Education Tech Research Dev (2012) 60:159–173
DOI 10.1007/s11423-011-9222-5

DEVELOPMENT ARTICLE

Improving the usability of the user interface for a digital textbook platform for elementary-school students

Cheolil Lim · Hae-Deok Song · Yekyung Lee

Published online: 13 October 2011

Abstract Usability is critical to the development of a user-friendly digital textbook platform interface, yet thorough research on interface development based on usability principles is in short supply. This study addresses that need by looking at usability attributes and corresponding design elements from a learning perspective. The researchers used a student survey, log files, and an expert heuristic evaluation to analyze needs for revision in the user interface of the existing Korea Education Research Information Service digital textbook platform. After using suggestions derived from this analysis to develop a new platform prototype, they tested its user interface for usability through a cognitive walk-through and a formative evaluation. The results show that the usability design elements identified through the use of this iterative design and evaluation model were essential to improving the usability of the user interface and thus facilitating users' actions and learning processes.

Keywords Usability testing · User interface · Digital textbook platform · Learning perspective · Iterative design and evaluation

C. Lim
Department of Education, Seoul National University,
Gwanak_1, Gwanak-ro, Gwanak-gu, Seoul 151-742, Korea
e-mail: chlim@snu.ac.kr

H.-D. Song (✉)
Department of Education, Chung-Ang University, Heukseok-dong, 221,
Dongjak-gu, Seoul 156-756, Korea
e-mail: hsong@cau.ac.kr

Y. Lee
Graduate School of Education, Sogang University, Shinsu-dong, 1,
Mapo-gu, Seoul 121-742, Korea
e-mail: ylee5@sogang.ac.kr

Introduction

Recent advances in information technology have led to increased interest in digital textbooks delivering digitally enhanced content. Digital textbooks started out as electronic books that transferred paper-based content to digital form and have evolved into teaching and learning support systems equipped with numerous tools to help learners explore, build, apply, and share knowledge (Rao 2003). Digital textbooks now incorporate a plethora of features supporting student learning, such as note-taking tools, memo pads, writing and highlighting tools, messenger services, discussion boards, navigation tools (e.g., bookmarking, page search/scroll, and course selection), screen-capture capabilities, textbook display options, and search tools.

A digital textbook platform is an underlying computer system on which application programs can run. It provides a framework for designing, developing, implementing, and managing digital textbooks and executing application tools within those textbooks. Students gain access to the content and interact with other students through the platform interface. Disordered displays, complicated procedures, and inadequate feedback within the user interface can lead to poor performance and learning dissatisfaction (Shneiderman and Plaisant 2009). As more functions are integrated into digital textbook platforms through advances in digital technology, their use becomes more complicated and various usability problems arise in their interfaces (Tullis and Albert 2008). Thus, it is important to design a user-friendly platform interface that will help users navigate this complexity and perform learning tasks comfortably and successfully (Koohang and Ondracek 2005).

Usability design elements for the digital textbook platform user interface

Usability is critical to the development of a user-friendly interface because it helps users to work in an effective, efficient, and manageable way (Crowther et al. 2004; Wilson and Landoni 2003). A measure of the quality of human–computer interaction (Corry et al. 1997; Matera et al. 2006), usability is not a single, one-dimensional property of a user interface but subsumes multiple components with a variety of measurable attributes (Rubin 1994; Tullis and Albert 2008; Welie et al. 1999). Shackel (1991) proposed four: learnability, effectiveness, flexibility, and user satisfaction. Nielsen (1993) insists on five: learnability, a low error rate, efficiency, memorability, and satisfaction. The International Standardization Organization (ISO) 9241-11 lists only effectiveness, efficiency, and satisfaction (ISO 1998).

Although different attributes are emphasized by different researchers, four appear over and over in the literature (ISO 1998; Lee et al. 2006, Tullis and Albert 2008): learnability (the degree of learning needed to accomplish tasks), effectiveness (the ability of users to complete a task successfully), efficiency (the amount of effort required to complete a task), and satisfaction (the degree to which a user is comfortable with and accepting of his or her experience).

Previous studies on usability have suggested specific usability design principles as well. Nielsen (1993) proposed using simple and natural dialogue, speaking the user's language, minimizing user memory load, striving for consistency, offering feedback, marking exits clearly, providing shortcuts, using effective error messages, preventing errors, and providing help and documentation. Shneiderman and Plaisant (2009) produced eight similar rules for designing human–computer interfaces: striving for consistency, creating universal usability, offering informative feedback, designing dialogs to yield closure, preventing errors, permitting easy reversal of actions, supporting an internal locus of control, and reducing short-term memory load.

Specific design principles such as these can be inferred from each of the general attributes of usability (Folmer and Bosch 2004; Seffah et al. 2001). Dix et al. (1998) suggest, for instance, that the design factors contributing to increased learnability include predictability, consistency, familiarity, generalizability, and synthesizability, so to facilitate learnability, the user interface should be designed to meet the user's expectations and be consistent in terms of function and visual display (Baxley 2003; Nielsen 1993). To increase efficiency, the interface should be designed to minimize the user's memory load and help the experienced user operate the system with flexibility and speed (Ardito et al. 2006; Hu et al. 2008). To increase effectiveness, the interface should be designed to prevent errors, enable prompt recovery from errors, provide adequate feedback or help in problem solving, and make the internal operations of the system observable to users (Ardito et al. 2006; Hu et al. 2008). Finally, to increase user satisfaction, the interface should be designed to allow students control over their learning and to meet their aesthetic needs (Baxley 2003).

