test and Post-test Scores from Three Conditions



ANCOVA yielded some interesting findings regarding how students' reading skills can intervene with math knowledge gain under different conditions when a reading score was used as a continuous covariate. In all ANCOVA analysis, reading scores were grand-mean-centered. Table 16 shows that there was a statistically significant two-way interaction effect between students' reading skills and the conditions in terms of their learning gains ($F[2,96]=3.29$, $p=.041$). This indicates that the effects of a condition on students' knowledge gain depend on their reading skills.

Table 17 displayed the coefficients and significance of each condition and interaction term. Students in the RS condition obtained 1.69 more knowledge gain than students in the Control condition given that all of them have average reading scores.

Students with average reading scores in the CS condition had 1.17 more knowledge gain than those in the control condition. The knowledge gain per reading score for students who had reading scaffolds was 0.4 less than those who were in the control condition group. The knowledge gain per reading score for students in the CS condition was 0.02 higher than those in the control condition.

Table 16

ANCOVA Results (Total Knowledge Gain)

Variable	df	Partial SS	MS	F	p
Condition	2	50.72	25.36	10.73	0.0001
Reading score	1	13.66	13.66	5.78	0.0182
Condition*reading score	2	15.56	7.78	3.29	0.0415
residual	96	227.00	2.36		

Table 17

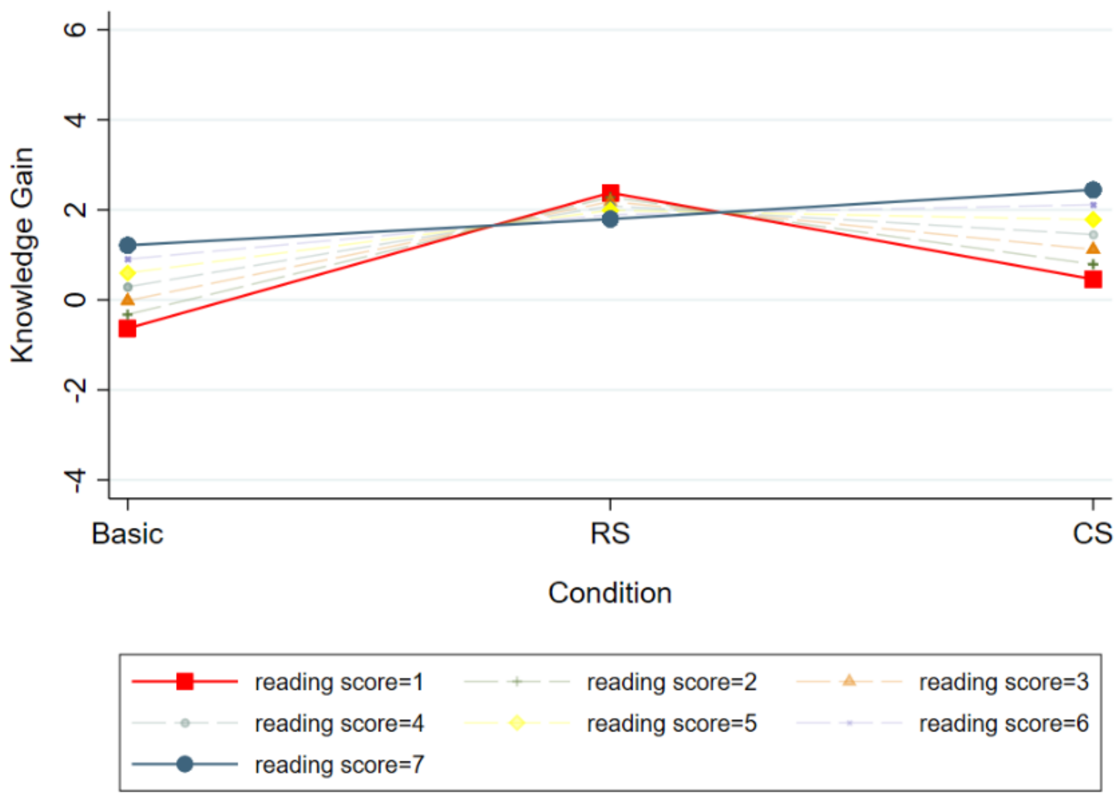
ANCOVA Results as a Regression Table (Total Knowledge Gain)

Variable	Coefficients	SE	t	p	95% C.I.	
Condition						
RS	1.69	0.37	4.52	<0.001	0.95	2.43
CS	1.17	0.37	3.13	0.002	0.43	1.91
Reading score	0.31	0.12	2.51	0.014	0.06	0.55
Condition*Reading score						
RS	-0.40	0.18	-2.22	0.029	-0.77	-0.04
CS	0.02	0.18	0.13	0.898	-0.33	0.38
Intercept	0.37	0.26	1.42	0.159	-0.15	0.90

Based on the coefficients in Table 17, we drew the interaction plot for the conditions and reading scores for predicted knowledge gain (Figure 4). In the plot, we can see that low-achieving readers can learn more on average with reading scaffolds than students with good reading skills. However, in the control or CS condition, high-achieving readers had better knowledge gain than students with low reading skills. Students with high reading scores had the largest average knowledge gain in the CS condition while those with low reading scores had the best increase in knowledge gain in the RS condition.

Figure 5

Line Plot of Condition and Reading Score for Knowledge Gain



Conceptual Knowledge Gain

In terms of conceptual knowledge gain, Table 18 exhibits that there were no significant two-way interaction effects between students' reading skills and conditions in their learning gains (F[2,96]=0.55, *p*=.5804). This indicated that the effects of a condition on students' conceptual knowledge gain was not moderated by their reading skills. According to the slope coefficients in Table 19, students in the RS condition obtained 1.25 more conceptual knowledge gain than students in the control condition if they all have average reading scores. Students with average reading scores in the CS condition showed 0.22 more conceptual knowledge gain than those in the control condition. The average increase in the conceptual knowledge gain of students in the control condition was 0.17 as reading scores increased by 1.

Table 18

ANCOVA Results (Conceptual Knowledge Gain)

Variable	df	Partial SS	MS	F	p
Condition	2	30.43	15.22	14.37	<0.001
Reading score	1	6.08	6.08	5.75	0.0185
Condition*reading score	2	1.16	0.58	0.55	0.5804
residual	96	101.64	1.06		

Table 19

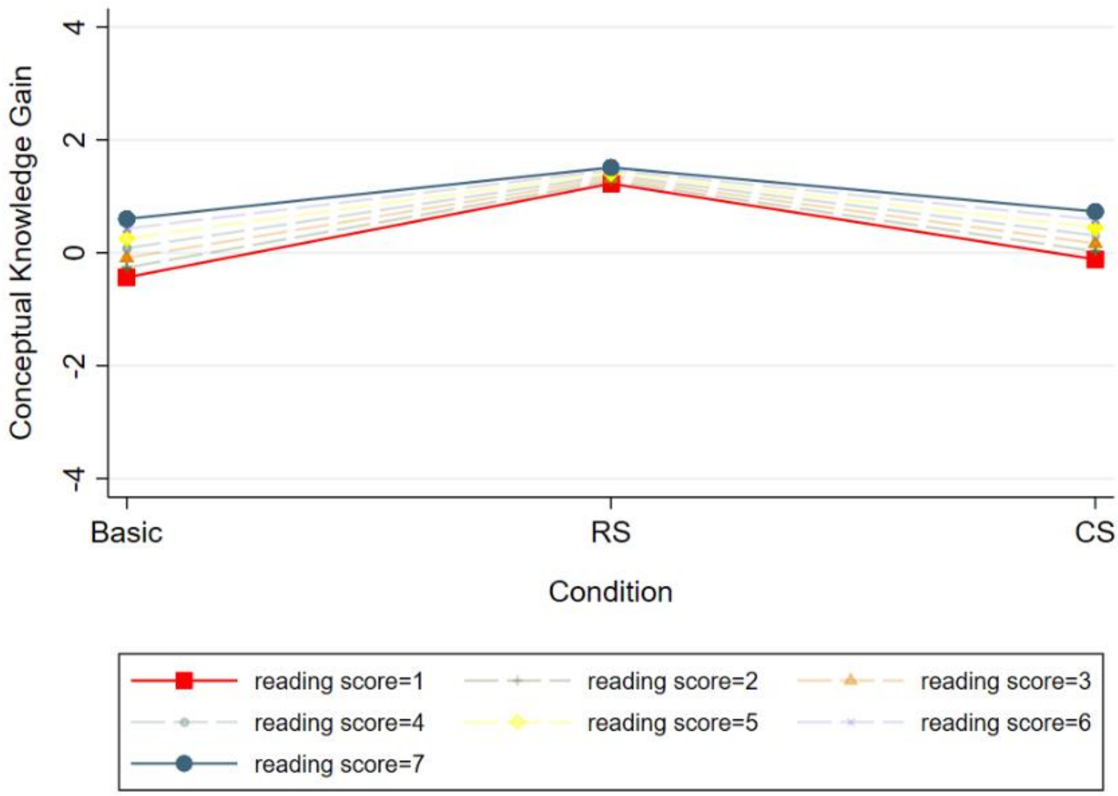
ANCOVA Results as a Regression Table (Conceptual Knowledge Gain)

Variable	Coefficients	SE	t	p	95% C.I.	
Condition						
RS	1.25	0.25	5.02	<0.001	0.75	1.75
CS	0.22	0.25	0.87	0.388	-0.28	0.71
Reading score	0.17	0.08	2.10	0.038	0.01	0.33
Condition*Reading score						
RS	-0.12	0.12	-1.02	0.310	-0.36	0.12
CS	0.03	0.12	-0.26	0.796	-0.27	0.21
Intercept	0.13	0.18	0.73	0.465	-0.22	0.48

In Figure 5, we can see that the main effects of both the predetermined conditions and reading scores rather than their interaction effects on students' conceptual knowledge gain are strong. In all three conditions, students with low reading scores achieved less compared to students with high reading scores. Regardless of reading scores, RS students had a greater average conceptual knowledge gain than those in other conditions.

Figure 6

Line plot of Condition and Reading Score for Conceptual Knowledge Gain



Procedural Knowledge Gain

Table 20 shows that there were statistically significant two-way interaction effects between students' reading skills and conditions in their procedural learning gains (F[2,96]=3.12, *p*=.0488). This suggests that the effects of a given condition on students' procedural knowledge gain can depend on their reading skills. According to the reported coefficients in Table 21, students in the RS condition obtained 0.43 more procedural knowledge gain than students in the control condition when all students have average reading scores. Students with average reading scores in the CS condition had 0.95 more procedural knowledge gain than those in the control condition. The procedural knowledge gain per reading score for students in the RS condition was 0.28 less than those in the control condition. The procedural knowledge gain per reading score for students in the CS condition was 0.05 higher than those in the control condition.

In Figure 6, we can clearly see the interaction effects between the conditions and reading scores. These results are similar to those for total knowledge gain. Students with low reading skills could learn more on average in the RS condition than students with high reading skills. However, in the control or CS condition, high-achieving readers had better procedural knowledge gain than students with low reading skills. Students with high reading scores had the largest average knowledge gain in the CS condition while those with low reading scores had the best increase in knowledge gain in the RS condition.

