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The Effectiveness of Cognitive Scaffolding in an Elementary Mathematics Digital Textbook*

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The purpose of this study is to find a way to improve digital textbooks for self-regulated learning by applying cognitive scaffolding designs to an elementary math digital textbook and examining the effectiveness of the system. Hence this study was conducted in two steps. First, a framework for scaffolding design was devised by examining the problems and difficulties students encounter when using a mathematics digital textbook. Second, after the digital textbook was revised by applying the scaffolding design frameworks, the effectiveness of the scaffolding framework was examined by comparing students' achievement levels in an experimental group and that of students in a control group. Seventy fifth-graders participated in this study. Students were divided into two groups: an experimental group and a control group. The students in the experimental group studied with the revised version of the digital textbook and the students in the control group studied with the original version of the digital textbook. The students received a pretest before the experiment. After the experiment, they took an achievement test and completed a usability questionnaire. The data were analyzed by ANCOVA with the SPSS Windows version. The results revealed that the students who used the revised program (to which design strategies for scaffolding were applied) showed higher levels of achievement than those who used the original version. In addition, students in the experimental group generally showed higher scores on the usability survey, which consisted of four sub-categories such as 'effectiveness', 'efficiency', 'satisfaction', and 'learnability'. There was a statistically significant effect on 'efficiency'. These results implied that scaffolding strategies were effective for mathematics learning through the use of an elementary digital textbook.

Keywords: Scaffolding, Digital textbooks, Design of digital textbooks, Mathematics learning.

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Introduction

In recent times, a promising innovation in public schools is the development of digital textbooks. Because of the advancement of mobile technology such as tablet PCs and smart pads, the common use of digital textbooks has become feasible. Digital textbooks have gained much attention in many countries because they are expected to free students from carrying heavy backpacks, reduce the production cost of textbooks and provide more dynamic and interactive books as replacements of traditional paper books (Kim & Jung, 2010; Lim, 2007; Maynard & Cheyne, 2005).

Digital textbooks originated from electronic books, which were paper books transformed to a digital form such as CD-ROMs, the internet and portable reading devices. The electronic book can offer added value to the printed book through its potential for including other media in addition to text (Maynard & Cheyne, 2005; McKierman, 2011). However, digital textbooks have special characteristics that differentiate them from e-books and other supplementary electronic materials.

First, a textbook is a core teaching/learning resource used in schools, which can make a great impact on the curriculum and the way of teaching and learning. However, the process of digitalizing paper-based textbooks cannot ensure effective learning (Guasco, 2003; Maynard & Cheyne, 2005; Mcfall, 2005). Therefore, the design and the development of a digital textbook should be rooted in theoretical foundations and empirical studies to enhance students' learning.

Second, digital textbooks can be used not only for teaching and learning in the classroom, but also for self-regulated learning outside of the classroom. According to the Education Ministry of South Korea, digital textbooks are defined as "core textbooks covering all kinds of learning materials, such as handbooks, workbooks, dictionaries, and reference materials, not to mention textbooks" (KERIS, 2007). Based on this definition, a digital textbook can be a good learning resource for students to study by themselves without the need for any other supplementary material.

However, at this stage, digital textbooks, at least the ones in South Korea, are far from what we actually want them to be. Digital textbooks for use in public schools in Korea are designed to copy traditional textbooks, which do not contain enough information for self-learning as reference books. In order to promote self-regulated learning as well as learning in the classroom, digital textbooks should be able to provide both sufficient information for students to understand by themselves as well as help and support according to their comprehension levels.

Furthermore, according to Azevedo and his colleagues' study (2008), learning with a hypermedia environment requires a student to regulate his or her learning. However, most students have difficulty in regulating their learning while they engage in learning activities in a hypermedia environment, which affects their learning of challenging topics (Aleve & Koedinger, 2000; Azevedo & Hadwin, 2005; Azevedo et al., 2008; Kirschner, Sweller, & Clark, 2006; Lazonder & Rouet, 2008). When students use electronic resources, they are likely to spend less time for learning and engage in learning activities superficially (Shepperd, Grace, & Koch, 2008; Wallace, Kupperman, Krajcik, & Soloway, 2000). These results imply that in order to enhance self-regulated learning through the use of digital textbooks, just-in-time help and support need to be incorporated into the digital textbooks.

One method for improving students' regulation of their learning when using digital textbooks may be to provide them with scaffolds. The concept of scaffolding, a form of help or support in which a learner is able to manage his or her learning and complete a task which cannot be completed without it (Brown & Palinscar, 1989; Wood, Brunner & Ross, 1976; Young, 1997), suggests guidelines for how to provide appropriate support for learning using digital textbooks.

There have been a number of studies on scaffoldings, but few studies have explored scaffolding strategies to support learning with digital textbooks. Scaffolding is a way to increase students' cognitive level to that of experts by closing the gap between the level of skills required to complete the task and the current level of skills of the students (Greenfield, 1984). Therefore, in order to support students' learning, we need to understand students' cognitive process for learning and problems that students confront when they study with digital textbooks.

In this context, this study attempted to find a way to design scaffoldings for digital textbooks by examining the problems and difficulties that students encounter when studying with a digital textbook and examine the effectiveness of the scaffoldings. Also, this study tried to examine if the effectiveness of scaffolding was different among students' achievement levels. This study assumed that low-level students would benefit the most from the scaffolding.

Theoretical Background

Digital Textbook

'Digital textbook' is a fairly new term, so there are not many public definitions for it. A well-known definition was released by the Korean government because Korea is a pioneer in the design and development of digital textbooks nationwide. According to the Education Ministry of South Korea (KERIS, 2007), 'digital textbooks' are defined as 'the digitalized forms of printed textbooks, which can be read, seen and listened to through wired or wireless networks'. Also, they are defined as 'core textbooks covering all kinds of learning materials, such as handbooks, workbooks, dictionaries, and reference materials, not to mention textbooks'. As seen by these definitions, it is an inevitable fact that digital textbooks are electronic textbooks used in schools to assist teaching and learning.