Developing usability design principles from a learning perspective

Since the purpose of a digital textbook platform is to support learning, it is critical to take a learning perspective when developing usability design principles. Usability features should both allow users to efficiently manipulate the digital textbook platform and facilitate their achievement of intended learning outcomes. Thus, a major challenge for designers is to develop a user interface that engages users in learning (Ardito et al. 2006). However, the pedagogical aspects of digital textbook design have been neglected in previous studies (Nokelainen 2006). Most usability studies on digital textbooks (Chong et al. 2009; Gingras et al. 2008; Wilson and Landoni 2003) pass over learning activities in favor of technical aspects of usability such as design preferences or ease of use of the physical devices used to read eBooks (e.g., Kindle) (Chong et al. 2009). For instance, a comparative analysis of e-readers (Son Reader, Adobe Acrobat Professional, Amazon Kindle, MBooks, Polymer ReadiUS) evaluates usability in terms of battery life, e-reader weight, display technology, ergonomics, and annotation/highlighting capabilities (Gingras et al. 2008). Preferences related to navigation design, page layout, and content design have been studied as well (Chong et al. 2009). These studies yield results that reflect problems occurring during "reading" rather than during "learning."

This study aims to remedy that situation. Although usability design principles that put the focus on learning have not been specifically identified or described before, ideas can be gleaned from the characteristics of digital textbook learning, pedagogical usability criteria, theories on cognition, and multimedia design guidelines. One of the key features of digital learning is that it is self-directed because it allows students to choose content related to their interests (Dhanasegaran 2006). Pedagogical usability features include learner control, learner activities, collaborative learning, goal orientation, added value, motivation, valuation of previous knowledge, flexibility, and feedback (Nokelainen 2006). These features are dependent on minimization of memory load, meaningful encoding, and user control. Guidelines for the design of user interfaces conducive to learning can be gleaned from theories on cognition, such as cognitive load theory (CLT), and multimedia design guidelines. The basic premise of CLT is that instruction should be designed to make learners focus on content, by reducing load caused by factors external to that content. Poorly designed instructional material involves high extraneous load generated by the way the material is presented to the learner (Sweller 2010). Good design principles will reduce extraneous load by clarifying processes for using applications, presenting information on a single screen rather than spread across multiple screens, and having interfaces reflect the

existing knowledge structure of the user. In the design of multimedia learning materials, Mayer (2009) suggests, design principles such as deleting extraneous words and graphics, highlighting essential words, and placing essential words next to corresponding graphics on the screen will help to reduce extraneous processing. Design principles such as these incorporate knowledge about how people learn into the development of user interfaces by supporting self-directed learning, providing learners with control over their learning activities, and integrating learning tools that decrease extraneous load.

Systematic development of a user interface

It is critical to take a systematic approach to improving usability. A systematic approach helps designers to identify design problems, elicit user requirements, design a user-friendly system architecture, appraise the completed systems and prototypes, and evaluate them methodically for usability (Hung et al. 2010). However, to date, researchers and developers have mainly focused on collecting data from users' experiences of inconveniences and have been updating their platforms based on these reports (Seo and Woo 2010). This unplanned approach is limited in that it does not begin with discovering valid usability problems and generating appropriate design specifications based on those problems; it can therefore result in disorganized and confusing interfaces that may cause students to misunderstand how platforms are intended to be used. Thus, a systematic guide that addresses user needs, system requirements, and the development process holistically needs to be applied in improving the usability of digital textbook platform user interface.

Purpose

The primary purpose of this study was to identify usability design principles conducive to learning and demonstrate how they can be systematically applied to the development of user interfaces for digital textbook platforms by describing how the user interface of the Korea Education Research and Information Service (KERIS) digital textbook platform was improved from a learning perspective. The following questions guided the study:

1. What usability design elements can be suggested by looking at the improvement of the user interface for the digital textbook platform from a learning perspective?
2. How can the user interface of the digital textbook platform be improved by taking a systematic approach? Specifically, what revisions are needed, from the students' point of view, and what are the experts' recommendations regarding the existing digital textbook user interface? What changes should be made to the user interface to improve its usability? What problems might students encounter in carrying out new tasks using the improved interface? What is the value of the improvements in usability, from a learning perspective?

Methods

The context of the project

The KERIS digital textbook platform, developed as a national project in Korea in 2007 for the purpose of providing digital content, includes subject content as well as tools for sharing and managing annotations, highlighting, displaying multimedia content,

bookmarking, importing and exporting files, editing text and images, and conducting formative evaluations. As the capacity of digital textbooks to support classroom learning has increased, so has the need for user interfaces to be revised based on learning principles. The KERIS platform was examined to see how easy it made it for students to carry out desired actions and how helpful it was in aiding them to learn content. Thus, the objectives of the study were to analyze the need for revisions to the existing platform user interface and to develop a new interface by testing for usability.

Data was collected from fifth- and sixth-grade students because the digital textbook had been developed on a trial basis for those grades only. Four schools were selected from twelve digital textbook model schools designated by the Korean Ministry of Education. Two were located in a metropolitan city area, one in a mid-sized city, and one in a rural area. All data except for student surveys were collected from one metropolitan elementary school located in Seoul due to its geographical proximity to the researchers in this study.