Table 20

ANCOVA Results (Procedural Knowledge Gain)

Variable	df	Partial SS	MS	F	p
Condition	2	15.43	7.72	5.59	0.005
Reading score	1	1.51	1.51	1.09	0.2983
Condition*reading score	2	8.61	4.31	3.12	0.0488
residual	96	132.60	1.38		

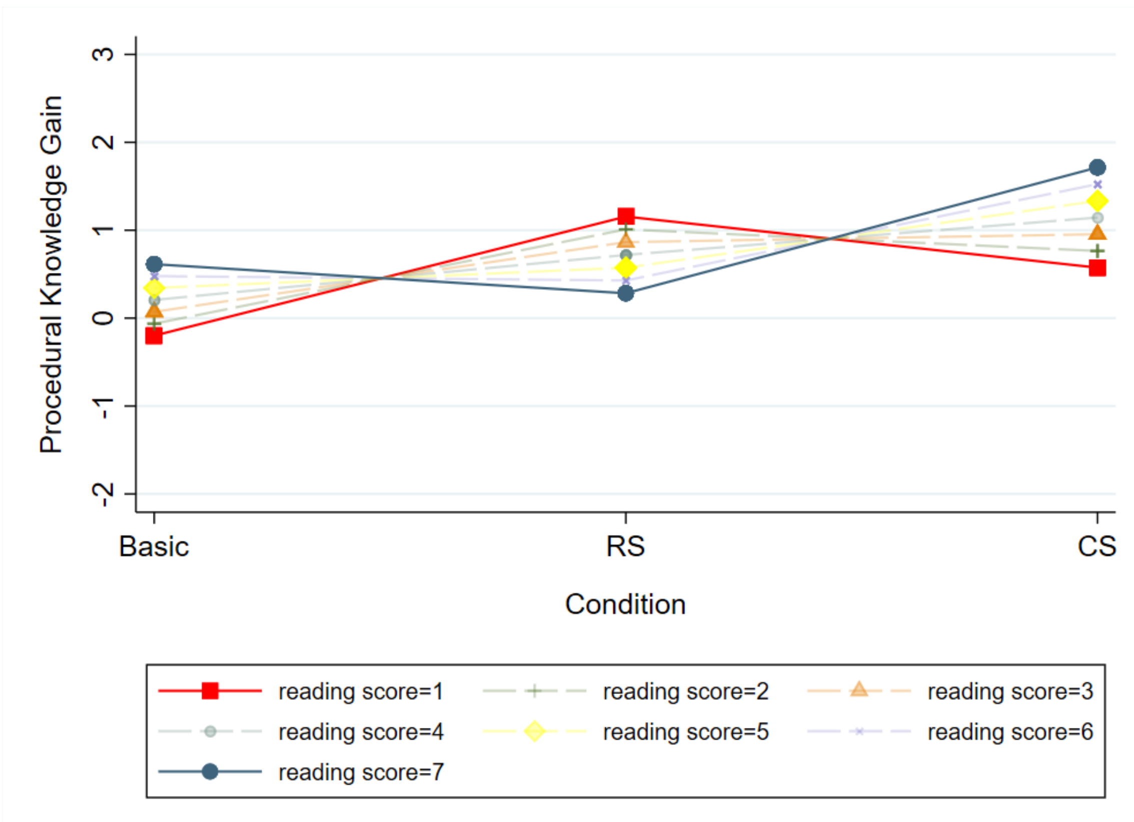
Table 21

ANCOVA Results as a Regression Table (Procedural Knowledge Gain)

Variable	Coefficients	SE	t	p	95% C.I.	
Condition						
RS	0.43	0.29	1.52	0.131	-0.13	1.00
CS	0.95	0.29	3.34	0.001	0.39	1.52
Reading score	0.14	0.09	1.45	0.151	-0.05	0.32
Condition*Reading score						
RS	-0.28	0.14	-2.01	0.047	-0.56	-0.004
CS	0.05	0.14	0.40	0.693	-0.22	0.33
Intercept	0.24	0.20	1.21	0.228	-0.16	0.65

Figure 7

Line plot of Condition and Reading Score for Procedural Knowledge Gain



Tool (RS condition) Evaluation

The descriptive statistics for each survey item are shown in Table 22. All means were greater than 3.5, ranging from 3.98 to 4.26. This indicates an overall positive response across three constructs in the measurement. Table 23 shows the frequency and percentage of responses for each survey item. Around 85% of teachers responded that it was easy to understand how to interact with the tool with reading scaffolds (RS condition). 80-85% of teachers agreed that the RS condition can help them teach the content more efficiently and improve students' learning in math concepts and problem-solving.

Table 22

Descriptive Statistics of Survey Items

Category	Variable	Mean	SD	Min	Max
Perceived ease of use (PE)	PE1	4.22	0.77	2	5
	PE2	4.20	0.81	1	5
	PE3	4.24	0.73	2	5
	PE4	4.26	0.74	1	5
Perceived usefulness for teaching (PUT)	PUT1	4.03	0.84	2	5
	PUT2	4.06	0.83	1	5
	PUT3	3.99	0.82	2	5
	PUT4	3.98	0.83	2	5
	PUT5	3.99	0.81	1	5
Perceived usefulness for students (PUS)	PUS1	4.16	0.76	1	5
	PUS2	4.24	0.82	2	5
	PUS3	4.12	0.79	1	5

Table 23

Frequency and Percentage of Responses for Each Survey Item

Variable	Strongly Disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree
	n (%)	n (%)	n (%)	n (%)	n (%)
PE1		4 (2.70)	19 (12.84)	65 (43.92)	60 (40.54)
PE2	1 (0.68)	2 (1.35)	25 (16.89)	57 (38.51)	63 (42.57)
PE3		2 (1.35)	20 (13.51)	66 (44.59)	60 (40.54)
PE4	1 (0.68)	2 (1.35)	14 (9.46)	71 (47.97)	60 (40.54)
PUT1		10 (6.76)	19 (12.84)	75 (50.68)	44 (29.73)
PUT2	1 (0.68)	6 (4.05)	23 (15.54)	71 (47.97)	47 (31.76)
PUT3		10 (6.76)	20 (13.51)	79 (53.38)	39 (26.35)
PUT4		7 (4.73)	31 (20.95)	68 (45.95)	42 (28.38)
PUT5	1 (0.68)	6 (4.05)	26 (17.57)	76 (51.35)	39 (26.35)
PUS1	2 (1.35)	3 (2.03)	12 (8.11)	82 (55.41)	49 (33.11)
PUS2		5 (3.38)	21 (14.19)	55 (37.16)	67 (45.27)
PUS3	1 (0.68)	7 (4.73)	12 (8.11)	81 (54.73)	47 (31.76)

How did teachers perceive the effects of the web-based tool with reading scaffolds on their teaching?

Teachers perceived that using the RS condition can influence their teaching in a variety of ways. Table 24 shows the frequency and percentages of teachers' responses to the first open-ended question (OE1). A total of 21 teachers responded that RS condition could be useful in supplementing the targeted math content in math classes using proper instructions and other additional resources, such as exercises or more examples; 16 teachers felt that RS condition could improve their teaching efficiency because it could improve students' learning of math concepts and problem-solving skills. Five teachers wanted to use RS condition to be given as homework assignments for students to review the content after their classes. Another four teachers liked its overall organization of the content and the embedded scaffolds for students' reading. Three teachers mentioned that RS condition could reduce their burden regarding class preparation.

Table 24

Frequency and Percentage of Responses for Each Subtheme (Effect on Teaching)

Subthemes	Details	N (%)
Increase teaching efficiency	Work as a good supplement	21 (28)
	Provide well-organized content/feedback	4 (5.33)
	Reduce the burden of teaching preparation	3 (4)
Improve students' learning	Help students learn math concepts and acquire problem-solving skills	16 (21.3)
	Help students' read math problems	3 (4)
	Help students review the content after class	5 (6.67)
Improve students' motivation		7 (9.33)
Need improvements	Need more resources, such as exercises, examples, or videos	3 (4)
	Need editing interfaces	2 (2.67)
	Need to provide teachers with students' records	3 (4)
	Others	4 (5.33)

In addition to the manual coding results, text mining techniques were applied to cross-validate the qualitative results. Figure 7 shows how we visualize the sentiment scores of words in teachers' responses. Analyzing sentiments in teachers' opinions, we observed that teachers used a wide range of positive words like "improve," "easy," "simplify," and "enthusiasm" more often than negative words. Further analyzing sentiment with the NRC lexicon (Figure 8), the results showed that teachers evaluated the effectiveness of the tool with “trust,” “anticipation,” and “joy” undertones.