Digital textbooks are expected to promote the user's convenience by integrating various types of multimedia resources for academic lessons. By quickly adopting the changes of knowledge and information, it is possible to both adjust and supplement the contents of the textbooks more easily and reduce publication costs. For these reasons, many countries, including the United States, Canada, and South Korea have embarked on 'Digital Textbook Projects' to adopt the widespread use of digital textbooks (Kim & Jung, 2010; Mardis & Everhart, 2011; Salpeter, 2009).

Since digital textbooks are stemmed from electronic books which have been converted into digital form, there have been numerous studies on the design issues and effectiveness of electronic books (or electronic textbooks) compared with printed books (Guasco, 2003; Maynard & Cheyne, 2005; McFall, 2005; Shepperd, Grace, & Koch, 2008; Wilson, Landoni, & Gibb, 2003). The results showed that the mere digitalization of printed textbooks cannot guarantee effective learning (Guasco, 2003; Maynard & Cheyne, 2005; McFall, 2005).

Digital textbooks can promote convenience and learning effectiveness with additional functions such as navigation, multimedia and learning supports with the advantages of printed textbooks (Byun, Choi, & Song, 2005). Although the effectiveness of digital textbooks depends on the quality of the digital textbooks, theoretical and empirical studies on the design of digital textbooks have been rarely conducted. Therefore, more researches on the design issues of or guidelines for digital textbooks need to be implemented.

Scaffolding

Scaffolding is a form of help or support in which a learner is able to manage his or her learning and complete a task which cannot be done without it (Brown & Palinscar, 1989; Wood, Brunner & Ross, 1976; Young, 1997). Literally, scaffolding means a structure made of long poles and thick boards which are built around a construction site to help construction workers carry building materials for the purpose of construction. The scaffolding used in the teaching and learning environment has the same function as the one used at a construction site. In other words, scaffolding helps the learner to become successful and expand his or her ability in a new field, but it needs to be removed when the learner becomes more responsible for his or her task.

Traditionally, scaffolding is provided through social interaction in which a more knowledgeable person, such as a parent or tutor, supports students in their learning (Wood, Bruner, & Rose, 1976). In a classroom, a teacher mainly provides scaffolding through the classroom lessons, which is known as teacher-enhanced scaffolding. A teacher can provide dynamic scaffolding by continuously observing the learning process of the learner and identifying the learner's level or needs through interactions with the learner. However, the teacher-enhanced scaffolding is challenging in a self-regulated learning situation and in a class of many students with various needs (Raes, Schellens, Wever, & Vanderhoven, 2012). This is the reason that the scaffolding provided by technology is an important resource.

In a technology environment, such as a digital textbook learning environment, a computer can take on the teacher role. The computer can predict the learner's response and provide various types of scaffolding in a stable and continuous manner; this is known as the technology-enhanced scaffolding. However, the technology-enhanced scaffolding has a limit in providing the learner with the dynamic or instant support rendered by a teacher and a fading effect when the learner no longer needs scaffolding (Belland, Glazewski, & Richardson, 2008).

Therefore, the design and development strategies of scaffolds in a technology environment have become a major issue. Several researchers have discussed how they designed and implemented scaffolds to promote students' learning. Bull and his colleagues (1999) suggested that scaffolding could be provided online via techniques such as visual cueing, links to web pages with directions, downloadable help pages and communication forms to contact the instructor or peers. Prompts are another way to provide scaffolds in a computer-based environment. Prompts are defined as measures to induce and stimulate cognitive, metacognitive, motivational, and/or cooperative activities during learning; these measures vary from hints, suggestions, reminders, and sentence openers to questions (Morris et al., 2010). They can be displayed on the screen at certain times in the learning process.

In the same context, Bell and Davis (2000) found that cognitive scaffolding such as prompts and task decomposition can assist in learning important scientific practices. Quintana (2002) sought to assess the ability of learners to use a suite of scaffolding tools for science inquiry, and provided scaffolds for decomposing the tasks, managing artifacts, and hiding complexity. The research on Model-It showed a variety of scaffolds such as process map, articulation textbook, and dynamic test scaffolds that helped students to investigate science problems (Fretz et al., 2002; Jackson, Krajcik, & Soloway, 1998). Research provides evidence that it is possible to improve individual learning in a technology environment by implementing appropriate question and reflection prompts that trigger students to activate their cognitive processes (Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008).

Since the types of scaffolding in a technology environment are diverse, Hannafin and his colleagues (1999) categorized the types of scaffolds provided in ill-structured problem-solving environments as (a) conceptual (help with what to consider), (b) metacognitive (how to manage the learning process), (c) procedural (how to use tools), and (d) strategic support (what strategies to use in approaching the problem). In addition, the Michigan team divided scaffolds into three types: (a) supportive scaffolding (support for doing the task without changing the task itself), (b) reflective scaffolding (support for thinking about the task), and (c) intrinsic scaffolding (support that changes the task by reducing the complexity of the task or by providing mechanisms for visualizing concepts) (Jackson, Krajcik, & Soloway, 1998). These studies provide guidelines for what and how to design scaffolding in a technology environment.

Meanwhile, scaffolding can be divided into cognitive and affective types according to the related purposes and contents. The cognitive type of scaffolding promotes the learner's understanding, while the affective type of scaffolding motivates the learner (Collins, 1988, 1993; Yelland & Masters, 2007; Yu & Park, 2008). According to Boyer, Philips, Willis, & Vouk’s study (2008), providing the affective scaffolding only did not have a constructive influence on the learning. The cognitive scaffolding effect was statistically significant in the achievement of learning. Also, when only the cognitive scaffolding was presented rather than it being presented together with the affective scaffolding, there was a higher level of achievement. Such a result reflects the fact that the cognitive scaffolding is more important in regard to the learning effect. In this context, this study mainly focused on the issue of design and development strategies of the cognitive scaffolding in the technology environment with digital textbooks.