Research design

An "iterative design and evaluation model" (Hartson et al. 2001) was used to improve the user interface of the KERIS digital textbook platform. The model-based approach consisted of four stages: (1) identifying the design elements of user interfaces from previous studies on usability and digital textbooks; (2) analyzing the need for revision of the user interface of the existing KERIS digital textbook platform; (3) designing a new user interface for the platform; and (4) evaluating the user interface prototype. Throughout these stages, students' and experts' ideas and reactions were collected and analyzed to help in the development of an appropriate platform user interface for the digital textbook.

Research procedure

As shown in Table 1, the researchers employed a variety of methods to improve usability during the different phases of the project. A literature review suggested important attributes of usability and corresponding design elements. A questionnaire, log files, and an expert heuristic evaluation allowed the researchers to determine which features of the existing user interface were in need of revision. The questionnaire was completed by 158 fifth-grade students and 166 sixth-grade students, for a total of 324 students at four elementary schools. The researchers analyzed the log files of ten fifth-grade and ten sixth-grade students at one school in a metropolitan area to identify students' patterns of action in using the digital textbook. In addition, seven professors of instructional technology participated in an expert heuristic evaluation to come up with design recommendations for improving the user interface. A new user interface prototype was designed based on the findings from the analysis and this prototype was evaluated twice for usability. Six fifth- and six sixth-grade students participated in a cognitive walkthrough to allow the researchers to evaluate critical tasks within the new user interface, and a formative interview evaluation with ten fifth- and ten sixth-grade students randomly selected from one participating school provided further ideas for improvements.

Identifying design elements related to usability

To be more specific, the researchers identified learnability, effectiveness, efficiency, and satisfaction as the main attributes of usability. They extracted usability design elements from these attributes and then re-examined them from a learning perspective based on

Table 1 Methods, purpose, numbers of participants, and methods in the study

Phase	Purpose	Participants	Methods
Identifying design elements	Identify attributes of usability and their associated design elements	Researchers	Literature review
Analyzing the need for revisions to the user interface	Analyze students'need for revisions to the existing digital textbook platform	324 5th- and 6th-grade students from four elementary schools	Survey
	Analyze problematic actions in using digital textbook	Ten 5th-grade and ten 6th-grade students at one participating school ($n = 20$)	Log file analysis
	Identify recommendations for improving the usability of the user interface for the digital textbook platform	Seven professors of instructional technology whose specialty is in digital textbooks	Expert heuristic evaluation
Designing the user interface prototype	Create a new user interface prototype	Researchers	Design elements
Evaluating the user interface	Evaluate high-frequency and critical tasks included in the new user interface by tracking users' cognitive reactions	Six 5th-grade and six 6th-grade students at one participating school ($n = 12$)	Cognitive walkthrough
	Evaluate users' thoughts about reactions to the newly designed platform interface	Ten 5th-grade and ten 6th-grade students at one participating school ($n = 20$)	Formative interview evaluation

relevant literatures related to digital learning environments, pedagogical usability criteria, theories on cognition such as CLT, and multimedia learning design guidelines. From a learning perspective, self-directedness, learner control, and learner activities are key. These factors were combined with the four attributes of usability and developed into nine learning-related usability principles. Learnability was associated with two design elements: agreement with user expectations and consistency. Efficiency was associated with two design elements: convenience of operation and minimization of memory load through screen design. Effectiveness was associated with three design elements: error prevention, advice and help information, and feedback. Satisfaction was associated with two design elements: aesthetic design and user control. A questionnaire was developed based on these design elements. The instrument included nine items scored on a 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). (e.g., "All of the functions of the digital textbook work as I expected"; "The menus of the digital textbook are easy to use"; "There is informative feedback that guides me when I make mistakes"; "I can easily create my own menus"). The questionnaire was then administered to ten fifth- and ten sixth-grade students to improve its readability.

Analyzing the need for revisions to the user interface

Three methods were used to determine the types of revisions to the user interface that were needed. A questionnaire was administered to 324 students at four elementary schools; students who had over a year of experience using KERIS digital textbooks were chosen to participate in this study because they had sufficient knowledge and skills to answer

questions about the usability of the platform. The user interface was examined through an analysis of the log files of ten fifth-grade and ten sixth-grade students who were randomly selected from among the participants from one metropolitan area school. Data were collected during a one-hour session with an English digital textbook. Morae software (http://www.techsmith.com) was used to save and analyze the students' use of menu buttons and note any repeated errors or unexpected behaviors. An expert heuristic evaluation was conducted to identify problems and improve the user interface of the platform. Seven experts specializing in digital textbook research and development offered ideas to improve the usability of the user interface.

Designing the new user interface prototype

The findings from the analysis were categorized and used in the development of a new layout and new functions for the interface. The design suggestions were developed by programmers into an actual prototype platform to be used in the usability testing stage.

Evaluating the new user interface prototype

The prototype was examined in two steps: a cognitive walkthrough and a formative interview evaluation. The cognitive walkthrough is a method that tracks users' cognitive reactions as they perform real tasks (Shneiderman and Plaisant 2009; Wharton et al. 1994). Major tasks were selected, action sequences were defined for each task, and those action sequences were organized in a storyboard format. Six fifth- and six sixth-grade students were asked to carry out the selected tasks, and their actions and thoughts were analyzed. Through this process, the researchers were able to identify users' mistake-related behaviors and determine the reasons for their failures.