Figure 8

Frequently Used Terms across OE1 Responses Ranked by Sentiment Score

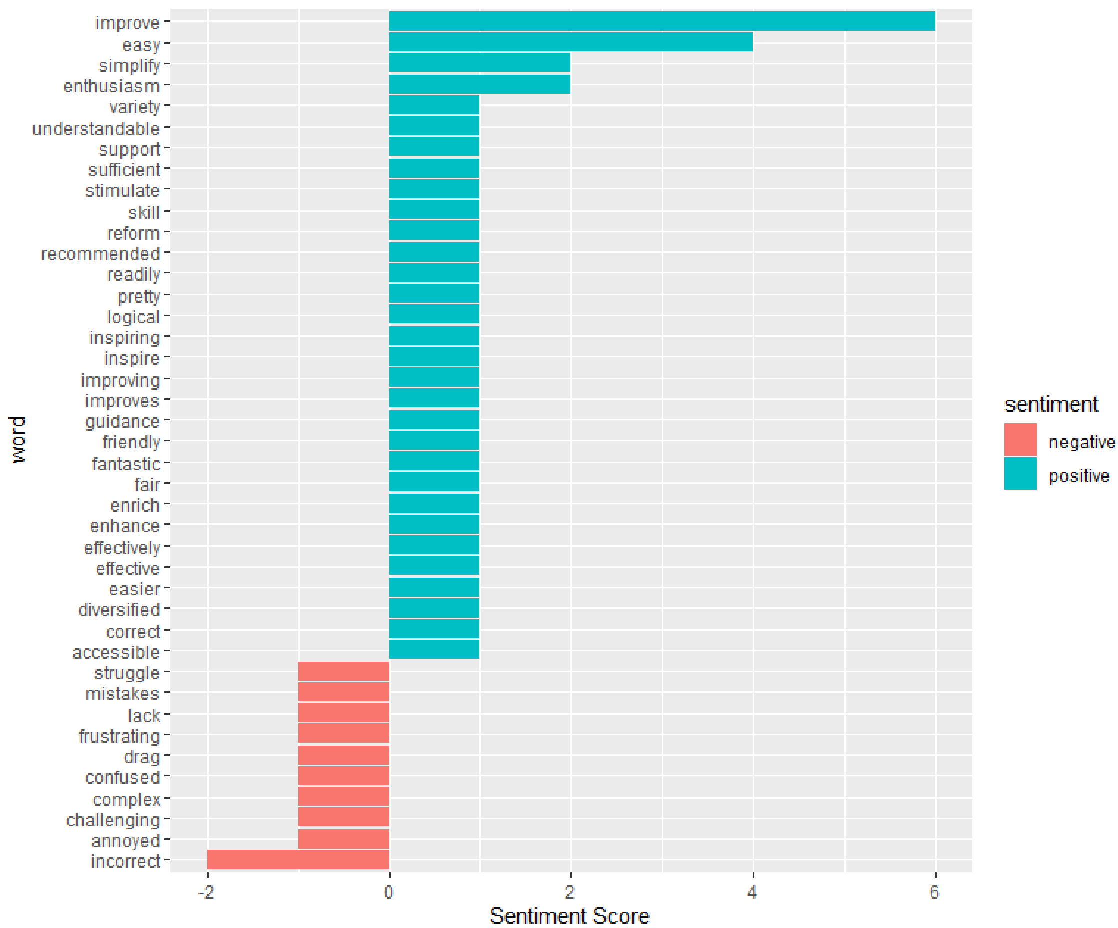


Figure 9

NRC Sentiment Results of OE1 Responses

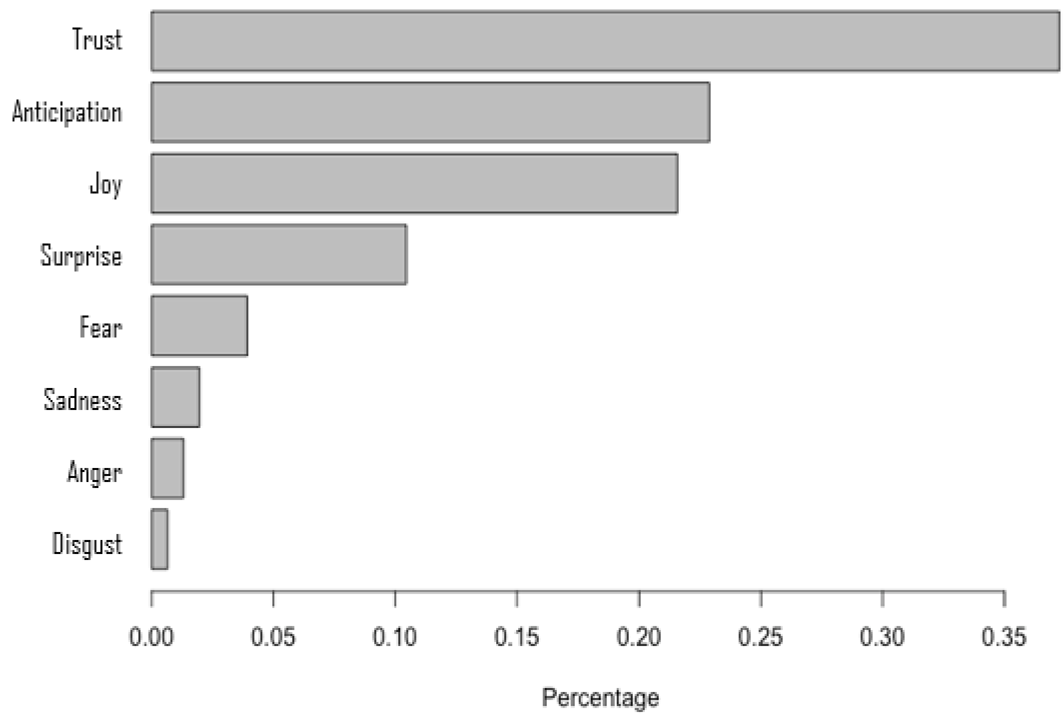
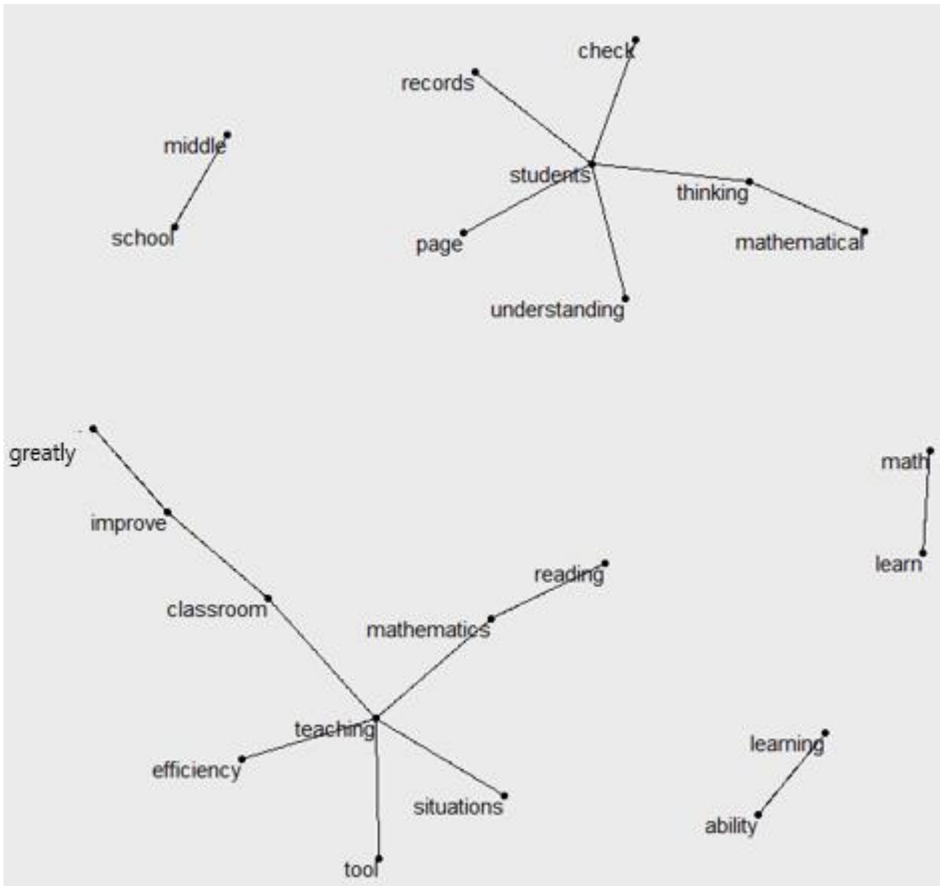


Figure 9 visualized common bigrams that appeared more than twice across teachers' responses. We can see that "teaching" forms a central node, linked to "efficiency," "tool," "mathematics," "situations," "improve," and others. Another central word was "students," which was linked to "thinking," "understanding," "page," "records," "check," and "mathematical." Considering that the majority of teachers perceived the effectiveness of the tool in terms of increasing teaching efficiency and improving students' learning in math, the common bigrams supported the coding results. Other pairs around the outside form common short phrases such as "middle school," "learning ability," and "learn math."

Figure 10

Common Bigrams in OE1 Responses



How did teachers perceive the effect of the web-based tool with reading scaffolds on students learning in math?

In the survey items regarding the usefulness of the RS condition on students' learning (PUS), around 90% of teachers evaluated that the RS condition could improve students' overall learning outcomes. Most teachers appreciated that RS condition could help students effectively learn the math concepts (82%) and the problem-solving process (86%).

We further analyzed what types of students can benefit from using the RS condition to determine the effects of the RS condition on students' learning of math. Table 6 shows the frequency and percentages of teachers' responses to the second open-ended question (OE2). Teachers responded the effects can vary based on students' skill levels. Taken together, 41 teachers mentioned that the RS condition could best help students with low reading or math skills. Another 20 teachers answered that self-motivated learners could get the most out of using RS condition because it allows them to study the content at their own pace. Five teachers said that the RS condition could help introverted students who are highly likely to hesitate to ask questions during the class.

Table 25

Frequency and Percentage of Responses for Each Subtheme (Target Students)

Subthemes	Details	N (%)
Students with different skill levels	All students	11 (9.91)
	Low achievers	41 (37)
	Average achievers	10 (9.01)
	High achievers	8 (7.21)
Self-motivated learners		20 (18.01)
Others	Introverted students	5 (4.5)
	Students who do not like math	4 (3.60)
	Others	7 (6.31)

In subjectivity analysis, Figure 10 shows that teachers used the negative word "poor" the most throughout their responses, even though they used a wide range of positive words like "strong," "benefit," and "love," The results of further analyzing sentiment with the NRC lexicon (Figure 11) showed that teachers evaluated the effectiveness of the tool with "trust," "joy," and "anticipation" undertones.

Figure 11

Frequently Used Terms across OE2 Responses Ranked by Sentiment Score

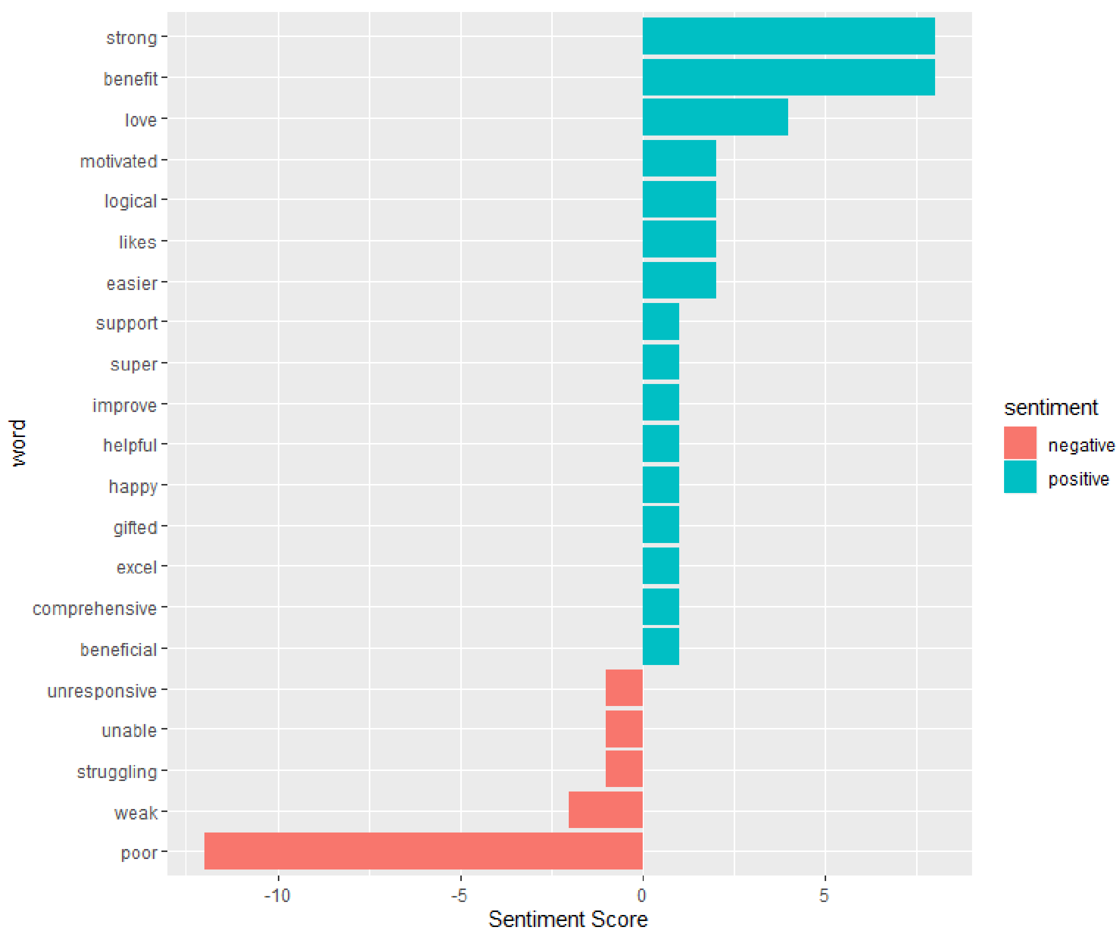
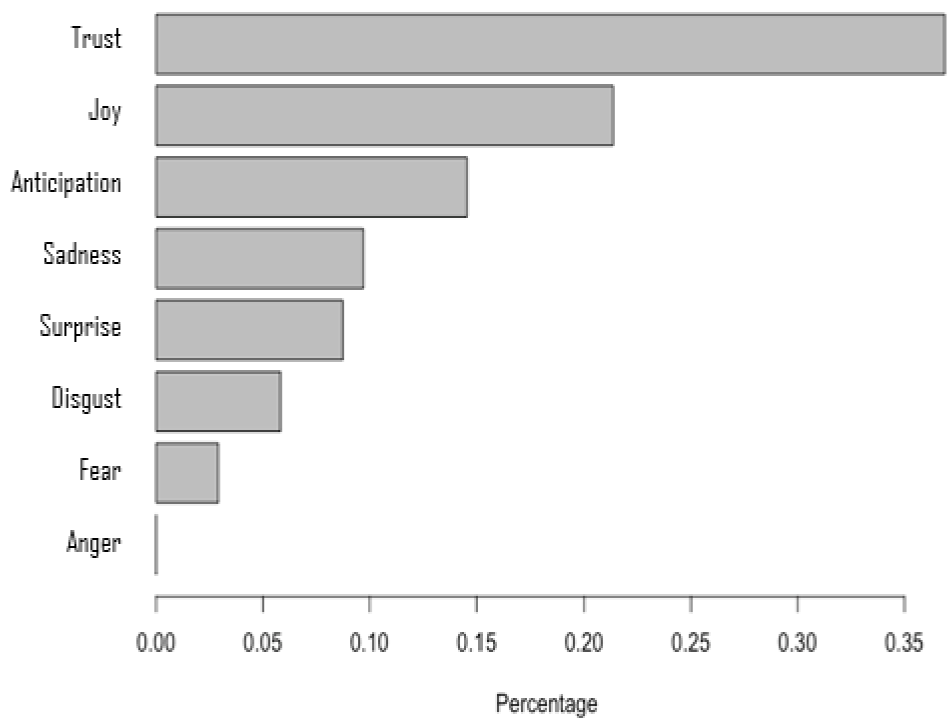