Scaffolding and Mathematics learning

Mathematics is a difficult subject. This problem of mathematics lies in its special characteristics. First, mathematics includes very abstract and generalized concepts (Skemp, 1987). Mathematics requires conceptual and higher order thinking because of its high abstractness and generality, which means just acquiring mathematical skills cannot guarantee the understanding of mathematical concepts. Learners who mastered mathematical skills but did not completely understand mathematical concepts would fail in the continuous learning (Whitehead, 1939).

Second, mathematics cannot be learnt directly from the everyday environment. It requires different terms and thoughts from everyday life. Even worse, it uses similar or even identical names in different meanings from everyday life.

These problems often result in misconceptions and confusions among preexisting concepts, and to inappropriate reversions to the use of traditional notions of everyday life (Reif, 1987).

Third, mathematical concepts have highly structured hierarchies in which higher order concepts are built on the lower order concepts. Therefore, learners need to have prior knowledge before proceeding to the next learning. The lack of prior knowledge may result in continuous failures in mathematical learning (Skemp, 1987). These problems of mathematics which may result in difficulties and misconceptions need to be overcome by appropriate scaffoldings. The unit of 'division of fraction' in the 6th grade mathematics used in this study is one of the difficult topics for the students to learn at elementary schools (Bitter, Hatfield, & Edwards, 1989). Many learners show misconceptions in the operation of 'division of fraction.' Furthermore, the unit is difficult to be rendered into digital textbooks because the tasks require complex operations and higher order thinking (Ma, 1999; Pang & Lee, 2009). Therefore, in order to make learners overcome the difficulties and misconceptions, cognitive scaffoldings followed by the systematic analysis on the contents and misconceptions need to be provided.

A Scaffolding Framework for Mathematics Digital Textbooks

In order to find scaffolding design strategies in digital textbooks, the author implemented an experiment to understand the problems and difficulties that students encounter when they study mathematics using a digital textbook. In order to represent all the levels of students, eighteen 6^{th} grade students were selected from three different levels (high, middle, low) based on their nationwide standardized achievement test scores, from two digital textbook model schools (a school in a suburban area and a school in a rural area).

Researchers observed and videotaped students' self-learning with a mathematical digital textbook. The students were asked to think aloud their thoughts and feelings during their learning process. Then they were interviewed after learning and were asked about their learning difficulties using the digital textbook. The data from the experiment were transcribed and analyzed by the researchers.

Based on the literature review and the observation of students' learning, a design framework for the scaffolding of a math digital textbook was produced. The design framework was then divided into two categories: scaffolding principles related with content and scaffolding principles related with digitizing. The design framework is summarized in Table 1.

Table 1. A scaffolding framework for mathematics digital textbooks

Design principle of scaffolding	Design strategies
I. Scaffolding principles with content	
1) Prevent misconceptions caused by the discrepancy between mathematical concept and real life	■ Clarify the differences in the statement of math problems. ■ Provide examples and hints.
2) Provide information about prior knowledge.	■ Provide hint for prior knowledge. ■ Provide feedback to correct errors. ■ Hyperlink with related contents or previous units.
3) Support awareness and clarification of learning objectives.	■ Present learning objectives at the beginning of lessons ■ Allow access to learning objectives anywhere. ■ Provide feedback to confirm learning objectives.
4) Allow students to select levels of practices.	■ Provide menu to select of levels of practices. ■ Organize problems from easy to difficult ■ Present complex problems step by step.
5) Support problem solving processes.	■ Provide hints to solve problems. ■ Visualize problem solving processes. ■ Provide information or feedback on problem- solving process.
6) Provide a chance to clarify ideas and thinking	■ Provide learning worklog, notes, or templates.
II. Scaffolding principles related with digitizing	
1) Present multimedia related with learning contents.	■ Present graphics or animations to facilitate understanding.
2) Organize multimedia functions in an easy-to-understand way	■ Provide information on Menu ■ Provide information on button or hypertext ■ Provide operating functions in a user-friendly way. ■ Provide clear guidance
3) Provide help in responding to questions	■ Require easy response in digital media. ■ Provide hints or examples for answers. ■ Provide multiple ways of response, such as text, graphic, or audio, etc.)
4) Provide functions to acknowledge the current place.	■ Provide outlines, site maps, or contents.

Scaffolding principles related with content

Prevent misconceptions caused by the discrepancy between concepts and real life

In the observation of students' learning, the students had difficulties in understanding mathematical concepts because of the discrepancies between the concepts and real life. According to constructivism, the real life context is very important to understanding the learning contents (Duffy & Jonassen, 2002). However, in science and math, some everyday life experiences may lead to misconceptions. For example, in the textbook, there was an activity to find the answer to '5/6 divided by 2/6'. Students were asked to divide a graphic bar by 2/6 m in order to find the answer and find the quotient and the remainders. The answer was 2 pieces and a half. However, more than half of the students answered '3 pieces' or '2 pieces and 1/6'. One of the reasons was that the question required the students to apply different cognition from that used in everyday life. In real life, people would tend to think the bar is divided into 3 pieces regardless of the size of each piece. However, for this question, the students had to find the answer of the exact size of the slice, which was not precisely written in the question. Therefore, to prevent misconceptions, scaffoldings, such as examples and hints about the differences between the concepts and everyday cognition, need to be integrated into digital textbooks.