A formative evaluation using interviews was conducted to ascertain users' thoughts about and reactions to the newly designed platform interface. Users were given two different interfaces: the existing user interface and new user interface. First, the existing user interface was presented along with explanations of its major functions. Next, the new user interface was presented along with descriptions of the changes that had been made. Students' reactions to the changes were recorded. These reactions were further analyzed to verify the strengths of the new user interface and come up with ideas for improvements. However, because only students' perceptions on the usability of the new prototype were examined, the formative evaluation results were limited in that data related to learning activities were not collected.

Results

Identification of the revision requirements of the existing user interface

A survey was administered to analyze students' needs in terms of revisions to the existing digital textbook platform. Table 2 presents the mean scores and standard deviations for the nine design elements. The results indicate that students perceived the usability of the existing user interface differently according to the design element identified. The lowest scored design element in terms of usability was error prevention ($M = 3.34$, $SD = .84$). Advice and help information ($M = 3.43$, $SD = 1.09$), feedback ($M = 3.53$, $SD = .82$), convenience of operation ($M = 3.59$, $SD = .75$), and user control ($M = 3.89$, $SD = 1.02$)

Table 2 Mean scores and standard deviations for nine design elements

Usability attributes	Usability design elements	*N*	*M*	*SD*
Learnability	Agreement with user expectations	308	3.69	1.26
	Consistency	243	3.67	.77
Efficiency	Convenience of operation	216	3.59	.75
	Minimization of memory load through screen design	304	3.85	.72
Effectiveness	Error prevention	253	3.34	.84
	Advice and help information	303	3.43	1.09
	Feedback	244	3.53	.82
Satisfaction	Aesthetic design	278	3.65	.84
	User control	296	3.89	1.02

followed. The results showed that students needed support to help them avoid errors, required help information and feedback in order to decrease the number of errors they made, and were in need of a more convenient user interface.

A log file analysis uncovered problematic actions that were difficult to discern from observations or student interviews. Several action patterns were found. For instance, students had difficulty finding the loading bars because these were located behind the text window; they tended to click on the help window several times to seek further information even when no feedback was provided. This analysis of students' actions made it possible to analyze their frequent error patterns or problems and to use these patterns to revise the user interface.

The results of the expert heuristic evaluation suggested several ways of improving the usability of the user interface for the digital textbook platform. To increase learnability, the participating experts suggested that the icons be revised because the icons in the Toolbox and the Status Progress bars were not arranged based on their similarities and thus were not recognized spontaneously. To increase efficiency, they suggested that the menus be restructured because the difference between the Lessons Menu and the Additional Menu was unclear. They reported that the Note and Memo options in the Toolbox menu did not work properly, requiring more operations than expected. To increase effectiveness, they suggested that guidance be provided to prevent errors, that feedback on selected menus be provided via a notification window, and that help information be placed in an appropriate location. To increase satisfaction, they suggested that shortcut menus be created to allow students to add functions according to their own interests and that the colors and tones used in the menus be revised.

Development of the new user interface prototype

Based on the results of the expert heuristic evaluation, a new user interface prototype was developed in the form of application software so that students would be able to use it. Figure 1 shows sample screens from both the existing digital textbook platform and the newly designed user interface prototype.

Many changes were incorporated into new user interface. Most importantly, the structure of the menus was changed. The user interface of the existing KERIS digital textbook platform consists of four main menus: (A) Lessons, (B) Additional, (C) Toolbox, and (D) Status Progress. The Lessons provides access to the instructional content and includes lists of contents, notes, bookmarks, and lesson hints. The Additional enables users