Figure 12

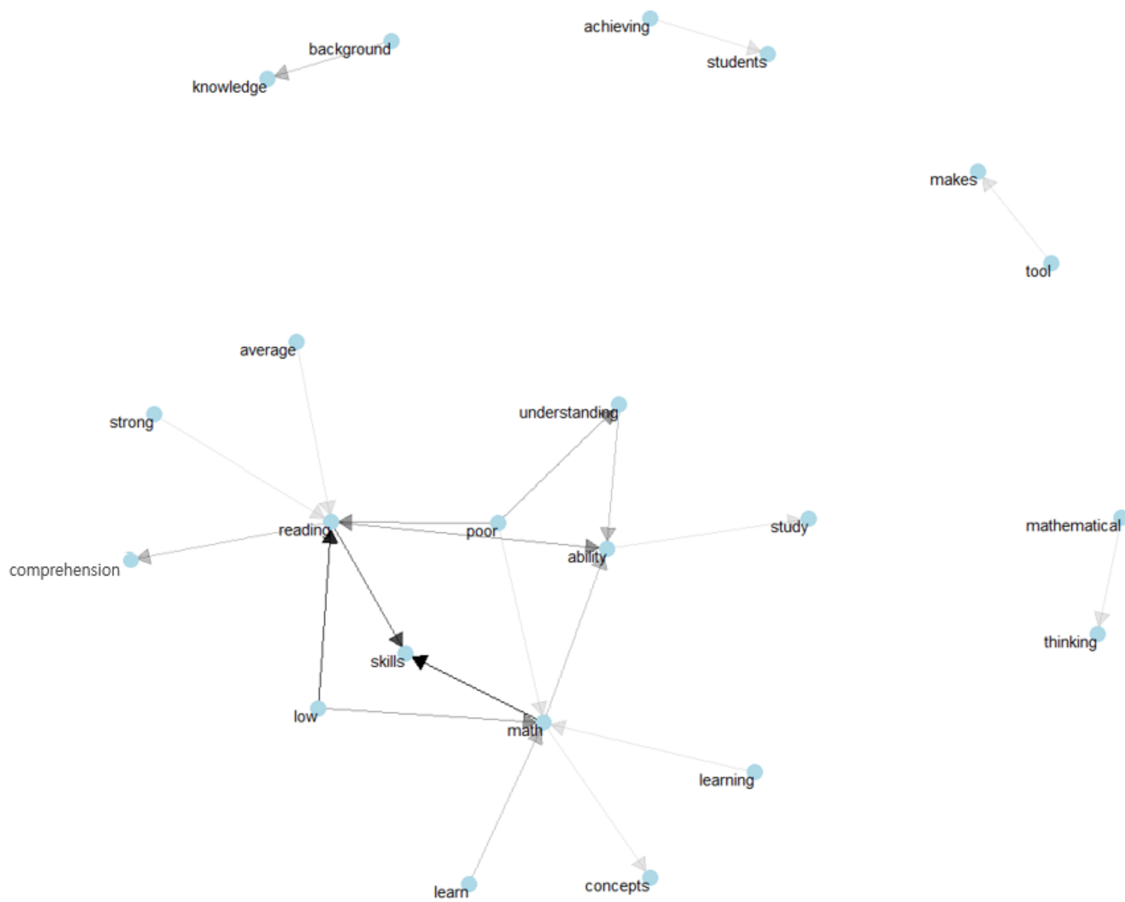
NRC Sentiment Results of OE2 Responses



When visualizing common bigrams that were used more than twice in teachers' responses, all common bigrams were linked together in a big chunk except some outside pairs (Figure 12). To see the relationships among these bigrams, we added a link layer that makes connections transparent based on how common or rare the bigram is and its directionality with an arrow. We found that teachers mentioned "low reading or math skills," "poor reading or math skills," and "poor understanding" a lot more often than other bigrams when following the directions and darkness of the arrows. Considering that teachers largely perceived that this tool can promote low achievers who have a low level of reading or math skills, the graph of common bigrams supported the qualitative coding results. Other pairs around the outside form common short phrases such as "background knowledge," "achieving students," "tool makes," and "mathematical thinking."

Figure 13

Directed Graph of Common Bigrams in OE2 Responses



Students' Perceived Effectiveness of the web-based Tool

After the sessions were completed, students were asked to respond to the survey about how effective they perceived each strategy in this tool to be on their learning of math content. Comparisons of how students in the three conditions responded regarding the effectiveness in the self-summary box yielded interesting results. Students largely agreed or strongly agreed that the self-summary strategy was helpful in learning how to solve questions (Table 27). However, looking at their responses in detail, only 30% of students in the RS condition strongly agreed that the self-summary strategy enhanced their problem-solving ability while 63% of students in the control condition and 48% of students in the CS condition did. Moreover, 26% of students in the CS condition chose the neutral option (neither disagree nor agree), while less than 5 % of students in both the control and RS conditions did. Thus, students in the scaffolded conditions, either RS or CS, are less likely to regard the self-summary box as an effective strategy in learning math compared to those in the control condition.

Table 26

Students' Perceived Effectiveness of Self-summary strategy

Condition	Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree	Total
	(%)	(%)	(%)	(%)	(%)	(%)
Control	0.00	0.00	4.17	33.33	62.50	100
RS	0.00	4.35	4.35	60.87	30.43	100
CS	4.35	0.00	26.09	21.74	47.83	100

Regarding how students recognized the effectiveness of each scaffold in the RS condition (Table 28), more than half of the students who worked on the RS condition strongly agreed that the math vocabulary images helped them understand the corresponding mathematical words (61%) and math concepts in the text (48%). Fifty-two percent of students in the RS condition also strongly agreed that solving "why questions" positively impacted their learning. Overall, it turns out that students perceived web-based reading scaffolds in the RS condition to be more helpful in helping them understand math concepts and gain problem-solving skills than the self-summary strategy, which was the default setting in our experimental design.

Table 27

Students' Perceived Effectiveness of Reading Scaffolds

	Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree	Total
	(%)	(%)	(%)	(%)	(%)	(%)
The word images were helpful for understanding the math concepts in the text.	0.00	0.00	21.74	30.43	47.83	100
The word images were helpful for understanding the corresponding words	0.00	0.00	8.70	30.43	60.87	100
Solving 'Why questions' was helpful	0.00	0.00	13.04	34.78	52.17	100
Filling summary box was helpful	0.00	4.35	4.35	60.87	30.43	100

In addition to questions about the effectiveness of the diverse scaffolds in the conditions, students were asked to respond to their experiences reading using our web-based tool compared to paper-based textbooks (Table 29). Fifty-two percent of students who learned the given content with the RS condition strongly agreed that they understood math concepts better by reading the text using this tool than reading from paper-based textbooks. This percentage is much higher than other students in the control or CS conditions as around 33–34% of them strongly agreed. Thus, based on both the results from the tool effectiveness experiment and the students' survey responses, we can conclude that web-based reading scaffolds (RS condition) not only promote students' learning in math but also allow them to have positive experiences reading mathematical texts via the help of diverse scaffolding strategies.

Table 28

Percentage of Student Responses on their reading experience

Condition	Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree	Total
	(%)	(%)	(%)	(%)	(%)	(%)
Control	4.17	4.17	16.67	41.67	33.33	100
RS	0.00	0.00	17.39	30.43	52.17	100
CS	0.00	8.70	26.09	30.43	34.78	100

Summary

The purpose of this investigation was to analyze the differences in the effectiveness of different scaffolding types on students' math learning. Based on the literature, it was expected that the scaffolded conditions (both RS and CS), compared to the control condition, would promote students' learning. The findings provide empirical evidence regarding how reading scaffolds and scaffolds for problem-solving steps with cognitive tutors can affect students' learning differently in terms of both conceptual and procedural knowledge gain. The results also stronly suggested how these effects of scaffolds can vary depending on students' reading skills. Table 26 is a summary of the research hypotheses and results.

Students in the RS and CS conditions had significantly better knowledge gain than those in the control condition. In terms of conceptual knowledge gain, students in the RS condition had significantly better learning outcomes than those in the control and CS conditions. However, students in the CS condition showed significantly better procedural knowledge gain compared to those in the control condition. However, there were no significant differences in average procedural knowledge gain between students in the CS and RS conditions.

Using ANCOVA, there was a significant interaction effect between the conditions and students' reading scores on their knowledge gain, specifically procedural knowledge gain. In conceptual knowledge gain, there were no interaction effects between the conditions and reading scores. Summarizing the interaction effects and line plots, students with high reading skills in the control and CS conditions obtained more procedural knowledge gain than those with low reading skills. However, in the RS condition, low-achieving readers gained more conceptual and procedural knowledge than high-achieving readers.

In addition to the student experiment to determine tool effectiveness, the RS condition was evaluated by teachers in terms of its ease of use and effects on their teaching. Overall, teachers found that using web-based reading scaffolds could enhance their teaching efficiency, help students learn math, and improve students' motivation. This study provides empirical evidence regarding the effectiveness of computer-based reading scaffold interventions for students learning math.

