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The identification, implementation, and evaluation of critical user interface design features of computer-assisted instruction programs in mathematics for students with learning disabilities

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ABSTRACT

Critical user interface design features of computer-assisted instruction programs in mathematics for students with learning disabilities and corresponding implementation guidelines were identified in this study. Based on the identified features and guidelines, a multimedia computer-assisted instruction program, '*Math Explorer*', which delivers addition and subtraction word problem-solving instruction for students with learning disabilities at the early elementary level, was designed and developed. Lastly, usability testing was conducted to assess whether *Math Explorer* was well-designed in terms of the interface for students with learning disabilities. Given the results of the usability testing, this study corroborated the fact that the critical user interface design features and guidelines in mathematics computer-assisted instruction programs would be essential for facilitating the mathematical learning of students with learning disabilities. Implications for practice and future research were discussed.

1. Introduction

With the advanced technology of the past decade, researchers in the field of special education have made efforts to incorporate technology into the instructional curriculum for students with a wide range of disabilities in order to enhance their learning outcomes in an effective and efficient way (Ferretti & Okolo, 1996; Torgesen & Barker, 1995; Woodward & Carnine, 1993). Such efforts have made it possible for students with learning disabilities (LD) to gain access to technology which assists their learning in various subject areas such as reading, mathematics, social studies, and science (Woodward & Carnine, 1993).

In mathematics, such technology has been advocated as a potential tool for students with LD to foster their successful learning (Lin, Podell, & Tournaki-Rein, 1994; Okolo, 1992a; Robinson, DePascale, & Roberts, 1989). Because of the comprehensive and abstract natures of mathematics, students with LD require a sufficient number of fast-paced practices, modeling with representative examples, and immediate feedback to learn and understand mathematics (Fuchs et al., 2008; Swanson, Hoskyn, & Lee, 1999). Such vital instructional components can be effectively delivered by technology (Anderson-Inman, Knox-Quinn, & Horney, 1996). Also, with technology, mathematics instruction can be individualized and adapted for students with LD to meet their special learning characteristics (National Council of Teachers of Mathematics (NCTM), 2000). Given these assets, a new trend of emphasizing technology as one of the critical mathematics instructional features for students with LD has been created in the field of special education (Hasselbring, Goin, & Bransford, 1988; Swanson et al., 1999; Symington & Stranger, 2000).

As a result of this trend, a large body of research involving computer-assisted instruction (CAI), defined as the use of a computer to provide instructional content, in mathematics for students with LD has emerged and proved CAI's effectiveness in teaching mathematics to these students (Adydin, 2005; Gleason, Carnine, & Boriero, 1990; Lewis, 1998). For example, several group-design CAI studies (Moore, 1988; Trifiletti, Frith, & Armstrong, 1984; Watkins & Webb, 1981) focusing on CAI versus teacher-directed instruction (TDI) found that the students in the CAI group outperformed their counterparts in the TDI group. Similarly, two single-subject design CAI studies (Howell, Sidorenko, & Jurica, 1987; Wilson, Majsterek, & Simmons, 1996) focusing CAI versus TDI reported that the student(s) with LD showed achievement gains during the CAI intervention period only. These CAI studies successfully demonstrated that CAI was an effective method

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of improving the mathematical skills of students with LD. These studies, however, did not fully describe the CAI programs' design features, which were the key to facilitating students' mathematical learning (Seo & Bryant, 2009). The importance of the design features of CAI programs has been emphasized in a review of media research by Clark (1983) who claimed that the instructional principles and features embedded in CAI programs, rather than a CAI program itself, are the critical factors most closely related to students' positive academic outcomes. In response to Clark's argument, several researchers conducted CAI studies focusing on the effects of the instructional features (e.g., cognitive strategy or mnemonic strategy) embedded in CAI programs on the mathematical performance of students with LD and argued that these instructional features helped create successful mathematical learning outcomes for these students (Irish, 2002; Okolo, 1992b; Shiah, Mastropieri, Scruggs, & Fulk, 1994/1995).