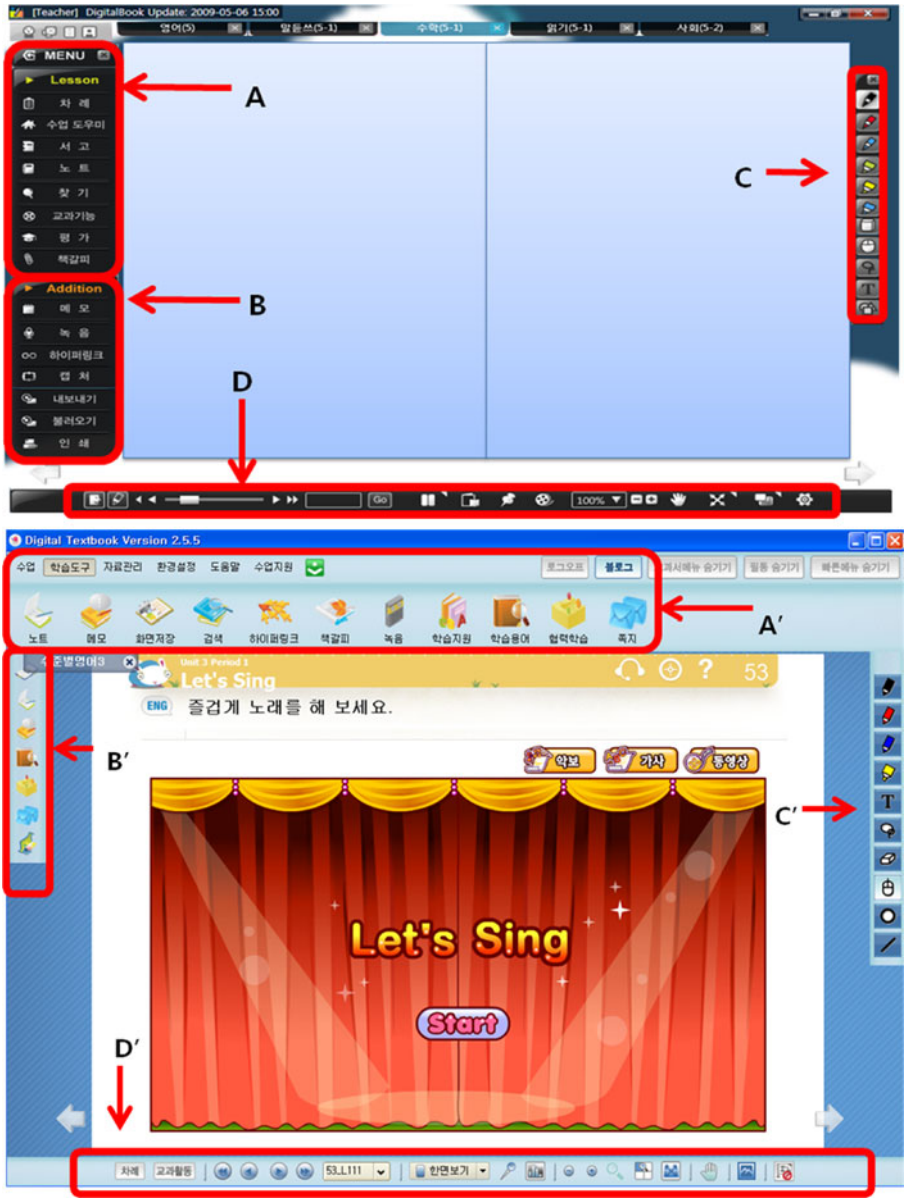

Fig. 1 Sample screens that show the existing and new user interfaces for the KERIS digital textbook platform

to access learning activities that will help them to edit their learning content. It includes memo, recording, hyperlink, capture, and print options. The Toolbox enables students to write memos and draw lines or diagrams on the screen with the use of a stylus. It includes pen, highlighted pen, remover, text box, and diagrams options. The Status Progress bar is located at the bottom of the screen and includes page navigation, multimedia play, and page viewing options.

The newly designed user interface has a different menu structure, with (A′) Basic, (B′) Shortcuts, (C′) Toolbox, and (D′) Viewer menus. The new Basic menu integrates sub-functions from both the old Lessons menu and the old Additional menu and contains new functions related to digital textbook learning activities. It consists of six sub-menus: Instructional Tools, Learning Tools, Data Management, Settings, Help, and Instructional Management. Particularly, the Learning Tools in the new Basic menu include a variety of functions that students use frequently during digital textbook learning, including Note, Memo, Screen Capture, Dictionary, Search Engine, Hyperlink, Index, and Recordings. Shortcuts was added to help students to save frequently used icons or menus. The old Toolbox menu was retained in the new user interface. The Viewer replaced the Status Progress bar in this new user interface and contains the functions that move digital textbook pages or adjust display settings.

To increase agreement with user expectations in terms of learnability, various menus were re-categorized, and the names of menus and icons were changed to better represent their purposes. Menus, buttons, and screen structure, as well as colors and terms on the digital textbook screen were made more consistent.

To increase convenience and efficiency of operations, URLs are provided when students click on hyperlinks. A new shortcut menu allows students to choose the functions that they use most often. To minimize memory load through screen design, thumbnails were added to allow users to move to different pages quickly. An announcement window was placed at the center of the screen to allow students to find it easily. It had been reported that the menus, which were originally on the left side of the screen, interfered with the main text, so their default location was moved to the top of the screen for the new prototype.

To increase effectiveness, various new functions were added for error prevention. Help information was provided for various keyboard shortcuts. A dictionary was added to aid students with difficult terms used in the digital textbook. New types of guidance and feedback were programmed to appear right after an error is reported. Feedback was added for selected menus and completed activities to allow students to easily check their progress.

To increase aesthetic satisfaction, background colors, fonts text styles, and icons were re-designed. The original digital textbook platform was a bit dark overall. The background was made a little brighter, the icons were re-designed to better represent their purposes, and their size was increased to allow them to be recognized more easily; for instance, the buttons used for minimizing, maximizing, and closing the digital textbook were made bigger. In addition, the display resolution was increased to show text and colors more clearly. To increase user control, students were enabled to add icons of their choosing to the shortcut menu. An Undo option was added under the Memo and Note functions to give students more control over their progress.

Evaluation of the new user interface prototype

A formative evaluation and a cognitive walkthrough of the new user interface prototype were conducted. For the cognitive walkthrough, ten frequently used and newly added tasks were selected. These involved page navigation, shortcut menu creation, note writing and saving, memo writing, screen capture, page enlargement, undoing actions, changing the color of the highlighting pen, diagram drawing and deleting, and changing text sizes and fonts. The steps required to complete each task were identified based on reviews by the researchers. These steps were then transferred onto a storyboard. Finally, a group of six fifth- and six sixth-grade students participated in a cognitive walkthrough of the steps. The

students were asked to determine what problems they might encounter in carrying out the required tasks and to identify the reasons that they failed to complete certain steps. Four questions were provided to help them to do this: (1) Did you understand the purpose of the operation?, (2) Did you understand the operations embedded in the user interface in the form of menus or buttons?, (3) Did you select the operations that were pertinent to the achievement of your objective?, and (4) Did you receive feedback if you carried out the operations correctly? Was the feedback valid?