Most teachers who participated in the tool evaluation process responded that using the reading scaffold web-based tool will help them teach math and improve students' mathematical knowledge. In terms of its usefulness for teaching, teachers responded that the reading scaffold web-based tool can make their teaching practices more effective by providing good supplemental material during/after class, improving students' math knowledge, and lessening the time needed for teaching preparation. Moreover, we found that teachers believe that computer-based reading scaffolds can promote learning in low achievers. With the majority of positive responses, some teachers evaluated our reading scaffold web-based as needing some improvements. They suggested that it needs more functions so that teachers can edit the content or check students' records.

Table 29

Summary of Hypotheses and Results

Hypothesis	Results
H1. There is no difference in the average knowledge gain of three scaffolded conditions.	Rejected.
H2. There is no difference in the conceptual knowledge gain of three scaffolded conditions.	Rejected.
H3. There is no difference in procedural knowledge gain of three scaffolded conditions.	Rejected.
H4. There is no difference in the effect of each condition among students with different levels of reading ability.	Partially supported. There was no significant interaction effect between condition and reading levels. However, in ANCOVA results, there was a significant interaction effect between conditions and reading scores in knowledge gain.

CHAPTER V

DISCUSSION

In general, secondary school mathematics texts feature complex structures, symbols, and specialized vocabulary. Math concepts in these texts are regarded to be more abstract and convey a heavier concept load than elementary school-level texts. These features cause the readability of mathematics textbooks to be above the indicated grade level (Heddens & Smith, 1964; Mallinson, 1972; Pinne, 1983). Thus, when reading mathematics texts, students encounter many problems in understanding math vocabulary and to interpret symbols and words as they relate to each other.

Even though students should be taught or receive proper guidance regarding how to read mathematics texts, this has been overlooked within mathematics teaching due to doubts and misconceptions as to whether this should be a math teacher's responsibility and whether there is a need at all to teach reading in math (Reehm & Long, 1996; Stewart & O'Brien, 1989). Moreover, most teachers in STEM areas are highly likely to be unaware of how to integrate reading practices in teaching the content since schools are reluctant to provide professional development for the teachers due to lack of time or funds (Wijekumar et al., 2017).

Effect of Text Cohesion

The results of this study provide empirical evidence that students' different levels of reading skills affect their mathematics learning. The findings showed that students who had low reading skills benefited more from reading scaffolds in their math learning, while those with high reading skills learned more from problem-solving scaffolds. These results are in line with previous studies on the effect of students' reading skills and text cohesion (McNamara & Kintsch, 1996). Text cohesion refers to the degree to which the concepts and relations within a text are explicit (Graesser et al., 2003). According to the literature, students' learning of new knowledge can be affected by their reading comprehension skills, their prior knowledge, and the cohesion of the given texts. In particular, many studies have indicated that increasing the cohesion of the text with information can promote the learning of readers with low levels of background knowledge and/or reading comprehension skills (McNamara, 2001; O'Reilly & McNamara, 2007). Moreover, they found that students with high prior knowledge and reading skills can learn more from less cohesive texts, which we called "the reverse cohesion effect," because texts with fewer hints/clues about the concepts can facilitate readers' inferences (O'Reilly & McNamara, 2007).

Texts without reading scaffolds (control or CS condition) can be regarded as "low-cohesion" texts, and they include less explicit elements or connections so that readers are required to make many inferences using their prior knowledge. On the other hand, texts with reading scaffolds (RS condition) can be classified as "high-cohesion" texts, and they have more explicit clues (words, features, signals and others) and relations of elements within them so that readers can comprehend the texts while making fewer inferences and using less prior knowledge (McNamara et al., 2010). This gap in text cohesion can explain the different learning outcomes between low-achieving readers and high-achieving readers in this study.

Why Did Reading Scaffolds work?

Why and how can reading scaffolds help students' learning in mathematics? Can reading practices improve mathematical learning? Few studies can help to explain how reading scaffolds work to improve the mathematical knowledge of students, especially low achievers. One potential explanation of why reading scaffolds successfully help students learn mathematical knowledge is that reading scaffolds actually assist students to read mathematical text like real mathematicians. Fang and Chapman (2020) investigated a mathematician's reading practices when he comprehended what he read. In their research, the mathematician gained motivation to work on the problems and seek answers when he understood new things by reading mathematical texts. While reading the text, he visualized content, summarized and paraphrased what he read, and actively used his prior knowledge, which helped him clarify his thinking, connect concepts, and deepen his comprehension. He also actively used the "storying" strategy, making up a story to follow the logic of the text, by which he could engage in logical reasoning of how prose, formulas, or equations work.

Weber's (2008) work also found that mathematicians used diverse reading strategies, including deductive reasoning, example-based reasoning, and zoom-in/zoom-out strategies, when they read mathematical proofs and examined the proofs' validity. Wilkerson-Jerde and Wilensky (2011) added an analysis in which mathematicians deconstructed mathematical texts into components using references, such as definitions, symbolic structures, and examples, and then recombined these fragments and checked their understanding with references. Shanahan et al. (2011) revealed that mathematicians weighed nearly every word and considered information using their understanding of text structure to determine where problems and solutions were located. Considering these findings regarding how mathematicians read mathematical texts, we can conclude that the invented computer-based reading scaffolds in this research helped students digest mathematical information within the text like mathematicians by understanding the meaning of each word, engaging in voluminous re-reading, reasoning with examples, and following the logic or causal relationships of concepts.

Another possible explanation is that these embedded reading scaffolds can optimize the cognitive load imposed on working memory. Working memory, in which all conscious cognitive processing occurs, can handle only a very limited number of interacting elements. Numerous research studies have reported that working memory is one of the most crucial predictors of students' academic performance in reading comprehension (Gathercole et al., 2006; Borella & Ribaupierre, 2014) and mathematical problem solving (Passolunghi & Mammarella, 2010; Bull et al., 2008). Swanson and Beebe-Frankenberger (2004) found that working memory accounted for around 30% of the variance in problem-solving performance and that they were strongly correlated even when controlling for the influence of other predictors such as phonological system or age. Giofre et al. (2018) also presented that working memory accounted for approximately 14% of the variance in mathematics and 15% in reading. Considering that students can fail to master the content because of a lack of reading comprehension skills, a low level of prior knowledge, and limited working memory, computer-based reading scaffolds in mathematics made the mathematical text more readable with less working memory/prior knowledge and helped students read the text more strategically.

CHAPTER VI

CONCLUSIONS

Significance of the Study

The primary contribution of this research is that it has provided an effective intervention to help students learn math via computer-based reading scaffolds. This approach gives us an insight into how reading scaffolds can impact students' conceptual and procedural knowledge in math and demonstrates the potential value of computer-based scaffolds in assisting students' disciplinary literacy in math. The experimental results also give us an insight into how students' knowledge gain via computer-based scaffolds can differ based on their reading levels. In addition to the experimental findings, we also found that the majority of math teachers considered reading ability to be an important skill to learn math concepts and problem-solving. They perceived that there is a need for reading scaffolds in math for all levels of students and have implemented various strategies to boost students' comprehension of mathematics texts. The findings from the tool evaluation analysis also highlight that well-designed computer-based reading scaffolds can also enhance teaching efficiency by reducing the teaching preparation burden and increasing content delivery.

Limitations of this study

This study has several limitations. First, the ethnic distribution of student participants might be different from the actual ethnic distribution in various school classrooms. Among student participants, 47 students were Asian, 52 students were Caucasian, and three students were African-American. This is because we conducted experiments only with students whose parents voluntarily contacted us and signed up for participation. Thus, the research results may not be representative of students from different ethnic backgrounds.

Second, we did not collect any demographic information on the teachers who participated in the tool evaluation. When creating tool evaluation survey items, we were highly interested in gathering data regarding what teachers thought about our web-based tool, but we did not contemplate that their perceptions on the tool might be different based on their gender or age. Even though we did not do any further quantitative analysis beyond descriptive statistics using these tool evaluation survey items, it would have been helpful to investigate possible differences in their perceptions of the tool while considering demographic variables, such as gender or age.

Lastly, the experimental design did not include the treatment conditions regarding both the reading and cognitive-tutor scaffolds. The current experimental design was deliberately sketched to analyze the effects of each scaffold type on students' conceptual or procedural knowledge gain while considering their different reading skill levels. However, we cannot fully determine how much students can learn when they receive both types of scaffolds simultaneously.

Suggestions for Future Research

Considerable improvements can be done in terms of the reading scaffolded condition based on the literature regarding strategies for promoting students' disciplinary literacy. For example, we can add a greater variety of reading scaffolds, such as interactive quizzes or videos, more questions on different difficulty levels, or intelligent peers. This tool can also be improved to support students who are unsuccessful when learning with this tool, such as by providing personalized guidance about where they can find the appropriate information to solve the question if they are stuck on any questions. Adding a tracking system that can track students' learning progress can also be helpful so that teachers can help those struggling students by providing timely feedback.

Moreover, future research can be conducted to identify the effectiveness of computer-based reading scaffolds in other concept-rich STEM topics, such as statistics, physics, chemistry, and others. In both these STEM areas and mathematics, the content becomes more abstract and difficult to learn as the grade level increases. If computer-based reading scaffolds can promote low achievers' knowledge in other STEM areas, these reading scaffolds can be regarded as effective and universal strategies for STEM content teaching.

To popularize computer-based reading scaffolds, future research should also strive to improve on the methods/techniques used to build these computer-based reading scaffolds. Developing a web-based tool with computer-based reading scaffolds required many months and human resources, including a teacher, researchers, and programmers. There is a strong need for techniques that can automatically link relevant images and mathematical words/concepts and also connect each question and the text paragraph containing the relevant information to solve the question.

REFERENCES

Adams, T. L. (2003). Reading mathematics: More than words can say. *Reading Teacher*, 56, 786–795.

Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science*, 26(2), 147-179.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Educational Psychology*, 84(3), 261-271.

Ames, C., & Archer, J. (1988). Achievement goals in the classroom: Students' learning strategies and motivation processes. *Journal of Educational Psychology*, *80*(3), 260-267.

Anderson, J. R. (1993). *Rules of the mind.* Hillsdale, NJ: Erlbaum

Anderson, J. R., Boyle, C. F., Corbett, A. T., & Lewis, M. W. (1990). Cognitive modeling and intelligent tutoring. *Artificial Intelligence*, *42,* 7-49

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *Journal of the Learning Sciences*, *4*, 167–207.

Aleven, V., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based Cognitive Tutor. *Cognitive Science, 26,* 147-179.

Anderson, J. R., & Lebière, C. (1998). *The atomic components of thought*. Mahwah, NJ: Erlbaum.

Azevedo, R. (2005). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational psychologist, 40*(4), 199-209.

Barton, M. L., & Heidema, C. (2002). *Teaching reading in mathematics*. Aurora, CO: Mid-Continent Research for Education and Learning.

Belland, B. R., Walker, A. E., & Kim, N. J. (2017). A Bayesian network meta-analysis to synthesize the influence of contexts of scaffolding use on cognitive outcomes in STEM education. *Review of Educational Research, 87*(6), 1042-1081.