Provide information related with prior knowledge

In the observation, many students, especially those at a lower level, had difficulties in math learning due to their lack of prior knowledge. When analyzing the wrong answers in the practice session, several students showed difficulties when expressing a natural number divided by a natural number as a fraction because they were confused about which number becomes the denominator and which number becomes the numerator. This process required the students to recall prior knowledge because they had learned the concept in the previous year.

Since a requirement of deep understanding is the integration of new information with existing knowledge, a program needs to encourage the use of prior knowledge (Shapiro, 2008). Prior knowledge is especially more important in mathematics learning because it involves strict hierarchies among concepts. That means if students failed to grasp concepts in previous learning, they tend to fail to proceed to the learning of subsequent concepts more easily. Therefore, it is critical for students to recall prior knowledge or provide information about it before the main learning process. Prior knowledge can be provided by the scaffoldings, such as hints and feedback on problem tasks, or hyperlinks to previous units (Shapiro, 2008).

Support awareness of learning objectives

During the observation, some students made errors by neglecting the learning objectives. Learning objectives play an important role in guiding the learning direction (Shapiro, 2008). Especially, learning objectives are important in math because the answers to problems can be changed according to the learning objectives. For example, in the observation, some students used decimals when they sought the answer with the division of fractions. This problem seemed to result due to the sequence of lessons in the curriculum. The students had learned how to express the quotients of a natural number divided by a natural number as decimals before this unit. Therefore, when they saw the division problem, they naturally recalled the expression of decimals although the learning objectives of this lesson were about the division of fractions. This interference caused the students to have difficulties in finding the right answers. Therefore, learning objectives needs to be presented at the beginning of the lesson and can be recalled properly whenever needed. This can be supported by a menu or feedback on learning objectives.

Allow students to select the levels of practices

Students' achievement levels can vary according to their prior knowledge and learning experiences in mathematics. Especially, because of the characteristics of hierarchical structure, there is a wide gap among students in terms of their achievement levels. Furthermore, the difficulties of learning tasks need to be changed along with learners' achievement. One way to solve this problem is to provide an opportunity for learners to select the levels of practices when they practice mathematical problems (Shapiro, 2008). Also, it is required to present information on the difficulty level of the problem, i.e., 'from easy to difficult', to motivate learners (Shapiro, 2008).

Support problem solving processes

Mathematical thinking requires multiple steps of the application of concepts or principles to solve a problem. Understanding a concept or a principle cannot guarantee the correct solution to a problem. Sometimes, the wrong application of a concept or a principle can turn out to be the right answer. In the observation, some students had displayed misconceptions because no feedback on the problem-solving process had been given. Some students arrived at the correct answer although their problem-solving process had been wrong, which caused them to keep using the wrong problem-solving process whenever they confronted similar problems. These cases imply that information about the problem-solving process is required. For complex problems, hints or visualization of the problem-solving process (for example, a process map) would be useful to help learners (Puntambekar & Hubscher, 2005; Quintana et al., 2002). Simplifying the complex task step by step is another way to support problem solving (Bell & Davis, 2000; Rose & Meyer, 2002).

Provide a chance to clarify ideas and thinking

It is possible to promote learning by having learners articulate their thoughts or ideas while engaging in problem solving (Belland et al., 2008). Learners can articulate their thoughts either verbally or graphically. In the case of math, learning can progress only when learners firmly understand the learning tasks in a unit before they move on to another unit. Therefore, it is important for students to have an opportunity to express their thoughts with their own language or methods. For this, work-logs, notes on the learning process, or templates for problem-solving processes can be used (Bell & Davis, 2000). Since learners' preferences may vary, it is appropriate to provide them with multiple ways to express their thoughts and ideas (Rose & Meyer, 2002). These scaffolds need to be integrated into the system and recalled when needed.

Scaffolding principles related with digitizing

Present multimedia related with learning contents

One of the advantages of digital textbooks is that they can include multimedia resources to supplement the limitation of printed textbooks. Research shows that students' learning can be promoted when information is presented in various modes, such as text, graphics, animations, simulations, etc. (Rose & Meyer, 2002). However, the use of multimedia resources itself does not guarantee effective learning, and such implementation needs to be carefully designed. In the observation, some animations in the digital textbook resulted in students' misconceptions due to the showing of wrong examples. In addition, some graphics and animations were not necessary to help the students understand the learning tasks. Multimedia resources should be logically related with the learning content and provide necessary information for problem solving to promote effective learning (Quintana et al., 2002).

Organize multimedia functions in an easily understandable way

In digital textbooks, menus and multimedia activities, such as animations or simulations, should be well-designed and easy to use. They should be organized in a way that allows students to easily find necessary information and understand the operations of the system, which aims to minimize the chances of overloading the learner's cognitive system (Mayer & Moreno, 2002). Students tend to learn more deeply when their visual and/or verbal working memories are not overloaded. Therefore, pictures and animations should be concise and unnecessary words and sounds should be eliminated.

The students in the observation had difficulties in using animations because it was hard to understand how to operate them. Students had to cut the graphic bar by dragging the divided pieces to the prepared slots. However, since the pieces moved only when they were double-clicked, which was not a common action, many students gave up on the activity after a couple of trials. This example shows the importance of multimedia design. This problem can be improved by providing embedded scaffoldings that clearly indicate how to use the animation and how doing so will help students reach their goals (Belland et al., 2008; Shapiro, 2008).

Provide help in responding questions

The ways of answering questions in digital textbooks should be changed from those in printed books. The math digital textbook used in this study required the same response types of questions as those in printed textbooks, such as writing numbers in a box or writing answers to open-ended questions using a stylus pen or the keyboard. However, writing numbers or sentences with a pen in digital textbooks was not as easy as performing such actions in printed books. Furthermore, the system did not offer any feedback on the writings, because the computer could not recognize handwriting resulting from the use of a stylus pen. This implies that response types need to be considered in different ways from those in printed books and organized in such a way that makes the responding process easy.