The results indicate that students had difficulty adding shortcuts due to the complexity of the procedure, writing memos due to the small area provided for that purpose, capturing screen shots because of a lack of instruction on how to do this, and adjusting areas for screen capture due to the fixed area provided. The prototype was revised according to the problems identified. After the first revision of the user interface prototype based on the findings from the cognitive walkthrough, a formative evaluation of the prototype user interface was conducted by showing the prototype to users and collecting feedback. The existing user interface was first presented to allow students to identify problems, and then the new user interface was presented.

Students received explanations of how the existing and new user interfaces differed in terms of their functions and menus, menu structures, names for menus and icons, and background colors, styles, and icons and were asked to rate the value of the improvements and to record additional opinions. Table 3 presents the results of the interviews, summarized according to the design elements.

The results of the formative evaluation indicate that students perceived the new interface as user-friendly. First, in terms of learnability, students were able to use the interface as expected because functions were categorized and arranged based on their similarities. Students were better able to intuitively discern the functions of the icons because ambiguous icons had been revised, and they found the interface more manageable because of the systematically increased font and button sizes. In terms of efficiency, students perceived the new user interface as convenient due to the changes in the locations of the menus and because of the shortcut menu, which allowed them to access frequently used functions. They appreciated that currently selected menus were clearly displayed. In terms of effectiveness, new functions such as increased mouse areas were successful in decreasing error rates. Students perceived feedback more clearly because they were able to easily recognize the currently selected menus. They also considered new functions such as Hint and Dictionary useful for their learning. In terms of satisfaction, students appreciated the Shortcuts menu because they were able to add their preferred menus and arrange them according to the learning situation. They perceived the new user interface as attractive because more menu colors were provided and a variety of menus were integrated into the top menu bar, which meant that more work spaces were available.

Discussion

Although design principles have been suggested for user interfaces in a variety of technological environments, including computer-assisted instruction platforms (Seo and Woo 2010), websites (Hu et al. 2008; Corry et al. 1997), cell phones (Lee et al. 2006), and electronic books (Chong et al. 2009; Wilson and Landoni 2003), few researchers have specifically considered principles for enhancing the design of user interfaces for digital textbooks used in classroom settings. This study identified four usability attributes for the digital textbook platform: learnability, efficiency, effectiveness, and satisfaction. These

Table 3 User test results for the user interface prototype

Design elements	User test results (strength)
Agreement with user expectations	Easy to perform expected functions because a variety of functions were categorized and arranged based on their similarities
	Easy to recognize the functions of the icons intuitively because the icons were revised
Consistency	Pen, Diagram Drawing, and Line Drawing tools were systematically revised in the Toolbox
	Different icons are provided for Toolbox menus such as Diagram and Line
	Increased font size systematically
Convenience of operations	Decreased number of procedures required to carry out operations
	Easy to move and operate the menu bars
	Easy to access the frequently used menus with shortcuts
	Easy to preview and go to pages with thumbnail menus
	Easy to navigate to next and previous pages with new icons
	A variety of menus, such as Memo, Learning Tools, and File Rooms added to make operations run more smoothly
Minimization of memory load through screen design	Easy to find icons with the change of menu locations
	Easy to work with newly designed icon buttons for minimizing, maximizing, and closing screens
	Easy to find menus due to clearer indications
Error prevention	Decreased errors with increased response areas for mouse selections
Advice and help information	Easy to understand advice and information with detailed explanations and shortcuts
Feedback	Easy to acquire feedback by highlighting selected menus
	Easy to track work progress using loading bars
Aesthetic design	More work space on the left side of the screen because the menu bar is placed at the top
	Increased size for menus, fonts, and images
	Menus color-coded for easier identification
User control	Easy to get back to index menu with esc key
	Easy to reach icons through shortcut menu; better satisfaction of student needs

attributes are consistent with findings from previous studies (ISO 1998; Lee et al. 2006; Tullis and Albert 2008).

Looking at issues of usability from a learning perspective, the researchers proposed nine design elements based on a review of previous work on digital learning environments, pedagogical usability criteria, theories of cognition, and multimedia design guidelines. These design elements were agreement with user expectations, consistency, convenience of operation, minimization of memory load through screen design, error prevention, advice and help information, feedback, aesthetic satisfaction, and user control. The students perceived the user interface that was designed based on these elements as helpful in supporting self-directed learning, allowing them to control their learning activities, and decreasing extraneous load. Although this study examined only students' perceptions of the usability of the new prototype and did not collect data on their learning progress; the

formative evaluation results show that that the design elements listed above can be used to address learning issues by facilitating users' actions and learning processes. Given that very few of the user interface design principles suggested in the past have come from a learning perspective, this study is important in that it provides researchers and designers of digital textbooks and eBook platforms with meaningful design elements that can diagnose users' learning problems and contribute to user interfaces that are more conducive to learning.