Bellocchi, A. & Ritchie, S. M. (2011). Investigating and theorizing discourse during analogy writing in chemistry. *Journal of Research in Science Teaching, 48,* 771–792.

Berenson, S., Van Der Valk, T., Oldham, E., Runesson, U., Moreira, C. Q., & Broekman, H. (1997). An international study to investigate prospective teachers' content knowledge of the area concept. *European Journal of Teacher Education, 20*(2), 137-150.

Borella, E., & De Ribaupierre, A. (2014). The role of working memory, inhibition, and processing speed in text comprehension in children. *Learning and Individual Differences, 34,* 86-92.

Bortnem, G. (2008). Teacher use of interactive read alouds using nonfiction in early childhood classrooms. *Journal of College Teaching & Learning, 5*(12), 29-44.

Brennan, A. D., & Dunlap, W. P. (1985). What are the prime factors of reading mathematics?. *Reading Improvement, 22*(2), 152-159.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*(3), 205-228.

Carlisle, J. F. (2010). Effects of instruction in morphological awareness on literacy achievement: An integrative review. *Reading research quarterly, 45*(4), 464-487.

Carter, T. & Dean, E. (2006). Mathematics intervention for grades 5–11: Teaching mathematics, reading, or both? *Reading Psychology, 27,* 127–146.

Chi, M. T., Glaser, R., & Farr, M. J. (1988). *The nature of expertise*. Hillsdale, NJ.

Clark, D. B., Touchman, S., Martinez-Garza, M., Ramirez-Marin, F., & Drews, T. S. (2012). Bilingual language supports in online science inquiry environments. *Computers & Education, 58*(4), 1207-1224.

Collins, A., Brown, J. S., & Newman, S. E. (1988). Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics. Thinking: *The Journal of Philosophy for Children, 8*(1), 2-10.

Collins, A. Hawkins, J., & Carver, S. M. (1991). *A cognitive apprenticeship for disadvantaged students. Teaching advanced skills to at-risk students: Views from research and practice.* San Francisco: Iose-Bass.

Connelly, F. M. (2008). *The Sage handbook of curriculum and instruction*. Sage.

Corbett, A. T., & Anderson, J. R. (1995). Knowledge tracing: modeling the acquisition of procedural knowledge. *User Modeling and User-Adapted Interaction, 4*, 253–278.

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why?. *Current directions in psychological science*, *19*(1), 51-57.

Culyer, R. C. (1988). Reading and mathematics go hand in hand. *Reading Improvement, 25*(3), 189-195.

Davis, F. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13,* 319 – 340.

Debue, N., & Van De Leemput, C. (2014). What does germane load mean? An empirical contribution to the cognitive load theory. *Frontiers in psychology, 5* (1099), 1-12.

Deci, E. L. (1992). Article commentary: on the nature and functions of motivation theories. *Psychological Science*, *3*(3), 167-171.

Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological inquiry, 11*(4), 227-268.

de Jong, T., & Njoo, M. (1992). Learning and instruction with computer simulations: Learning processes involved. In *Computer-based learning environments and problem solving* (pp. 411-427). Springer, Berlin, Heidelberg.

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research, 68*(2), 179-201.

Ding, X., Liu, B., & Yu, P. S. (2008, February). A holistic lexicon-based approach to opinion mining. In *Proceedings of the 2008 international conference on web search and data mining*.

Doctorow, M., Wittrock, M. C., & Marks, C. (1978). Generative processes in reading comprehension. *Journal of Educational Psychology*, *70*(2), 109-118.

Duffy, M. C., & Azevedo, R. (2015). Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system. *Computers in Human Behavior, 52*, 338-348.

Elliot, A. J., & McGregor, H. A. (2001). A 2× 2 achievement goal framework. *Journal of Personality and Social Psychology, 80*(3), 501-519.

Elliot, A. J., & Murayama, K. (2008). On the measurement of achievement goals: Critique, illustration, and application. *Journal of Educational Psychology, 100*(3), 613-628.

Elsom-Cook, M. (1987). *Intelligent Computer-aided instruction research at the Open University.* Educational Resources Information Center.

Fang, Z., & Schleppegrell, M. (2010). Disciplinary literacies Across content areas: Supporting secondary reading through functional language analysis. Journal of Adolescent & Adult Literacy: *A Journal from the International Reading Association 53*(7): 587–597.

Fang, Z., & Chapman, S. (2020). Disciplinary literacy in mathematics: One mathematician's reading practices. *The Journal of Mathematical Behavior, 59,* 1-15.

Flick, L. B., & Lederman, N. G. (2002). The value of teaching reading in the context of science and mathematics. *School Science and Mathematics, 102*(3), 105-107.

Garbe, D. G. (1985). Mathematics Vocabulary and the Culturally Different Student. *Arithmetic Teacher, 33*(2), 39-42.

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93*(3), 265-281.

Giofrè, D., Donolato, E., & Mammarella, I. C. (2018). The differential role of verbal and visuospatial working memory in mathematics and reading. *Trends in Neuroscience and Education, 12,* 1-6.

Goforth, C. (2015). Using and Interpreting Cronbach's Alpha. Available at: http://data.library.virginia.edu/using-and-interpreting-cronbachs-alpha.

Graesser, A. C., McNamara, D. S., & Louwerse, M. M. (2003). What do readers need to learn in order to process coherence relations in narrative and expository text. *Rethinking Reading Comprehension, 82,* 98.

Grimm, K. J. (2008). Longitudinal associations between reading and mathematics achievement. *Developmental Neuropsychology, 33*(3), 410-426.

Guzdial, M. (1994). Software-realized scaffolding to facilitate programming for science learning. *Interactive Learning Environments, 4*(1), 1-44.

Hagen, Å. M., Braasch, J. L., & Bråten, I. (2014). Relationships between spontaneous note-taking, self-reported strategies and comprehension when reading multiple texts in different task conditions. *Journal of Research in Reading, 37*(S1), 141-157.

Halliday, M. A. K. (1978). *Language as social semiotic: The social interpretation of language and meaning.* Hodder Arnold.

Hannafin, M., Land, S., & Oliver, K. (1999). Open learning environments: Foundations, methods, and models. In *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. 2, 115-140). Taylor and Francis.

Harris, A., Bonnett, V., Luckin, R., Yuill, N., & Avramides, K. (2009, July). Scaffolding effective help-seeking behaviour in mastery and performance-oriented learners. In *Proceedings of the 14th International Conference on Artificial Intelligence in Education*.

Heddens, J. W., & Smith, K. J. (1964). The readability of elementary mathematics books. *The Arithmetic Teacher, 11*(7), 466-468.

Heffernan, N. T., & Heffernan, C. L. (2014). The ASSISTments Ecosystem: Building a platform that brings scientists and teachers together for minimally invasive research on human learning and teaching. *International Journal of Artificial Intelligence in Education, 24*(4), 470-497.

Hiebert, J., Carpenter, T. P., Fennema, E., Fuson, K., Human, P., Murray, H., ... & Wearne, D. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. *Educational Researcher, 25*(4), 12-21.

Hulleman, C. S., Schrager, S. M., Bodmann, S. M., & Harackiewicz, J. M. (2010). A meta-analytic review of achievement goal measures: Different labels for the same constructs or different constructs with similar labels?. *Psychological bulletin, 136*(3), 422-449.

Iseman, J. S., & Naglieri, J. A. (2011). A cognitive strategy instruction to improve math calculation for children with ADHD and LD: A randomized controlled study. *Journal of Learning Disabilities, 44*(2), 184-195.

Jemmott, J. B., Jemmott, L. S., & Fong, G. T. (2010). Efficacy of a theory-based abstinence-only intervention over 24 months: A randomized controlled trial with young adolescents. *Archives of pediatrics & adolescent medicine, 164*(2), 152-159.

Kaplan, A., Middleton, M. J., Urdan, T., & Midgley, C. (2002). Achievement goals and goal structures. *Goals, goal structures, and patterns of adaptive learning*, 21-53.

Kester, L., Van Rosmalen, P., Sloep, P., Brouns, F., Brouwers, M., & Koper, R. (2006, March). Matchmaking in learning networks: a system to support knowledge sharing. In *International Workshop in Learning Networks for Lifelong Competence Development, TENCompetence Conference*.

Kiewra, Kenneth A., Nelson F. Dubois, Maribeth Christensen, Sung-Il Kim, and Nancy Lindberg. (1989). A more equitable account of the note-taking functions in learning from lecture and from text. *Instructional Science, 18*(3), 217-232.

National Research Council, & Mathematics Learning Study Committee. (2001). *Adding it up: Helping children learn mathematics.* National Academies Press.

Kim, M. C., & Hannafin, M. J. (2011). Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers & Education, 56*(2), 403-417.

Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano, J. (2018). From cognitive load theory to collaborative cognitive load theory. *International Journal of Computer-Supported Collaborative Learning, 13*(2), 213-233.

Koedinger, K. R., & Aleven, V. (2007). Exploring the assistance dilemma in experiments with cognitive tutors. *Educational Psychology Review, 19*(3), 239-264.

Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A. (1997). Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education, 8,* 30–43.

Koedinger, K. R., Corbett, A. T., & Perfetti, C. (2012). The Knowledge-Learning-Instruction framework: Bridging the science-practice chasm to enhance robust student learning. *Cognitive Science, 36*(5), 757-798.

Koedinger, K. R. & Sueker, E. (2014). *Monitored design of an effective learning environment for algebraic problem solving.* Carnegie Mellon University.

Korpershoek, H., Kuyper, H., & van der Werf, G. (2015). The Relation between Student Math and Reading Ability and their Mathematics, Physics, and Chemistry Examination Grades in Secondary Education. *International Journal of Science and Mathematics Education*, *13*(5), 1013-1037.

Kozma, R. B. (1991). The impact of computer-based tools and embedded prompts on writing processes and products of novice and advanced college writers. *Cognition and instruction, 8*(1), 1-27.

Krawec, J., Huang, J., Montague, M., Kressler, B., & Melia de Alba, A. (2013). The effects of cognitive strategy instruction on knowledge of math problem-solving processes of middle school students with learning disabilities. *Learning Disability Quarterly, 36*(2), 80-92.

Kurz, A., & Elliott, S. N. (2012). MyiLOGS: My instructional learning opportunities guidance system (Version 2) [Online measurement instrument]. Tempe, AZ: Arizona State University.

Land, S. M., & Hannafin, M. J. (1997). Patterns of understanding with open-ended learning environments: A qualitative study. *Educational Technology Research and Development, 45*(2), 47-73.

Land, S. M. (2000). Cognitive requirements for learning with open-ended learning environments. *Educational Technology Research and Development, 48*(3), 61-78.

Linnenbrink, E. A., & Pintrich, P. R. (2001). Multiple goals, multiple contexts: The dynamic interplay between personal goals and contextual goal stresses. In S. Volet & S. Järvelä (Eds.), *Advances in learning and instruction series. Motivation in learning contexts: Theoretical advances and methodological implications* (p. 251–269). Pergamon Press.

Maccini, P., Mulcahy, C. A., & Wilson, M. G. (2007). A follow-up of mathematics interventions for secondary students with learning disabilities. *Learning Disabilities Research & Practice, 22*(1), 58-74.

Magliano, J. P., Millis, K. K., Ozuru, Y., & McNamara, D. S. (2007). A multidimensional framework to evaluate reading assessment tools. In D. S. McNamara (Ed.), Reading comprehension strategies: Theories, interventions, and technologies (pp. 107–136). Mahwah, NJ: Erlbaum.