Another problem related with answering was that most students had difficulties in responding to open-ended questions. Students were asked to write answers to "Why do you think so?" or "Find out the way to calculate ~." Although students knew the answers to the questions, they had problems in expressing their thoughts and ideas. Therefore, it is necessary to provide scaffoldings for the responses such as hints, examples, and sentence starters. In addition, some students preferred speaking out the answers to writing them on the screen. This can be supported by providing multiple means of expression, such as audio and graphics as well as text (Rose & Meyer, 2002).

Provide functions to acknowledge the current place

One of the disadvantages of digital textbooks is that it is hard to see the contents all at once. Therefore, in digital textbooks, students need to be guided to where they are in the system. In the math digital textbook used in the observation, there was no site map or menu of the learning contents. Some students were confused about what they were learning and what they had learned before the unit. Especially, since math is a very hierarchical subject, several scaffoldings, such as outlines, site maps, or contents are required to be used in the digital textbooks (Quintana et al., 2002; Belland et al., 2008).

Methods

Participants

A total of 70 fifth-graders from an elementary school located in a suburban area participated in this study. The school was one of the biggest digital textbook model schools of Korea and managed three digital textbook pilot classes out of 7 classes. All of the students of the three pilot classes participated in this study. They had been using the digital textbook for more than one semester, so they were skillful in utilizing digital textbooks.

Participants were randomly divided into two groups: an experimental group that used a revised program with cognitive scaffolding and a control group that used the original program. 38 of them were male and 32 of them were female. They were volunteers and filled out consent forms before their participation.

Before the experiment, the students were given a pretest in order to confirm that all participants had little knowledge of the topic and the two groups had the same condition. The results showed that there were no significant differences between the experimental group (M=7.86, SD=1.31) and the control group (M=6.27, SD=1.32) in the pretest scores (F=.729, p=.396).

Research tools

Achievement Test

Students received a paper-and-pencil achievement test as a pretest and a posttest. The pretest and the posttest were identical. The achievement test consisted of 20 items (10 items for the 1st lesson and 10 items for the 2nd lesson). The items were made based on the textbook by a content expert and reviewed by another content expert and an instructional designer. The reliability of the achievement test was Cronbach' α= .97.

Usability questionnaire

After the experiment, students were asked to respond to a usability questionnaire. The questionnaire was designed to measure the usability of the digital textbook programs based on the usability literature review (Finstad, 2010; Shackel, 2009). It consisted of a total of 20 items with four categories: effectiveness ('how effective it is to accomplish the desired goals'), efficiency ('how much it streamlines the learning process), satisfaction ('how much people enjoy using the program'), and learnability ('how easy it is to understand and learn'). Each category consisted of 5 items. Students were asked to score them from 1(strongly disagree) to 5(strongly agree). Two instructional designers reviewed the questionnaire to verify its validity. The reliability of the questionnaire was Cronbach a=.90.

Learning Materials

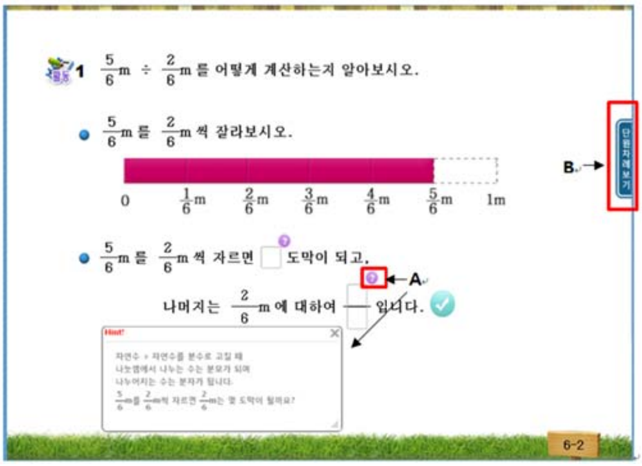
The program with scaffolds was developed according to the design framework. The newly developed program had the same contents as the original version, but several scaffolding functions were added. The scaffolding features and contents were examined by two instructional designers and a content expert. Usability test for the program was conducted with six elementary students. The system was implemented in the Windows of the Tablet PC.

The chapter of 'Division of Fraction' in the 6th grade mathematics was used in this study. That is the one of the arithmetic areas which is difficult to be developed into digital textbooks and a difficult material to be taught at elementary schools (Bitter, Hatfield & Edwards, 1989; Kim, 2009). It requires students to use various kinds of knowledge in a complicated way (Ma, 1999). Even, it is not easy to find related examples in our daily life (Cheon & Park, 2003). Furthermore, the parts related to the reciprocal numbers of divisors and the multiplication of such numbers in the division of fraction require a high level of understanding (Bang & Lee, 2009) Therefore, it is the mathematical area in which cognitive supports are necessary. In the study, students studied the lesson 1 'division of fraction with the same denominator' and the lesson 2 'division of fraction with the different denominator'.

The following table and figures show the examples of scaffolding strategies implemented in the revised version.

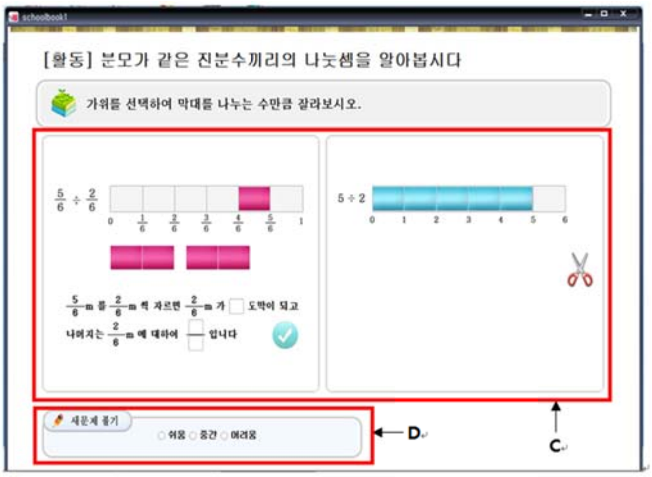
Table 2. Examples of scaffolding strategies implemented in the scaffolding program