Improvements in the usability of the digital textbook platform user interface were achieved systematically through the use of an iterative design and evaluation model. Using the approach of Hartson et al. (2001) as a framework, the researchers analyzed the need for modifications to the existing user interface, designed a new interface prototype, and conducted a formative evaluation. Usability testing is most powerful when implemented as part of an iterative development process that includes designing, testing, and redesigning (Rubin 1994), so, unlike previous studies on usability, which focused mainly on updating platforms based on data from users' experiences of inconvenience, this study went through a cycle of usability testing beginning with a needs assessment and ending with a post-task interview. The improvement was accomplished in four stages: identifying the design elements of user interfaces, analyzing the revision requirements of the existing digital textbook platform, designing a new user interface, and evaluating the new user interface. The systematic design approach of this study can provide designers with a guide to detecting needs for revision and shaping a user interface to fit users' needs by paying attention to the critical progress on the development of instructional material.

A variety of usability testing methods contributed to the systematic development of the new digital textbook platform user interface. Specifically, to diagnose the need for changes to the existing user interface, three methods were employed: student questionnaires, a log file analysis, and an expert heuristic evaluation. To identify potential problems before the prototype was complete, two methods were used: a cognitive walkthrough and formative evaluation. The varied methodologies used in this study will provide designers with tools that will be useful for the systematic development of user interfaces for other technological environments by providing logical processes for discovering and prioritizing usability problems, developing recommendations to revise existing user interfaces, and testing the usability of proposed interface prototypes.

The results of this study suggest several areas for future research. First, a coherent pedagogical framework should be developed to make the continued development of usability design principles more systematic from a learning perspective. In this study, design elements for the user interface of the digital textbook platform were extracted from various sources focusing on learning-related topics such as digital learning environments, theories on cognition such as CLT and multimedia learning, and pedagogical usability criteria. The identified design elements seem to have enhanced usability from a learning perspective because of their emphasis on the student's active role as a learner and their support of learning activities. However, their implications may be inconsistent since they were not based on a single, coherent theoretical perspective. If future studies were to examine design principles with a specific theoretical underpinning, the finding could be more consistently applied in the design of user interfaces.

Second, data related to learning activities should be examined. Only students' usability-related responses were considered in this study. Future research should incorporate learning tasks in specific subject areas in order to further validate the effectiveness of the usability design principles identified here.

Third, the identified usability design elements should be tested with students of different ages. This study involved only elementary-school students. Future studies should

investigate the same design elements in terms of usability by students of different ages, such as middle-school students.

Fourth, a variety of new tools should be developed to facilitate student learning. For this project, for instance, a shortcut menu helped students to maintain control over their learning activities by allowing them to save frequently used icons, and a Learning Tools menu offered functions to facilitate learning such as information search tools and writing tools. More work should be done to create affordable learning tools to help students identify and use functions with a minimum of attention and effort.

Additional research on improving usability for teachers is needed as well. In this study, several menus and icons were created to assist teachers with digital textbook instruction, but teachers' needs were not addressed systematically during the development of the user interface. Reflecting on teachers' perspectives can help instructional designers to arrive at a more balanced understanding of usability. Therefore, future research should examine teachers' acceptance of digital textbooks, their skills for using them, their perceptions about their pedagogical value, and their other views and observations regarding the usability of these tools in order to incorporate the findings into the development of new user interfaces.

Lastly, alternative usability testing methods should be examined. A systematic method based on an iterative design and evaluation model was used to improve the usability of a user interface for a digital textbook platform in this study. However, since unexpected demands on user interface are increasing due to recent advances in information technology, an alternative usability testing method should be employed for continuous improvement of the user interface. A rapid prototyping methodology would be such a method, allowing designers to use a working model of a final product and to design tasks concurrently through a non-linear approach.

References

Ardito, C., Costabile, M., Marsico, M., Lanzilotti, R., Levialdi, S., Roselli, T., et al. (2006). An approach to usability evaluation of e-learning applications. *Universal Access in the Information Society, 4*(3), 270–283. doi:10.1007/s10209-005-0008-6.

Baxley, B. (2003). Universal model of a user interface. In *Proceedings of the 2003 conference on designing for user experiences* (pp. 1–14). New York: Association for Computing Machinery.

Chong, P. F., Lim, Y. P., & Ling, S. W. (2009). On the design preferences for ebooks. *IETE Technical Review, 26*(3), 213–222. doi:10.4103/0256-4602.50706.

Corry, M., Frick, T., & Hansen, L. (1997). User-centered design and usability testing of a website: An illustrative case study. *Educational Technology Research and Development, 45*(4), 65–76.

Crowther, M. S., Keller, C. C., & Waddoups, G. L. (2004). Improving the quality and effectiveness of computer-mediated instruction through usability evaluations. *British Journal of Educational Technology, 35*, 289–303. doi:10.1111/j.0007-1013.2004.00390.x.

Dhanasegaran, G. (2006). Components of the digital learning environment. In *Proceedings of the DRTC conference on ICT for facilitating digital learning environment*, Bangalore, India (pp. 11–13).

Dix, A., Abowd, G., Beale, R., & Finlay, J. (1998). *Human-computer interaction*. New York: Prentice Hall.

Folmer, E., & Bosch, J. (2004). Architecting for usability: A survey. *The Journal of Systems and Software, 70*, 61–78. doi:10.1016/S0164-1212(02)00159-0.