Marra, A. (2014, July). For a dynamic semantics of necessity deontic modals. In International Conference on Deontic Logic in Computer Science (pp. 124-138). Springer, Cham.

Mather, J. R. C., & Chiodo, J. J. (1994). A mathematical problem: How do we teach mathematics to LEP elementary students. *The Journal of Educational Issues of Language Minority Students*, *13*, 1-12.

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning?. *American Psychologist, 59*(1), 14-19.

McNamara, D. S. (2001). Reading both high-coherence and low-coherence texts: Effects of text sequence and prior knowledge. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 55*(1), 51-62.

McNamara, D. S., & Kendeou, P. (2011). Translating advances in reading comprehension research to educational practice. International Electronic *Journal of Elementary Education, 4*(1), 33–46.

McNamara, D. S., & Kintsch, W. (1996). Learning from texts: Effects of prior knowledge and text coherence. *Discourse processes, 22*(3), 247-288.

McNamara, D. S., Louwerse, M. M., McCarthy, P. M., & Graesser, A. C. (2010). Coh-Metrix: Capturing linguistic features of cohesion. *Discourse Processes, 47*(4), 292-330.

Mendicino, M., Razzaq, L., & Heffernan, N. T. (2009). A comparison of traditional homework to computer-supported homework. *Journal of Research on Technology in Education, 41*(3), 331-359.

Meyer, B. J., & Ray, M. N. (2017). Structure strategy interventions: Increasing reading comprehension of expository text. *International Electronic Journal of Elementary Education, 4*(1), 127-152.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81-97.

Mohammad, S. M., & Turney, P. D. (2013). Crowdsourcing a word–emotion association lexicon. *Computational Intelligence, 29*(3), 436-465.

Montague, M., Enders, C., & Dietz, S. (2011). Effects of cognitive strategy instruction on math problem solving of middle school students with learning disabilities. *Learning Disability Quarterly, 34*(4), 262-272.

Montague, M., Krawec, J., Enders, C., & Dietz, S. (2014). The effects of cognitive strategy instruction on math problem solving of middle-school students of varying ability. *Journal of Educational Psychology, 106*(2), 469-481.

Montgomery, A. A., Peters, T. J., & Little, P. (2003). Design, analysis and presentation of factorial randomised controlled trials. *BMC Medical Research Methodology, 3*(1), 1-5.

Morgan, G. A., Harmon, R. J., & Maslin-Cole, C. A. (1990). Mastery motivation: Definition and measurement. *Early Education and Development, 1*(5), 318-339.

Murzyn, A., & Hughes, T. (2015). Making Mathematics Placement Decisions for High School Students with High Incidence Disabilities: A Collective Case Study. *American Secondary Education, 43*(2), 44-58.

Nathan, M. J., Kintsch, W., & Young, E. (1992). A theory of algebra-word-problem comprehension and its implications for the design of learning environments. *Cognition and Instruction, 9*(4), 329-389.

Ní Ríordáin, M. & O'Donoghue, J. (2009). The relationship between performance on mathematical word problems and language proficiency for students learning through the medium of Irish. *Educational Studies in Mathematics, 71*, 43–64

Nwana, H. S. (1990). Intelligent tutoring systems: an overview. *Artificial Intelligence Review, 4*(4), 251-277.

O'Reilly, T., & McNamara, D. S. (2007). The impact of science knowledge, reading skill, and reading strategy knowledge on more traditional "high-stakes" measures of high school students' science achievement. *American Educational Research Journal, 44*(1), 161-196.

Ozuru, Y., Dempsey, K., & McNamara, D. S. (2009). Prior knowledge, reading skill, and text cohesion in the comprehension of science texts. *Learning and instruction, 19*(3), 228-242.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Pane, J. F., Griffin, B. A., McCaffrey, D. F., & Karam, R. (2014). Effectiveness of cognitive tutor algebra I at scale. *Educational Evaluation and Policy Analysis, 36*(2), 127-144.

Passolunghi, M. C., & Mammarella, I. C. (2010). Spatial and visual working memory ability in children with difficulties in arithmetic word problem solving. *European Journal of Cognitive Psychology*, *22*(6), 944-963.

Pea, R. D. (1993). Practices of distributed intelligence and designs for education. Distributed cognitions: *Psychological and Educational Considerations, 11*, 47-87.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *The Journal of the Learning Sciences, 13*(3), 423-451.

Pimm, S. L., & Rice, J. C. (1987). The dynamics of multispecies, multi-life-stage models of aquatic food webs. *Theoretical Population Biology, 32*(3), 303-325.

Pintrich, P. R. (1999). The role of motivation in promoting and sustaining self-regulated learning. *International Journal of Educational Research, 31*(6), 459-470.

Polman, J. L., & Pea, R. D. (2001). Transformative communication as a cultural tool for guiding inquiry science. *Science Education, 85*(3), 223-238.

Pólya, G. (1945). *How to solve it. Princeton*. New Jersey: Princeton University.

Reehm, S. P., & Long, S. A. (1996). Reading in the mathematics classroom. *Middle School Journal, 27*(5), 35-41.

Reikerås, E. K. (2006). Performance in solving arithmetic problems: A comparison of children with different levels of achievement in mathematics and reading. European *Journal of Special Needs Education, 21*(3), 233-250.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*(3), 273-304.

Renninger, K. A., Cai, M., Lewis, M. C., Adams, M. M., & Ernst, K. L. (2011). Motivation and learning in an online, unmoderated, mathematics workshop for teachers. *Educational Technology Research and Development, 59*(2), 229-247.

Rittle-Johnson, B., Siegler, R. S., & Alibali, M. W. (2001). Developing conceptual understanding and procedural skill in mathematics: An iterative process. *Journal of Educational Psychology*, *93*(2), 346-362.

Ritter, F. E., Tehranchi, F., & Oury, J. D. (2019). ACT-R: A cognitive architecture for modeling cognition. *WIREs Cognitive Science, 10*(3), 1-19.

Rolliston, P. (2005) Using peer feedback in the ESL writing class. *ELT Journal, 59*(1): 23-30.

Rupley, W. H., & Wilson, V. L. (1996). Content, domain, and word knowledge: Relationship to comprehension of narrative and expository text. *Reading and Writing: An Interdisciplinary Journal, 8,* 419-432.

Sales, A. C., & Pane, J. F. (2015). Exploring causal mechanisms in a randomized effectiveness trial of the cognitive tutor. In *Proceedings of the 8th International Conference on Educational Data Mining.*

Segedy, J. R. (2014). *Adaptive scaffolds in open-ended computer-based learning environments.* Vanderbilt University.

Segedy, J. R., Kinnebrew, J. S., & Biswas, G. (2011, November). Modeling learner's cognitive and metacognitive strategies in an open-ended learning environment. In *2011 AAAI Fall Symposium Series*.

Self, J. (Ed.). (1988). *Artificial intelligence and human learning: intelligent computer-aided instruction.* London: Chapman and Hall.

Shanahan, C., T. Shanahan, and C. Misischia. 2011. Analysis of expert readers in three disciplines history, mathematics, and chemistry. *Journal of Literacy Research 43* (4): 393–429.

Shealy, R., & Stout, W. (1993). A model-based standardization approach that separates true bias/DIF from group ability differences and detects test bias/DTF as well as item bias/DIF. *Psychometrika, 58*(2), 159-194.

Sherin, B., Reiser, B. J., & Edelson, D. (2004). Scaffolding analysis: Extending the scaffolding metaphor to learning artifacts. *The Journal of the Learning Sciences, 13*(3), 387-421.

Snow, R. E. (1974). Representative and quasi-representative designs for research on teaching. *Review of Educational Research, 44*(3), 265-291.

Sorden, S. D. (2005). A cognitive approach to instructional design for multimedia learning. *Informing Science, 8.* 263-279.

Stewart, R. A., & O'Brien, D. G. (1989). Resistance to content area reading: A focus on preservice teachers. *Journal of Reading, 32*(5), 396-401.

Strickland, T. K., & Maccini, P. (2013). The effects of the concrete–representational–abstract integration strategy on the ability of students with learning disabilities to multiply linear expressions within area problems. *Remedial and Special Education, 34*(3), 142-153.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology, 96*(3), 471-461.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257-285.

Sweller J., Ayres P., & Kalyuga S. (2011). *Cognitive Load Theory*, New York: Springer.

Teo, T., & Van Schalk, P. (2009). Understanding technology acceptance in pre-service teachers: A structural-equation modeling approach. *Asia-Pacific Education Researcher, 18*(1), 47-66.

Thompson, D., Hammond, P. S., Nicholas, K. S., & Fedak, M. A. (1991). Movements, diving and foraging behaviour of grey seals (Halichoerus grypus). *Journal of Zoology, 224*(2), 223-232.

Urdan, T. C. (1997). Examining the relations among early adolescent students' goals and friends' orientation toward effort and achievement in school. *Contemporary Educational Psychology, 22*(2), 165-191.

Van Gerven, P. W. M., Paas, F. G., Van Merriënboer, J. J. G., & Schmidt, H. G. (2002). Cognitive load theory and aging: Effects of worked examples on training efficiency. *Learning and Instruction, 12*(1), 87-105.

Vanlehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education*, *16*(3), 227-265.

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist*, *46*(4), 197-221.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, Mass.: Harvard University Press.

Walker, C. M., Zhang, B., & Surber, J. (2008). Using a multidimensional differential item functioning framework to determine if reading ability affects student performance in mathematics. *Applied Measurement in Education, 21*(2), 162-181.

Weber, K. (2008). How mathematicians determine if an argument is a valid proof. *Journal for Research in Mathematics Education, 39*(4), 431-459.

Wiggins, G. (2012). Seven keys to effective feedback. *Feedback*, *70*(1), 10-16.

Wijekumar, K., Meyer, B. J. F., & Lei, P. (2017). Web-based text structure strategy instruction improves seventh graders’ content area reading comprehension. *Journal of Educational Psychology, 109*(6), 741-760. http://dx.doi.org/10.1037/edu0000168

Wilkerson-Jerde, M. H., & Wilensky, U. (2011). Designed and Emergent Pedagogical Supports for Coordinating Quantitative and Agent-Based Descriptions of Complex Dynamic Systems. In *Proceeding of the 33rd Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education.*

Wolters, C. A. (2004). Advancing Achievement Goal Theory: Using Goal Structures and Goal Orientations to Predict Students' Motivation, Cognition, and Achievement. *Journal of Educational Psychology, 96*(2), 236-250.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89-100.

Yelland, N., & Masters, J. (2007). Rethinking scaffolding in the information age. *Computers & Education, 48*(3), 362-382.

APPENDIX A

ASSENT SCRIPT FOR STUDENTS

Study Title: Computer-based reading scaffolds to realize an equitable and effective STEM learning environment

Researcher contact information: Prof. Michael de Miranda (demiranda@tamu.edu)
Seoyeon Park (pseoyeon5@tamu.edu)

Howdy! We are a research team in the College of Education and Human Development Department at Texas A&M University. We are trying to learn new things and test new ideas. I am asking you to join a research study. A research study is a science project that is trying to answer a question.