In line with these CAI studies in mathematics for students with LD, the critical instructional features of CAI programs for students with LD have been emphasized, but the orthogonal technical issue regarding how to effectively deliver such instructional features has not been fully addressed. In other words, a good user interface scheme for delivering such instructional features effectively via the interaction between CAI programs and students with LD has not been explored. In general, a well-designed user interface plays a crucial role in delivering the content, maintaining users' attention and interest in the content, and increasing users' interaction with CAI programs (Cho, Cheng, & Lai, 2009; Hinostroza & Mellar, 2001). Such interaction with CAI programs can cause users to actively participate in the learning process, comprehend instruction, and, finally, improve their learning outcomes (Cho et al., 2009; Chou, 2003; Crowther, Keller, & Waddoups, 2004; Hinostroza & Mellar, 2001). Particularly, in the case of mathematics CAI programs, instruction regarding abstract mathematical concepts and relationships can be effectively delivered by using various user interface features (e.g., interactive graphics and virtual simulation), thereby increasing students' mathematical learning and understanding (Akpinar & Hartley, 1996; Kong, 2008; Pierce, Stacey, & Barkatsas, 2007; Reimer & Moyer, 2005; Steffe & Olive, 1996). For example, interactive two- and three-dimensional graphics embedded in mathematics CAI programs allow students to visually explore the properties of geometric shapes and help them understand geometric relationships (Ittigson & Zewe 2003; Steen, Brooks, & Lyon, 2006). Given the importance of the user interface design of CAI programs for students' mathematical learning, many studies in the field of educational technology have analyzed the critical user interface design features of mathematics CAI programs (Baki & Güveli, 2008; Jonassen, Howland, Moore, & Marra, 2003; Kong, 2008; Pierce et al., 2007). Because the previous studies targeted normally achieving students who do not have LD or learning difficulties, rather than students with LD, a systematic analysis of the critical user interface design features of mathematics CAI programs for students with LD has been limited. In fact, there is a dearth of studies focusing on the user interface design features of mathematics CAI programs for students with LD based on an in-depth analysis of their mathematical performance and biological characteristics. Therefore, little is known about how the user interface of such CAI programs must be designed for students with LD in order to effectively deliver mathematics instructions and, consequently, improve their mathematical learning.

Given the absence of this information, this study was conducted to (1) identify the critical user interface design features of mathematics CAI programs for students with LD, (2) design and develop a multimedia CAI program, '*Math Explorer,*' to demonstrate how the identified user interface design features could be practically embedded in mathematics CAI programs for students with LD and (3) conduct usability testing to assess whether *Math Explorer* was usefully designed in terms of its interface for students with LD.

2. Identification of critical user interface design features of CAI programs in mathematics for students with LD

To identify the critical user interface design features of mathematics CAI programs for students with LD, this study analyzed the relationship between the mathematical performance and biological characteristics of students with LD, and the critical mathematics instructional features for these students through a review of related studies in the field of special education (Bryant et al., 2008; Carnine, 1997; Geary, 1990; Geary, 1993; Geary, 2004; Geary, Brown, & Samaranayake, 1991; Geary, Hamson, & Hoard, 2000; Geary, Hoard, & Hamson, 1999; Maccini, Gagnon, & Hughes, 2002; Mazzocco & Myers, 2003; Mazzocco & Thompson, 2005; Okamoto & Case, 1996; Steel, 2002).

Through this analysis, the three main user interface design features, *instruction-driven*, *manifest structure*, and *adaptive interaction interfaces,* emerged and were further itemized as seven implementation guidelines such as *controlling the amount of mathematics instruction*, *having simplicity and consistency*, and *providing interactive and ability/effort feedback* (see Fig. 1). The identified critical interface design features and implementation guidelines were validated through corroborative findings in the literature on mathematics instruction or CAI for students with LD and described in detail as follows:

2.1. Instruction-driven interface

2.1.1. Controlling the amount of mathematics instruction

Mathematical concepts and skills are hierarchically interrelated (Hudson & Miller, 2006; Lerner, 2000). Therefore, mathematics instruction must consist of a review of prerequisite skills and core instruction in targeted skills (Hudson & Miller, 2006; Steel, 2002). For students with LD who are not able to remember what they have learned before due to poor working memory or long-term memory, mathematics instruction must include a series of reviews of varied prerequisite skills to teach targeted skills (Carnine, Dixon, & Siberts, 1998; Jitendra, Salmento, & Haydt, 1999).

In mathematics CAI programs, however, presenting entire instructional content covering all relevant prerequisite skills as well as targeted skills at one time on the screen may be overwhelming for students with LD who can remember only a certain amount of information at a time (Bley & Thornton, 2001). Thus, separating relevant content into smaller chunks and breaking such chunks into smaller segments is necessary for these students (Bley & Thornton, 2001). In general, no more than three instructional lines per screen with a maximum of 65 characters, or 8–10 words, per line are suggested for normally achieving students (Galitz, 1989; Garner, 1990). However, the appropriate amount of instruction per screen for students with LD has not yet been determined.

2.1.2. Using visual representations, animations and graphics

In general, using representations in mathematics has been identified as an effective way to help students visualize and understand complex and abstract mathematical concepts (Akpinar & Hartley, 1996; Kong, 2008; Steffe & Olive, 1996). Using representations is particularly