Gingras, L., Escobar, M., Quintero, E., & Shah, T. (2008). *Comparative analysis of e-readers*. Retrieved February 1, 2010, from http://www.leannagingras.com/comparative-analysis.pdf.

Hartson, H. R., Andre, T. S., & Willings, R. C. (2001). Criteria for evaluating usability education methods. *International Journal of Human-Computer Interaction, 13*(4), 373–410.

Hu, H.-J., Yen, J., & Guan, S.-S. (2008). A study on the interface usability of B2C hypermarket E-commerce website. In *Proceedings of the IEEE Asia-Pacific services computing conference, 2008, Yilan, Taiwan* (pp. 1202–1207).

Hung, W.-C., Smith, T. J., Harris, M., & Lockhard, J. (2010). Development research of a teachers' educational performance support system: The practices of design, development, and evaluation. *Educational Technology Research and Development, 58*, 61–80. doi:10.1007/s11423-007-9080-3.

ISO 9241-11 (1998). *Ergonomic requirements for office work with visual display terminals (VDTs), part 11: Guidance on usability* (p. 22). Geneva, Switzerland: International Organization for Standardization.

Koohang, A., & Ondracek, J. (2005). Users' views about the usability of digital libraries. *British Journal of Educational Technology, 36*(3), 407–423. doi:10.1111/j.1467-8535.2005.00472.x.

Lee, Y., Hong, S., Smith-Jackson, T. L., Nussbaum, M., & Tomioka, K. (2006). Systematic evaluation methodology for cell phone user interfaces. *Interacting with Computers, 18*, 304–325. doi:10.1111/j.0007-1013.2004.00390.x.

Matera, M., Rizzo, F., & Toffetti, C. G. (2006). Web usability: Principles and evaluation methods. In E. Mendes & N. Mosley (Eds.), *Web engineering* (pp. 143–180). Berlin: Springer Verlag.

Mayer, R. E. (2009). *Multi-media learning* (2nd ed.). New York: Cambridge University Press.

Nielsen, J. (1993). *Usability engineering*. San Diego, CA: Morgan Kaufman.

Nokelainen, P. (2006). An empirical assessment of pedagogical usability criteria for digital learning material with elementary school students. *Educational Technology and Society, 9*(2), 178–197.

Rao, S. S. (2003). Electronic books: A review and evaluation. *Library Hi Tech, 21*(1), 85–93.

Rubin, J. (1994). *Handbook of usability testing: How to plan, design, and conduct effective tests*. New York: John Wiley and Sons.

Seffah, A., Donyahee, M., Kline, R., & Padda, H. (2001). Usability measurement and metrics: A consolidated model. *Software Quality Control, 14*(2), 159–178. doi:10.1007/s11219-006-7600-8.

Seo, Y. J., & Woo, H. (2010). The identification, implementation, and evaluation of critical user interface design features of computer-assisted instruction programs in mathematics for students with learning disabilities. *Computers and Education, 55*, 363–377. doi:10.1016/j.compedu.2010.02.002.

Shackel, B. (1991). Usability—Context, framework, definition, design and evaluation. In B. Shackel & S. J. Richardson (Eds.), *Human factors for informatics usability* (pp. 21–37). Cambridge: Cambridge University Press.

Shneiderman, B., & Plaisant, C. (2009). *Designing the user interface* (5th ed.). Reading, MA: Addison Wesley.

Sweller, J. (2010). Cognitive load theory: Recent theoretical advances. In J. Pass, R. Moreno, & R. Brünken (Eds.), *Cognitive load theory* (pp. 29–47). New York: Cambridge University Press.

Tullis, T., & Albert, B. (2008). *Measuring the user experience: Collecting, analyzing, and presenting usability metrics*. Burlington, MA: Morgan Kaufmann.

Welie, M., van der Veer, G. C., & Eliëns, A. (1999). Breaking down usability. In *Proceedings of INTERACT 99*, Edinburgh, Scotland (pp. 613–620). Retrieved February 2, 2009, from http://www.cs.vu.nl/~gerrit/gta/docs/Interact99.pdf.

Wharton, C., Rieman, J., Lewis, C., & Polson, P. (1994). The cognitive walkthrough method: A practitioner's guide. In J. Nielsen & R. L. Mack (Eds.), *Usability inspection methods*. New York: John Wiley and Sons.

Wilson, R., & Landoni, M. (2003). Evaluating the usability of portable electronic books. In *Proceedings of the 2003 ACM symposium on applied computing,* Melbourne, Florida (pp. 564–568).

Cheolil Lim is Professor of Educational Technology Program at Seoul National University, Korea. His research is in the areas of instructional system design, learning environment design, distance education, corporate education, and e-learning. Dr. Lim is Past-Vice President of the Korean Society for Educational Technology and Past-President of the Korean Society for Learning and Performance. He has served on many editorial boards of the Korean journals. His current projects focus on designing support systems for creativity, self-regulated learning, and Learning Design.

Hae-Deok Song is Associate Professor of Education and Director for Center for Teaching and Learning at Chung-Ang University, Korea. His research is in the areas of problem-based learning, learning environment design, and pedagogical user interface design principles.

Yekyung Lee is Assistant Professor at the Graduate School of Education, Sogang University, Korea. Her research is in the areas of critical thinking skills, motivational interface design, unconscious decision making and learning in education, and social cognition in digital learning environments.