This research study is trying to see if how our web-based tools can help students learn math concepts. To do this, I will ask you to use a software that we have developed. The study will last 1.5~2 hours.

You will be asked to …

- Respond to a 5-minute survey about perceived reading ability
- Take a 10-minute reading pre-test
- Take a 10-minute math pre-test
- Learn algebra with web-based tools
    - reading mathematical text which explains math concepts such as lines, equations, systems of equations, and others
    - filling in the blank of self-summary box tools
    - solving conceptual and procedural questions
- Take a 10-minute math post-test
- Respond to a 5-minute survey about the tools

You do not have to be in this research study. It is totally up to you. If you say yes now you can still change your mind later. No one will be upset if you change your mind.

I want you to ask any questions that you have. You can ask questions at any time. You can talk to your parents, or you can ask me questions.

Do you understand what I am saying? Do you want to be in this research study?

Please write your full name.

____

I can understand what I am asked to do in this study.

○ Yes

○ No

Are you willing to participate in this study?

○ Yes

○ No

APPENDIX B

INFORMED CONSENT FOR PARENTS

Study Title: Computer-based reading scaffolds to realize an equitable and effective STEM learning environment

Researcher contact information: Prof. Michael de Miranda (demiranda@tamu.edu)

Your child is invited to take part in a research study being conducted by Prof. Michael de Miranda, a researcher from Texas A&M University. The information in this form is provided to help you and your child decide whether or not to take part. If you decide to allow your child to take part in the study, you will be asked to sign this permission form. If you decide you do not want your child to participate, there will be no penalty to you or your child, and your child will not lose any benefits they normally would have.

Why is My Child being asked to be in this study?

A research study is usually done to find a better way to help or treat people or to understand how things work. You are being asked to take part in this research study because your child is an 8th or 9th grade student.

Why is this study being done?

The purpose of the study is to test the effectiveness of computer-based reading scaffolds on students' learning in math.

How long will the research last?

I expect that your child will be in this research study for about 1.5-2 hours.

What will My Child be asked to do in this study?

If it is okay with you and you agree to join this study, your child will be asked to follow the tasks listed below:

A. Respond to a 5-minute survey about perceived reading ability
B. Take a 10-minute reading pre-test
C. Take a 10-minute math pre-test
D. Use the computer-based scaffolded condition: Your child will then use one of three computer-based scaffolded conditions. Each condition includes text paragraphs that explain math concepts (line, slope, systems of equations), assessments, and self-summary boxes.

E. Take a 10-minute math post-test
F. Respond to a 5-minute survey about the tools

Your child's participation in this study will last up to 120 minutes.

What should I know about a research study?

Your child's participation in this research is completely up to you. It is your choice whether or not to be in this research study. If you decide your child do not want to participate, no one will be upset and there will be no penalty. You can ask all the questions you want before you decide.

What if I Change My Mind About Participating?

This research is voluntary and you have the choice whether or not to allow your child to be in this research study. Your child may decide to not begin or to stop participating at any time.

Could bad things happen to My Child?

The things that your child will be doing are no greater than risks than your child would come across in everyday life.

Could this research help My Child?

I cannot promise that this research will help you but we think that being in this research may help your child to learn math concepts and solve algebra questions.

What happens to the information collected for the research?

I will take steps to limit the use of your child's personal information, including research study records, to only the people who have a need to see this information. I cannot promise complete secrecy.

Will There Be Any Costs To My Child?

Aside from their time, there are no costs for taking part in the study.

Who may I Contact for More Information?

You may contact the Principal Investigator, Prof. Michael de Miranda, Professor and Department Head of Teaching, Learning, and Culture, to tell him about a concern or complaint about this research at 979-458-0808 or demiranda@tamu.edu.

If your questions, concerns, or complaints are not being answered by the research team; or you want to talk to someone besides the research team; or you have questions about your rights as a research participant. you may call the Texas A&M University Human Research Protection Program (HRPP) by phone at 1-979-458-4067, toll free at 1-855-795-8636, or by email at irb@tamu.edu

STATEMENT OF CONSENT

The procedures, risks, and benefits of this study have been told to me and I agree to allow my child to be in this study. My questions have been answered. I may ask more questions whenever I want. I do not give up any of my child's or my legal rights by signing this form. A copy of this consent form will be given to me.

What is your(parent) first name?

____

What is your(parent) last name?

____

What is your (parent) email address? We will contact you by email.

____

What grade is your child in?

____

Do you allow your child to participate in this algebra research study? (If you say no, we will not contact you further)

○ Yes

○ No

If you have any concerns or questions, please let us know.

____

APPENDIX C

INFORMED CONSENT FOR TEACHERS

Title of Research Study: Computer-based reading scaffolds to realize an equitable and effective STEM learning environment
Investigator: Prof. Michael de Miranda (demiranda@tamu.edu)
Funded/Supported By: This research is funded/supported by Texas A&M University.

Why are you being invited to take part in a research study?
You are being asked to participate because you have teaching experience in secondary mathematics.

What should you know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

Who can I talk to?
If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at 979-458-0808 or demiranda@tamu.edu

This research has been reviewed and approved by the Texas A&M Institutional Review Board (IRB). You may talk to them at at 1-979-458-4067, toll free at 1-855-795-8636, or by email at irb@tamu.edu., if

- You cannot reach the research team.

Your questions, concerns, or complaints are not being answered by the research team.

- You want to talk to someone besides the research team.
- You have questions about your rights as a research participant.
- You want to get information or provide input about this research.

Why is this research being done?
The purpose of the study is to test the effectiveness of computer-based reading scaffolds on students' learning in math.

How long will the research last?
We expect that you will be in this research study for 30-40 minutes.

What happens if I say "Yes, I want to be in this research"?
You will be asked to

- log in to the web-based tool (http://35.155.121.125/). Random ID and password will be given.
- Review "reading scaffold" condition of our web-based tool with your expertise
- Respond to the evaluation survey

You can participate in this research whenever and wherever you feel comfortable.

What happens if I do not want to be in this research?
You can leave the research at any time and it will not be held against you.

What happens if I say "Yes", but I change my mind later?
You can leave the research at any time and it will not be held against you.

What happens to the information collected for the research?
Efforts will be made to limit the use and disclosure of your personal information, including research study and other records, to people who have a need to review this information. We cannot promise complete privacy. Organizations that may inspect and copy your information include the TAMU HRPP/IRB and other representatives of this institution.

In this study, you will be asked about illegal activities or highly personal behavior. We have obtained a Certificate of Confidentiality from the federal government. However, we may still be required under certain circumstances to release your information.

What is your first name?

____

What is your last name?

____

Are you willing to participate in this web-based tool evaluation study?

- o Yes
- o No

If you have any concerns or questions, please let us know.

____

____

APPENDIX D

TOOL EVALUATION SURVEY FOR TEACHERS

You have been a teacher in

- ◯ Middle school
- ◯ High school
- ◯ Both Middle and High school

How do you feel about using computers in daily life?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Computers make my teaching work more interesting.	◯	◯	◯	◯	◯
Working with computers is fun.	◯	◯	◯	◯	◯
I like using computers.	◯	◯	◯	◯	◯
I look forward to those aspects of my job that require me to use computers.	◯	◯	◯	◯	◯

Please select the ‘reading scaffold’ condition and evaluate it.
The condition has three units – Line Basics, Writing Equations, and Systems of Linear Equations. Each unit has text paragraphs, questions to solve, and a summary box for students to fill in after reading the text.

We embed two scaffolds in this condition to promote students’ learning in algebra
1) Word images: Students can see the word images when they put the cursor on the words
2) Why questions: These questions allow students to think about the cause-and-effect relationships among concepts and principles.

How do you feel about using this tool?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
My interaction with this tool is clear and understandable.	○	○	○	○	○
I find it easy to get this tool to do what I want it to do.	○	○	○	○	○
Interacting with this tool does not require a lot of mental effort.	○	○	○	○	○
I find this tool easy to use.	○	○	○	○	○

If you can use this 'reading scaffold' condition in your teaching, how can this tool affect your teaching?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Using this tool will improve my overall teaching practices.	○	○	○	○	○
Using this tool will help me deliver the given content effectively.	○	○	○	○	○
Using this tool will help me prepare to teach the given content before the class.	○	○	○	○	○
Using this tool will help me teach mathematical concepts effectively.	○	○	○	○	○
Using this tool will help me teach how to solve math problems effectively.	○	○	○	○	○

If you have any other ideas about how this tool could affect your teaching, please let us know:

____

Describe how you feel concerning students using this tool to learn algebra.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Using this tool will improve students' learning outcomes.	○	○	○	○	○
Using this tool will help students learn mathematical concepts effectively.	○	○	○	○	○
Using this tool will help students learn effectively how to solve math problems related to the given content.	○	○	○	○	○

Which students can benefit most from this tool? (ex. Those with low math skills, reading skills, introvert, etc.)

____

____

If you have any concerns about this tool, please share with us.

____

____

If you have any more suggestions for the improvement of this tool, please share with us!

____

____

Thank you for your participation!

APPENDIX E

TOOL EVALUATION SURVEY FOR STUDENTS

First of all, thank you for participating in this research study!
We will ask some questions about how you feel using our web-based tool.
Thank you for your time and feedback!

What condition did you use?

- ○ Basic
- ○ Reading scaffold
- ○ Cognitive tutor

Display This Question:

If What condition did you use? = Basic

Or What condition did you use? = Cognitive tutor

When I read the text of each chapter (1~3) in the tool,

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I could understand the mathematical text in the chapter 1 (Line basics)	○	○	○	○	○
I could understand the mathematical text in the chapter 2 (Writing the equation of a line)	○	○	○	○	○
I could understand the mathematical text in the chapter 3 (Systems of Linear equation)	○	○	○	○	○

Display this question:

If What condition did you use? = Basic

Or What condition did you use? = Cognitive tutor

When I was solving questions below each chapter,

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
The examples of how to solve problems in the text were helpful	○	○	○	○	○
Filling summary box were helpful	○	○	○	○	○

Display This Question:

If What condition did you use? = Reading scaffold

When I read the text of each chapter (1~3) in the tool,

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
I could understand the mathematical text in the chapter 1 (Line basics)	○	○	○	○	○
I could understand the mathematical text in the chapter 2 (Writing the equation of a line)	○	○	○	○	○
I could understand the mathematical text in the chapter 3 (Systems of Linear equation)	○	○	○	○	○
The word images were helpful for understanding the corresponding words	○	○	○	○	○
The word images were helpful for understanding the math concepts in the text.	○	○	○	○	○

Display This Question:

If What condition did you use? = Reading scaffold

When I was solving questions below each chapter (conceptual and procedural questions),

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
The examples of how to solve problems in the text were helpful	○	○	○	○	○
Filling summary box were helpful	○	○	○	○	○
Solving 'Why questions' were helpful	○	○	○	○	○

How difficult was each section?

	Extremely easy (6)	Somewhat easy (7)	Neither easy nor difficult (8)	Somewhat difficult (9)	Extremely difficult (10)
pre-test	○	○	○	○	○
Ch1. Line basics	○	○	○	○	○
Ch2. Writing linear equations	○	○	○	○	○
Ch3. Systems of linear equations	○	○	○	○	○
post-test	○	○	○	○	○

If you have any suggestions or concerns when using this tool, please let us know.

____

____

____

Thanks for your participation!