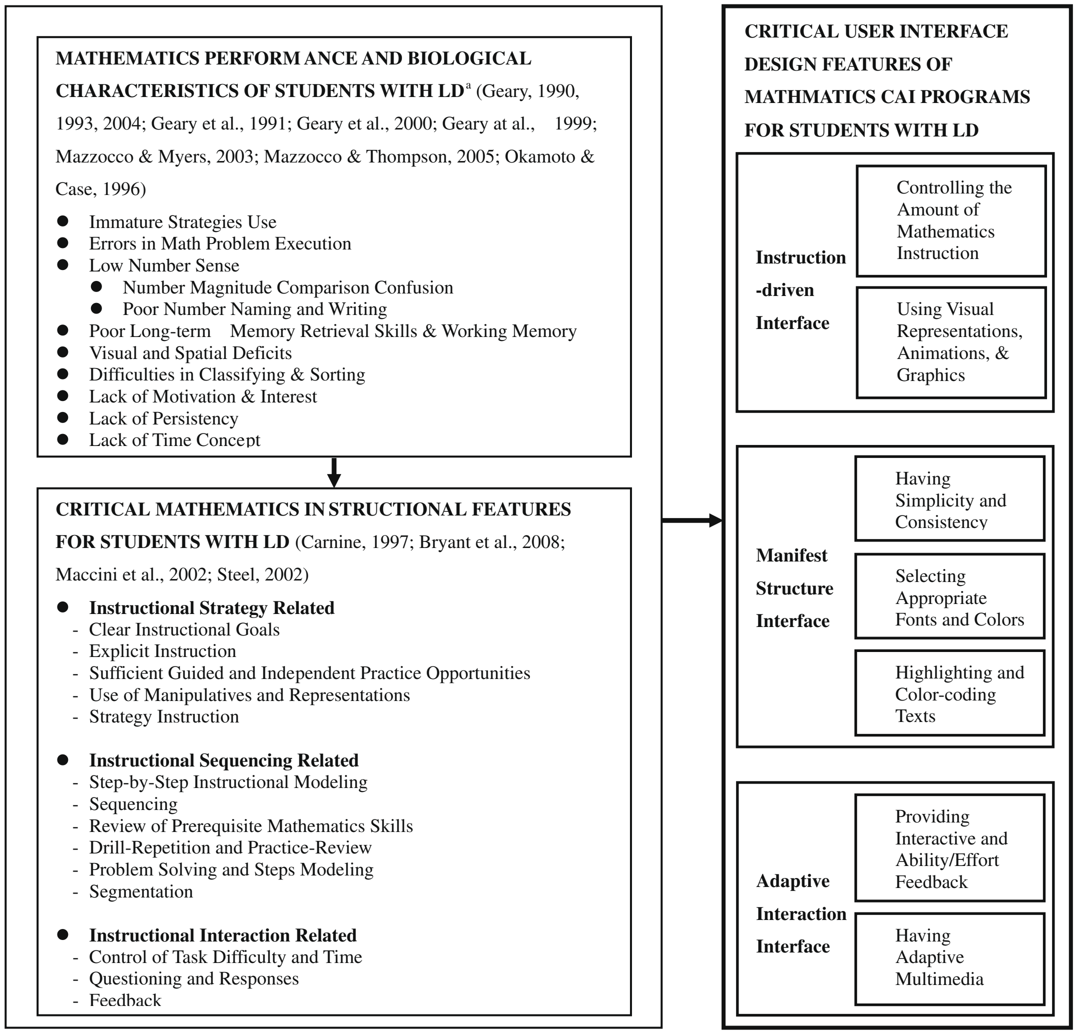

Fig. 1. Identification of the critical user interface design features of CAI programs in mathematics for students with LD.

important for students with LD to improve their abilities to visualize mathematical problem-solving processes and then understand complex and abstract mathematical concepts (Jitendra et al., 1999; Miller, Butler, & Lee, 1998; Miller & Mercer, 1993; Steel, 2002). Miller et al. (1998) found that when representations were incorporated into mathematics instruction, students with LD showed significant improvements in their problem-solving and computation skills. Therefore, instructional aides (e.g., counters, number lines, fraction diagrams, hundreds charts, and algebra tiles) at the representational level should be embedded in mathematics CAI programs for students with LD (Babbitt, 1999; Sayeski, 2008). By using such instructional aides, students with LD can visualize mathematical problem-solving processes and increase their understanding of abstract mathematical concepts and relationships during CAI (Babbit & Miller, 1996; Babbitt, 1999; Sayeski, 2008). The instructional aides must be overtly presented on the screen to lead students with LD to access them during CAI (Babbitt, 1999).

Using visually attractive animations and graphics is also helpful for students with LD as it will increase their learning motivation and attention during CAI. For example, Okolo (1991) found that students with LD perceived animations and graphics to be the most helpful features of the CAI program for their mathematical learning. While using the CAI program, these students enjoyed watching illustrated correct answers and a variety of actions performed by graphic characters (Okolo, 1991). However, too many graphics which are not directly related to instructional purposes tend to interfere with the mathematical learning of students with LD, as they are easily distracted (Babbitt, 1999; Higgins, Boone, & Williams, 2000; Okolo, 1991). Therefore, the number of animations and graphics in the CAI programs must be carefully determined to help students with LD develop and maintain interests, focus on instructional content, and, ultimately improve their mathematical learning (Babbitt, 1999; Higgins et al., 2000).

2.2. Manifest structure interface

2.2.1. Having simplicity and consistency

A clear and simple interface is necessary for students with LD to increase their attention to the instructional content on the screen (Babbitt, 1999; Jerrett, 1999). A cluttered interface with too many stimulus options and activities, for example, hotspots, hot text, and hyperlinks, often causes students with LD to be confused and distracted from the main instructional content and procedures (Babbitt, 1999; Higgins et al., 2000; Jerrett, 1999; Lewis, 1999) so that they are likely to spend most of their time clicking hotspots, which are not related to the instructional topic (Babbitt & Miller, 1996; Yook, 2000).