Design principle of scaffolding	Design strategies in the scaffolding program
I. Scaffolding principles with content	
1) Prevent misconceptions caused by the discrepancy between mathematical concepts and real life.	■ An animation related with calculating the numbers of ribbons using the division of fractions to wrap Christmas gifts was provided as a real-life example.(Fig.1.C) ■ Hint buttons to explain the gap between the concept and real life were provided.
2) Provide information about prior knowledge.	■ When a student hit a wrong answer, a hint button to recall the prior knowledge necessary for problem solving was presented.(Fig.1.A) ■ When a student hit a wrong answer, a hyperlink with related contents or previous units was provided.
3) Support awareness and clarification of learning objectives.	■ A contents button was added to show the learning objectives and the outline of the unit. ■ Feedback to confirm the learning objectives was provided on the related wrong answer.
4) Allow students to select levels of practices.	■ In the exercise section, a menu for selecting the levels of practices was presented.(Fig.1.D) ■ The difficulty levels of practice problems were presented as ranging from easy to difficult. ■ A complex problem-solving process was broken down into small units and presented step by step.
5) Support problem-solving processes.	■ Information on problem-solving processes was presented in the form of hints.(Fig.1.A) ■ A note for problem solving was provided.(Fig.1.E) In the note, a 'show the problem-solving process' button was inserted to provide help by visualizing problem-solving processes.(Fig.1.E')
6) Provide a chance to clarify ideas and thinking.	■ A note for problem solving was provided. In the note, a 'save' button was inserted to allow students to look back at the note when they needed to check previous answers or memos.(Fig.1.F)
II. Scaffolding principles related with digitizing	
1) Present multimedia related with learning contents.	■ Animations which are not related with learning contents were deleted and replaced by those that are necessary to understand the learning contents.
2) Organize multimedia functions in an easy-to-understand way.	■ An awkward task for the practice section was replaced by an authentic task (ribbon cutting with scissors).(Fig.1.C)
3) Provide help in responding to questions.	■ Radio buttons for 'Yes/No' were inserted in open-ended questions.(Fig.1.G) ■'Sentence starter' and 'Hint' buttons were added to help students write answers to open-ended questions.(Fig.1.G')
4) Provide functions to acknowledge the current place.	■ A contents menu was added to show the learning objectives, outline of the unit and the current pages.(Fig.1.B)



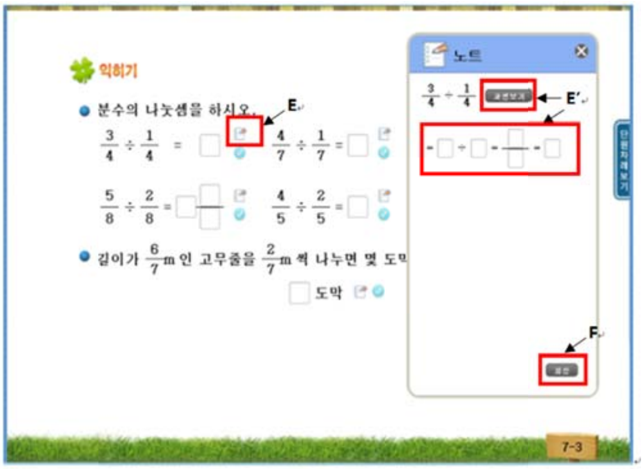
A. *I.2) Provide information related with prior knowledge* & *II.3) Provide help in responding to questions:* Hint buttons are inserted to show the prior knowledge related to the problem.

B. *I.3) Support awareness of learning objectives* & *II.4) Provide functions to acknowledge the current place*: A contents button was added to show the learning objectives and the outline of the unit.



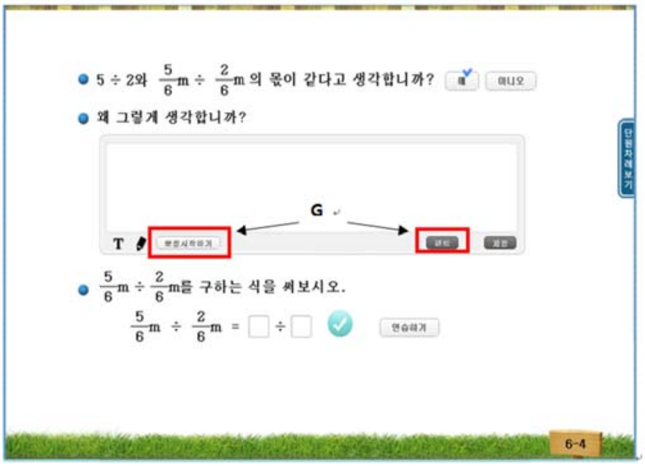
C. *I.1) Prevent misconceptions caused by the discrepancy between concepts and real life.* & *II.2) Organize multimedia functions in an easily understandable way: An animated activity was changed from 'moving blocks' to 'Cutting a ribbon' which is an easy-to- operate authentic task in everyday life.*

D. *I.4) Allow students to select levels of practices*: A 'solving new problems' button was added to allow student to practice the problem according to their comprehension levels.



E. *I.5) Support problem solving processes:* A Note button was inserted to provide a note for problem solving and a 'show the process' button was provided in the note to show the problem solving process (E').

F. *I.6) Provide a chance to clarify ideas and thinking*: In the note, a 'save' button was inserted to allow students to look back at the note when they need to check previous answers or memos



G. *II.3) Provide help in responding to questions*: The 'Sentence starter' and 'Hint' buttons were added to help students write answers to open-ended questions.