All instructional components should be clearly presented with appropriate signals (e.g., titles and headings) and consistently placed on the same part of the screen throughout the program because students with LD often have deficits in memory (Bley & Thornton, 2001; Higgins et al., 2000). Rhee (1997) emphasized that for students with LD, important parts of mathematics instruction must be centered on the screen whereas navigational and functional buttons must be placed on the bottom of the screen. Such consistency in the interface structure of the CAI program helped students with LD spend more time on actual learning instead of searching for key components of mathematics instruction (Rhee, 1997).

2.2.2. Selecting appropriate fonts and colors

Students with LD often have visual and spatial deficits so that they have difficulty recognizing and differentiating numbers. Such deficits also lead students with LD to fail to develop numerical magnitudes skills and further fact-retrieval skills (Jordan, Hanich, & Kaplan, 2003). Therefore, using clear and simple font styles (e.g., *Sans-serif* and *Serif* fonts) and different font styles is suggested to help students with LD easily recognize and differentiate numbers on the screen (Bley & Thornton, 2001). Font size must be adjustable to ensure that numbers and letters are large enough for all students with LD to easily recognize them on the screen (Bley & Thornton, 2001). Using both upper- and lower-case letters in left-justified texts (e.g., using upper-case letters only for the first letter of a sentence) helps students with LD easily read the text on the screen (Higgins et al., 2000). Using all upper-case letters on screen, however, can also be used for students with LD who have difficulties discriminating between the lower-case letters presented on screen and the upper-case letters on the keyboard (Bley & Thornton, 2001). Additionally, letters and numbers should be typed in from right to left for these students (Bley & Thornton, 2001).

Colors in CAI programs must be carefully selected for students with LD to facilitate their learning and hold their attention (Higgins, Boone, & Pierce, 2005; Higgins et al., 2000). Bright colors must be chosen for important or new instructional content so that students with LD can pay more attention to the content on the screen (Bley & Thornton, 2001; Higgins et al., 2005). In general, light and highly-saturation colors, which tend to come forward visually on the screen, must be used for content, whereas dark and low-saturation colors should be used for backgrounds (Davidoff, 1987; Faiola, 1989; Faiola & DeBloois, 1988). Likewise, a high level of contrast between colors used for letters or numbers and for background must be used for students with LD who have attention and visual discrimination problems (Higgins et al., 2005). Too many colors on the screen may distract these students (Bley & Thornton, 2001; Higgins et al., 2000). Therefore, the number of colors must be limited for students with LD. The optimum number of colors per screen for students with LD has not been identified yet, but, in general, a maximum of 10 colors per screen has been recommended for normally achieving students (Faiola, 1989; Garner, 1990).

2.2.3. Highlighting and color-coding texts

Text highlighting helps students with LD easily identify and focus on important content on the screen (Higgins et al., 2000). Various methods, such as blinking, underlining, color changing, and differentiating font sizes and styles, can be used for text highlighting in CAI programs. Text color-coding is also useful for students with LD who have difficulty sorting and sequencing instructional content in mathematics (Higgins et al., 2000, 2005). With color-coded texts in CAI programs, students with LD can understand the relevancy and hierarchy of instructional content. Consistency in the color-coding system with a limited number of colors throughout CAI programs is recommended for students with LD who have poor attention and visual discrimination (Bley & Thornton, 2001).

2.3. Adaptive interaction interface

2.3.1. Providing interactive and ability/effort feedback

Feedback in mathematics instruction is a key factor for students with LD to master mathematical content and skills, and develop their ability to complete mathematical activities on their own (Kroesbergen & Van Luit, 2003; Miller & Hudson, 2007). During CAI, feedback with error correction, explanation, and instructional clues is effective for students with LD to improve their mathematical problem-solving accuracy and complete more complex mathematics problems on their own (Kroesbergen & Van Luit, 2003; Rhee, 1997).

Feedback encouraging their abilities and efforts during CAI is necessary to improve the mathematical performance of students with LD because these students often have a tendency to attribute their successes not to their own efforts and abilities, but to luck or the ease of a task (Okolo, 1992b). Okolo (1992b) found that the students with LD who received ability attribution feedback (i.e., "You really know these.") and effort attribution feedback (i.e., "You are really trying hard.") during CAI significantly improved their computation skills.

2.3.2. Having adaptive multimedia

Audio (i.e., speech, music, and sound) embedded in CAI programs can be effectively used for students with LD to hold their attention and foster their mathematical learning (Bley & Thornton, 2001; Higgins et al., 2005). Music and sounds must be embedded in CAI programs without any extraneous sounds to facilitate the mathematical learning of students with LD (Bley & Thornton, 2001; Okolo, 1991). However, music and sounds that are too loud must be avoided to help these students concentrate on mathematics instructions on the screen (Bley & Thornton, 2001; Okolo, 1991). A volume control as well as start and stop buttons must be overtly presented on the screen so that students with LD can adjust them depending on their individual needs (Bley & Thornton, 2001).

Text-to-speech audio systems which deliver auditory reading of instructional texts on the screen are necessary in mathematics CAI programs for students with LD who have reading difficulties. Text-to-speech audio systems help these students proceed with mathematical activities and lessons successfully even if they do not have adequate reading skills. Text-to-speech audio systems using different pitches, stresses, tones, and paces can be used for students with LD who have attention problems (Yook, 2000).

Incorporating videos into mathematics CAI programs can be an effective way to show students with LD a variety of problems in real-world contexts, thereby increasing their interest and motivation (Bley & Thornton, 2001). However, providing too many videos must be distracting for these students. Thus, a limited number of videos, closely related to instructional content, is recommended to facilitate their learning processes during CAI (Babbitt, 1999).

3. Implementation of critical user interface design features of CAI programs in mathematics for students with LD: *Math Explorer* development

A multimedia CAI program, '*Math Explorer,*' was designed and developed to demonstrate how the identified user interface design features and guidelines could be practically embedded in mathematics CAI programs for students with LD. *Math Explorer* was created by the researcher using Macromedia Flash Professional 8 (Macromedia, 2006) through consultations with the professors and graduate students in the department of instructional technology and the graduate students in the department of computer science. In *Math Explorer*, the four-step cognitive and three-step meta-cognitive strategies, adapted from the previous research on cognitive and meta-cognitive strategies, are presented to teach students with LD at the early elementary level how to solve addition and subtraction word problems. The cognitive strategy steps are *Reading* (Step 1), *Finding* (Step 2), *Drawing* (Step 3), and *Computing* (Step 4). For each of the cognitive strategy steps, the three meta-cognitive strategy steps, such as *Do Activity*, *Ask Activity*, and *Check Activity,* are included. Specifically, for *Reading* (Step 1), the three meta-cognitive strategy steps, such as "I read the problem aloud for understanding (*Do Activity*)", "Have I read and understood the problem? (*Ask Activity*)", "I understand the problem. I read the problem again (*Check Activity*)", are included. For *Finding* (Step 2), the three meta-cognitive strategy steps, such as "I find and click the important information in the problem (*Do Activity*)", "Have I found and clicked the important information correctly? (*Ask Activity*)", "I check the important information that goes with the problem (*Check Activity*)", are included. For *Drawing* (Step 3), the three meta-cognitive strategy steps, such as "I draw or click a picture to show the problem using my drawing tool (*Do Activity*)", "Does the picture fit the problem? (*Ask Activity*)", "I check the picture against the problem information (*Check Activity*)", are included. For *Computing* (Step 4), the three meta-cognitive strategy steps, such as "I write the number sentence and find the answer using my computing tool (*Do Activity*)", "Are the number sentence and answer correct? (*Ask Activity*)", "I check that the number sentence and answer are correct (*Check Activity*)", are included.

The seven instructional procedures of *Math Explorer* include (1) title, (2) welcome, (3) instructional goal, (4) instructional modeling, (5) guided practice, (6) independent practice and (7) computer- or paper/pencil-based testing. After the title, welcome, and instructional goal sessions, students have opportunities to learn the cognitive and meta-cognitive strategies during the instructional modeling session and then practice solving addition and subtraction word problems using the cognitive and meta-cognitive strategies during the guided and independent practice sessions. Lastly, students take the computer- or paper/pencil-based test which consists of 18 addition and subtraction word problems. In the following sections, each of the identified user interface design features and guidelines embedded in *Math Explorer* was explained with the corresponding exemplary screen captures.

3.1. Instruction-driven interface

3.1.1. Controlling the amount of mathematics instruction in Math Explorer

In *Math Explorer*, only one step of the cognitive and meta-cognitive strategies or one prerequisite skill is accessible at a time to prevent students with LD from being confused by too many strategy steps and activities per screen. The instructions for the cognitive and meta-cognitive strategies are succinctly presented in two or three lines using no more than 20 words on the screen. The words are shorter than ones that would be used with normally achieving students. Fig. 2 shows a screenshot of the instruction in *Math Explorer*.

3.1.2. Using visual representations, animations and graphics in Math Explorer

Math Explorer presents the drawing tool in Step 3 (i.e., *Drawing*), with which students can draw pictures to understand and solve addition and subtraction word problems. When students click the pencil icon on the drawing tool, the students are able to draw pictures in the blank drawing area by moving the mouse. Pre-drawn pictures of problem objects (e.g., birds, dogs, and oranges) are also available on the right side of the drawing tool for students who have difficulties drawing pictures due to a lack of motor skills. Students can click the pictures of objects and then drag them onto the blank drawing area to understand and solve addition and subtraction word problems. Fig. 3 shows a screenshot of the drawing tool in *Step 3* (i.e., *Drawing*).

Math Explorer also presents the dictionary tool in Step 1 (i.e., *Reading*) to explain words in the problem with corresponding pictures. Students are able to click the tabs of the dictionary tool to understand each word by checking its picture. Fig. 4 shows a screenshot of the dictionary tool in Step 1 (i.e., *Reading*).