Figure 1. Examples of scaffolding strategies implemented in the revised version.

Procedure

For the experiment, students from the three classes were randomly assigned into two groups: a treatment group and a control group. The day before the experiment, researchers installed the different digital textbook programs on the participants' Tablet PCs according to the assignment: the revised version (with scaffoldings) for the treatment group, the original version for the control group.

Right before the experiment, a researcher per each class explained the purpose and the process of the experiment and implemented a pretest on the learning content. After that, participants studied by themselves (without any instruction from a teacher) the unit of 'Division of fraction' with digital textbooks. A researcher per each class observed the learning process and provided explanations or help when students had difficulties in operating the program.

The unit consisted of two lessons. Participants spent 30 minutes for the 1st lesson and then received a posttest for the 1st lesson. After a two-hour break including lunch time, they studied the 2nd lesson and received a posttest for the 2nd lesson and a usability questionnaire. After the experiment, 18 students from the respective achievement levels of high, middle, low participated in a group interview, in which participants were asked about the thoughts and feelings about the digital textbook programs they used. The achievement levels were categorized based on the final exam scores of the semester on math and 2 students on each level in each class were randomly selected. The interview lasted about 20 minutes. Researchers prepared a structured interview sheet and asked about the thoughts and feelings in using the programs in general.

Data analysis

All the data were analyzed by SPSS Windows 12.0. The pretest result was analyzed by t-test and the posttest result was analyzed by ANCOVA. In addition, 2-

way ANCOVA was used to measure the interaction effect between the type of program and the students' achievement level. The final exam scores in math were used to divide students into three achievement levels of high, middle, and low. Also, the t-test was used to analyze the usability questionnaire. The interview data were collected according to the interview questionnaire sheet and summarized with Excel.

Results

Results of Achievement Test

Result on the achievement test according to the types of program

To measure the students' achievement, ANCOVA was computed with the pretest score as a covariate. The result of the achievement test revealed that a significant difference was found between the experimental group (total M=15.11) and the control group (total M=10.91) (F=6.30, *p*=.015). It suggested that the experimental group gained higher degree of achievement, which means cognitive scaffolding was effective for the mathematical self-learning using the digital textbook.

Table 3. Descriptives of the achievement test

	Total		Lesson1		Lesson2	
	M	SD	M	SD	M	SD
Experimental group (n=37)	15.11	6.06	8.11	3.26	7.27	3.59
Control group (n=33)	10.91	7.74	5.03	4.50	5.88	4.07

Table 4. The ANCOVA result of the achievement test

	SS	*df*	MS	F	*p*
Model	1493.01	2	745.53	24.34	.000
Prior knowledge	1185.518	1	1185.518	38.656	.000***
Type of program	193.152	1	193.152	6.30	.015*
Residual	2054.777	67	30.67		
Total	3547.843	69			

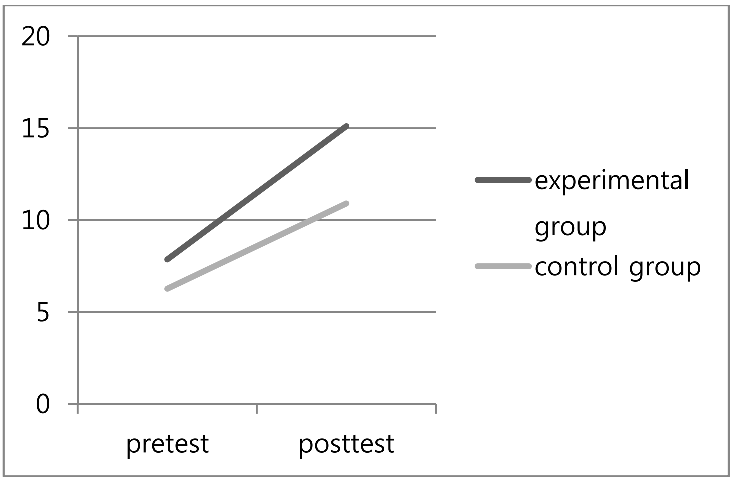


Figure 2. Line graph illustrating pre and posttest descriptives

In addition, in order to find out if the program effect is different among students' achievement levels, the two-way ANCOVA was conducted. However, the result revealed that there was no significant effect between the treatment (experimental group and control group) and the students' achievement levels (high, middle, and low) (F(2, 63)=0.25, *p*=0.975). Although, the major effect of the achievement level was found, which means students who had a high achievement level showed the best result (total M=16.12) and students who had a low achievement level showed the worst result (total M=7.76) regardless of the program types. Also, all levels of students showed significant increases of achievement in the experimental group (scaffolding program) and the rate of increase was almost identical. This implies that cognitive scaffolding was effective evenly for high, middle, and low level students.

Table 5. Descriptives of the achievement test scores according to students' levels

Levels		Total		Lesson1		Lesson2	
		M	SD	M	SD	M	SD
high	Experimental group (n=17)	17.88	3.33	9.41	1.70	8.47	2.55
	Control group (n=16)	14.25	7.27	6.75	4.24	7.50	3.37
	Total (n=33)	16.12	5.80	8.12	3.42	8.00	2.97
middle	Experimental group (n=9)	16.89	4.11	9.78	0.44	8.22	3.38
	Control group (n=7)	10.29	6.55	3.57	4.50	6.71	3.45
	Total (n=16)	14.00	6.13	7.06	4.28	7.56	3.39
low	Experimental group (n=11)	9.36	6.99	4.73	3.95	4.64	3.98
	Control group (n=10)	6.00	7.02	3.30	4.30	2.70	3.95
	Total (n=21)	7.76	7.04	4.05	4.08	3.71	3.99

Table 6. The 2way ANCOVA result between the treatment and students' level

	SS	*df*	MS	F	*p*
Main effect					
Prior knowledge	558.952	1	558.952	20.277	.000***
Treatment	178.176	1	178.176	6.483	.013*
Students' level	313.615	2	156.808	5.688	.005**
Interaction effect	z				
Treatment x Students' level	1.39	2	0.69	.025	.98
Residual	1736.675	63	27.566		

* p<.05, ** p<.001

Results of usability test

To measure the usability of the programs, a questionnaire was given at the end of the experiment. The questionnaire consisted of a total of 20 items with four categories of 'effectiveness', 'efficiency', 'satisfaction', and 'learnability' and each category consisted of 5 items.