Math Explorer also presents visually appealing animations and graphics to obtain students' learning motivation and attention. For example, an animated character, a goldfish, is embedded in *Math Explorer*. Metaphorically, the goldfish exploring under the sea represents the students who begin to learn new cognitive and meta-cognitive strategies for word problem-solving. It does not have any instructional functions, for example, delivering instructional prompts or feedback. However, the goldfish is animated with moving fins so that it appears to

Fig. 2. Screenshot of the instruction in *Math Explorer*.

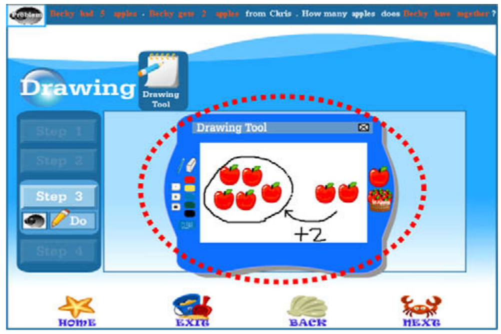

Fig. 3. Screenshot of the drawing tool in *Math Explorer*.

Fig. 4. Screenshot of the dictionary tool in *Math Explorer*.

be attractive to students. Animated bubbles and surface sea waves are added for visual attractiveness. Also, all navigational buttons (i.e., *Next*, *Back*, *Home*, and *Exit*) are made with graphics related to sea, such as pail, shovel, crab, starfish, and shell, to hold students' attention. However, the limited number of animations and graphics is used for the instruction to avoid distracting students' attention to the main instructional content. Therefore, only the animations and graphics which are necessary to explain the main instructional content are used, such as graphics to explain words in the vocabulary tool and animations to explain computing strategies in Step 4 (*Computing*). Also, the relatively slow speed of animations is used to hold students' attention. For example, the gold fish gradually moves on the limited part of the screen so that students cannot be overly distracted by his movement. In addition, the graphic navigational buttons are automatically changed to arrow graphics for *Next* and *Back* buttons, house graphic for *Home* button, and stop symbol for *Exit* button with their name when a cursor is moved over the buttons to avoid students' confusion about using the buttons. Fig. 5 shows screenshots of the animation (i.e., computing strategy) sequence in *Math Explorer*.

3.2. Manifest structure interface

3.2.1. Having simplicity and consistency in Math Explorer

In *Math Explorer*, the main instructions on the cognitive and meta-cognitive strategies are presented at the center of the screen to help students with LD find and focus on the targeted instructions without any confusion. Strategy and navigational buttons are located at the same place on each screen throughout *Math Explorer*. For example, all buttons for the four-step cognitive and three-step meta-cognitive strategies are shown on the left side of screen. All navigational buttons are placed at the bottom of the screen. Fig. 6 shows a screenshot of the structure in *Math Explorer*.

3.2.2. Selecting appropriate fonts and colors in Math Explorer

A clear and simple *Serifa BT* font, often recommended for multimedia programs (Poncelet & Proctor, 1993), is used for the texts in *Math Explorer*. A distinctive *Ravie* font is used for the important words to get students' attention. A font size of 27 is used for main instructional texts whereas a font size of 50 is used for important words.

In *Math Explorer*, colors for letters or numbers and background are carefully chosen to maintain a high level of contrast between the two. For example, dark blue was chosen for the main content texts whereas light blue was chosen for the overall background of *Math Explorer*. Additionally, dark blue was chosen for the button texts whereas light blue was chosen for the button background. Except for the colors used for animations and graphics on the screen, no more than five colors, which is smaller than the number suggested for normally achieving students, are used on each screen of *Math Explorer*. Fig. 7 shows a screenshot of the fonts and colors in *Math Explorer*.

3.2.3. Highlighting and color-coding texts in Math Explorer

While students work with one step of a strategy at a time in *Math Explorer*, the buttons for that specific step are highlighted. This function helps students recognize the step they are working on. The button texts are also highlighted when students click on the buttons or move the mouse over them.

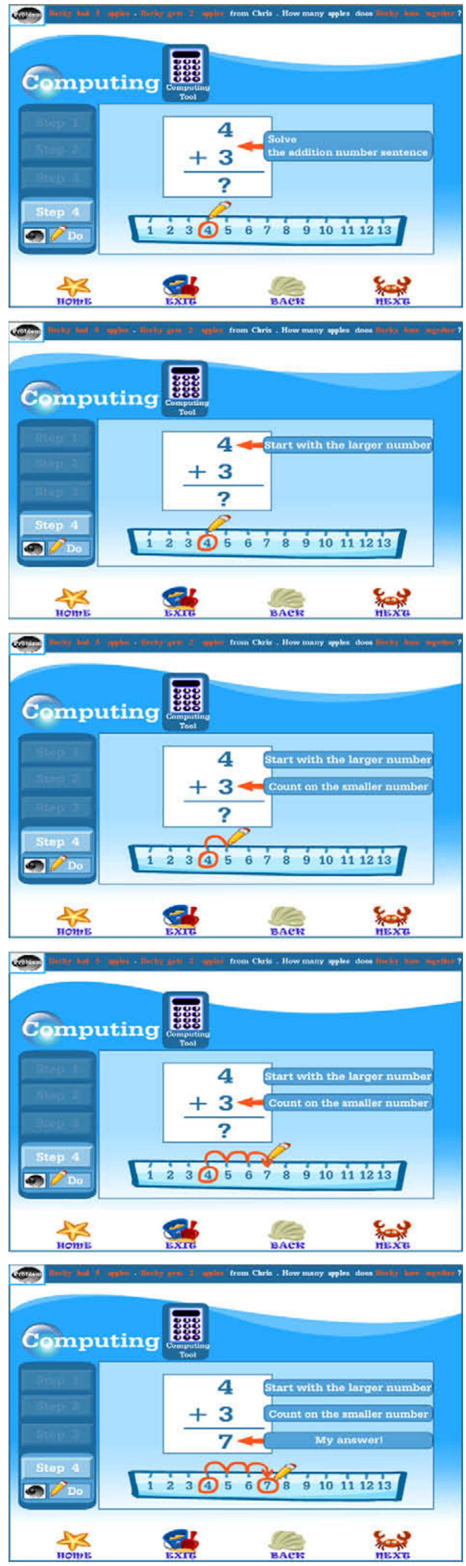

Fig. 5. Screenshots of the animation sequence in *Math Explorer*.

In Step 2 (i.e., *Finding*) if students successfully find and click important words and numbers in the problem, those words and numbers are immediately highlighted on the screen. The words and numbers are highlighted continuously after Step 2 (i.e., *Finding*), so that students are able to recognize them in later steps. Fig. 8 shows a screenshot of the highlighted words and numbers in Step 2 (i.e., *Finding*).

The texts for the instructions and buttons in *Math Explorer* are color-coded based on their components. For example, the instructional texts for the strategies are consistently dark blue throughout the program whereas the button texts for the strategies and problem texts are consistently white. By using color-coded texts in *Math Explorer*, students with LD are able to sort and organize relevant components without any confusion.

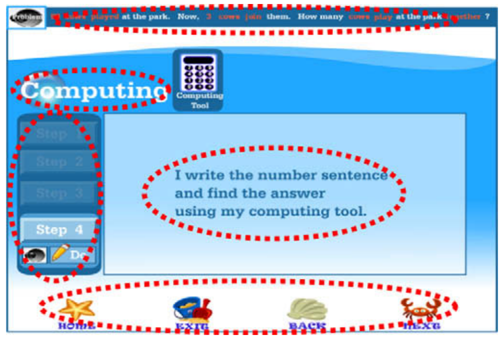

Fig. 6. Screenshot of the structure in *Math Explorer*.

Fig. 7. Screenshot of the fonts and colors in *Math Explorer*.

Fig. 8. Screenshot of the highlighted words and numbers in *Math Explorer*.

3.3. Adaptive interaction interface

3.3.1. Providing interactive and ability/effort feedback in Math Explorer

Three-level interactive feedback depending on students' responses is provided in *Math Explorer*. When students fail to perform *Do Activity* correctly, the first-level feedback is provided. After the first feedback, students still fail to perform *Do Activity* correctly, the second-level feedback with more specific and easier explanations is provided. Again, after the second feedback, students still fail to perform *Do Activity* correctly, the third-level feedback with more specific and easier examples of how to perform *Do Activity* correctly is provided. After the third-feedback, students have the last chance to perform *Do Activity*. When students still fail to complete *Do Activity* correctly, *Math Explorer* provides a correct answer.

Ability and effort attribution feedback are provided in each step of cognitive strategy based on students' responses in *Math Explorer*. When students perform *Do Activity* successfully, *Math Explorer* provides the ability attribution feedback such as "*Good work! You really know this!*" When students fail to perform *Do Activity* successfully, *Math Explorer* provides the effort attribution feedback such as "*You tried very hard! Keep trying! You can get it next time!*" and then provides a correct answer. Fig. 9 shows a screenshot of the ability feedback in *Math Explorer*.

3.3.2. Having adaptive multimedia in Math Explorer

In *Math Explorer*, the texts for strategy instructions, feedback, and word problems are read aloud by the text-to-speech program, *NaturalReader*, for students with LD who have reading difficulties. When developing *Math Explorer*, the researcher typed the texts for the instructions, feedback, and word problems presented in *Math Explorer* using Microsoft Office Word 2003, and converted them into voices

Fig. 9. Screenshot of the ability feedback in *Math Explorer*.

Fig. 10. Screenshot of the voice buttons in *Math Explorer* tables.

using *NaturalReader*. All voices were saved into MP3 audio files and inserted into the voice buttons presented in *Math Explorer*. Students are able to adjust the volume to find a comfortable volume level. Fig. 10 shows the screenshot of the voice buttons in *Math Explorer*.