Table 7. Descriptives of the usability test

	Effectiveness		Efficiency		Satisfaction		Learnability	
	M	SD	M	SD	M	SD	M	SD
Experimental group (n=37)	21.65	2.71	22.22	2.70	22.51	2.23	20.68	2.82
Control group (n=33)	21.30	3.16	20.48	3.02	21.85	3.38	19.51	3.15
T-test	.49		2.53		.98		1.63	
p-value	.64		.014*		.34		.11	

$^{*}p<.05$

The result showed that generally the experimental group showed higher scores in every category. However, there was a statistically significant effect only on 'efficiency'. The experimental group showed a higher score than the control group on the 'efficiency' (t=2.53, p=0.014). This means that the cognitive scaffolding program was proven effective by simplifying and streamlining the learning process.

This tendency was supported by the results of the focus group interview. To complement the results of the survey questionnaire, a focus group interview was conducted. 18 students from the three achievement levels (6 students from each level of high, middle and low from each group) participated in the interview. The students were asked about their thoughts and feelings about the digital textbook programs they had used. An open-ended interview questionnaire asking students about their experience using and the usefulness of the program, their difficulties in using the program, their favorite parts of the program, and their opinion about things to be improved in the program was prepared before the interview.

In general, there were no differences in the students' feelings about the program between the experimental group and control group. The students in both groups answered that the program was interesting and fun to use for learning. However, there were some different ideas about the question asking about the usefulness and favorite part of the program. The students in the experimental group answered that hints about the answers and the note feature were the most helpful and easy to use. On the other hand, the students in the control group answered that they had experienced difficulties in using the program because there had been no help or hints about the answers and it had been inconvenient to write memos on the screen. These results imply that the cognitive scaffolding was effective for simplifying and streamlining the learning process.

Discussion and Conclusion

The purpose of this study was to find a way to improve an elementary mathematics digital textbook by providing guidelines on the scaffolding design for digital textbooks. Since a digital textbook can be a useful resource for self-regulated learning as well as classroom learning, it needs to be designed to support students learning with scaffolds. Although there have been many of studies on scaffolding, few studies have provided general guidelines for designing scaffolds for digital textbooks, especially for elementary mathematical learning. Furthermore, in the sense that scaffolding is an organized process of "reducing the scope for failure in the task" that the learner is attempting to achieve (Maybin, Mercer, & Stierer, 1992, p.188), it was necessary to understand students' cognitive process for learning and the problems that students confront when they use digital textbooks. Therefore, based on the literature review and the observation of students' learning process with an elementary mathematical digital textbook, a scaffolding design framework for a mathematical digital textbook was developed.

The scaffolding design principles from this study can be a guideline for similar subjects, such as science. However, some principles, such as the importance of prior knowledge, the learning objectives, and the clarification of ideas and thinking, can be commonly applied to other subject areas. Therefore, more research on the application of the scaffolding design principles to other digital textbooks needs to be conducted in the future.

After the scaffolding design framework was developed, an elementary mathematical digital textbook was redesigned with scaffolding and the effectiveness of the scaffolding design framework was measured. Participants were divided into two groups (the experimental group who used the scaffolding program and the control group who used the original program) and took an achievement test and completed a usability survey.

The results showed that the cognitive scaffolding design framework was effective in learning mathematics with a digital textbook. The experimental group gained a significantly higher degree of achievement than that of the control group. This implies that cognitive scaffolding was effective for mathematical learning using the digital textbook. In the usability survey, students were asked about their thoughts and feelings about the program, in specific, its 'effectiveness', its 'efficiency', its 'learnability' and their 'satisfaction'. The results showed that the experimental group showed a significantly higher score than the control group on the program's 'efficiency'. This means that the scaffolding program simplified and streamlined the learning process, which contributed to the effectiveness of the students' learning. There are some limitations of this study. First, since this study was conducted in a self-learning situation, the effectiveness of the digital textbook can differ when it is used in a classroom setting. Some functions of cognitive scaffoldings can be provided by a teacher in the classroom and some features, such as checking answers and providing hints for problems, can keep students from focusing on classroom learning. Moreover, several studies reported that the role of the teacher is still crucial even in the technology-supported learning environment (Raes, Schellens, Wever, & Vanderhoven, 2012; Schetz & Stremmel, 1994; Yelland & Masters, 2007). Therefore, future research on the use of the scaffolded digital textbook in everyday classroom settings is needed.

Second, it is expected that low-level students would benefit the most from scaffoldings. However, the result showed no differences among students' levels. This result might have been due to the self-regulated and experimental learning situation. Low-level students might have found it more difficult to study through self-learning than studying in the classroom because they lack self-regulated learning skills. Research shows that high-level students tend to benefit more in a learner-control situation than low-level students (Azevedo et al., 2008; Kirschner et al., 2006). Moreover, low-level students may need affective scaffoldings as well as cognitive scaffoldings because they tend to possess low self-esteem and motivation for learning. Additionally, human interactions with the teacher may be important especially for low-level students because the teacher can dynamically monitor their learning processes and help them to overcome their lack of domain knowledge as well as their low self-esteem (Kim & Hannafin, 2011; Raes et al., 2012). Therefore, the scaffolding strategies to encourage low-level students' learning achievements need to be explored further in various aspects.

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