4. Evaluation of critical user interface design features of CAI Program in mathematics for students with LD: *Math Explorer* usability testing

Upon completion of *Math Explorer*'s development, the first usability testing was conducted to assess whether *Math Explorer* was usefully designed in terms of the interface for students with LD and obtain participants' feedback for revising the program. After revising *Math Explorer* based on the results of the first usability testing, the second usability testing was conducted to assess whether the program's interface features were improved and well-designed for students with LD. All procedures and questionnaires for the usability testing were prepared according to the usability testing guidelines outlined by Crowther et al. (2004) and Nielsen, Snyder, Molich, and Farrell (2000).

4.1. Participants

In the schools, located in central Austin, Texas, US, the five special education teachers who were willing to participate in the usability testing were identified and contacted. The teachers were asked to sign their consent forms and complete the background questionnaire regarding their demographic information and computer experience before the first usability testing. The teachers were also asked to select students who were identified as having LD or were in the LD identification process in grades 2–3 (age range from 7 to 9) for the second usability testing and provide them with the consent forms for their parents to sign. Seventeen students returned their consent forms and completed the background questionnaire regarding their demographic information and computer experience. Finally, the five special education teachers and 17 students, specifically, five students who were identified as having LD in the areas of reading and mathematics and 12 students who were in the LD identification process based on response to intervention (RTI) model in grades 2–3 participated in the first and second usability testing, respectively. Table 1 summarizes the background information for the teachers and students. Appendix A presents the background questionnaire.

4.2. Setting

For the usability testing, the researcher set up the windows-based laptop computer on which *Math Explorer* was installed, along with other computer equipment such as a mouse and earphones. The teachers participated in the first usability testing in their classroom after all classes were over, whereas the students participated in the second usability testing in the school conference room or computer lab. The testing places were organized and controlled by the researcher to avoid possible distractions and interruptions.

Table 1
Usability testing: participants' demographics and computer experience.

Variables	Usability testing 1		Usability testing 2	
	Teachers	N[a]	Students	N
Age			7 years old	8
	31–40	3	8 years old	7
	41–50	2	9 years old	2
Gender	Female	5	Boy	11
			Girl	6
Grade	Grade 2	3	Grade 2	8
	Grade 3	2	Grade 3	9
Ethnicity	African–American	1	African–American	7
	Hispanic	1	Hispanic	6
	White	3	White	4
Computer	6–10 year	2	1–5 year	17
Experience	Over 10 year	3		
Frequency of using computer	Frequently/everyday	5	About once each week	13
			About five times each week	4

[a] Number.

Table 2
Usability testing: tasks and corresponding questions on task questionnaire.

Tasks	Questions
Task 1:general impression	
• Work on *Math Explorer*	Q1: I think that *Math Explorer* looks easy to use
• Indicate the extent to which you agree or disagree with the following statements:	Q2: I think that structures and content are simple and well-organized Q3: I find that interesting animations and graphics are provided
1 = Strongly Disagree	Q4: I think that font sizes are appropriate/easy to read
2 = Disagree	Q5: I feel that overall colors are well-chosen
3 = Neutral	Q6: I feel that *Math Explorer* is visually appealing
4 = Agree	Q7: I feel very confident to use *Math Explorer*
5 = Strongly Agree	Q8: I imagine that most students/friends would learn to use *Math Explorer* very quickly
• Time assigned: 15 min	Q9: I imagine that most students/friends would learn word problem-solving easily by using *Math Explorer*
	Q10: I imagine that most students/friends would like to use *Math Explorer* frequently in future
Task 2: scenario	
• Review an instructional modeling session	Q1: I think that *Math Explorer* is well-designed to review the instructional modeling session
• Solve three guided and three independent practice problems	Q2: I think that *Math Explorer* is well-designed to solve three guided and independent practice problems
• Indicate the extent to which you agree or disagree with the following statements:	Q3: I feel very confident to complete the tasks
1 = Strongly disagree	Q4: I imagine that most students/friends would complete these tasks in a reasonable amount of time
2 = Disagree	
3 = Neutral	Q5: I think that *Math Explorer* provides appropriate amount of instructions and activities on each screen
4 = Agree	
5 = Strongly agree	Q6: I think that words used in *Math Explorer* are clear
• Time assigned: 25 min	Q7: I think that graphics or animations are appropriately used to explain the instructions and activities
	Q8: I find that enough interactions (e.g., feedback & audio) are available
	Q9: I find that the various functions in *Math Explorer* were well-integrated
	Q10: I think that instructions and activities would be helpful for students/friends to learn word problem-solving

4.3. Procedures

The teachers individually participated in the first usability testing for one and a half hours. The usability testing included (1) introduction, (2) task and (3) post-task sessions. During the introduction session, the teachers were informed of the purpose of the usability testing and introduced to *Math Explorer*. The teachers were also told that the information they provided would not be used for any other purpose. The introduction session lasted 10 min. After the introduction session, the teachers were given the task session in which they were asked to execute task 1 for 15 min and then continue with task 2 for 25 min. During the task session, the researcher sat behind the teachers to monitor and supervise their performance. All distractions and interference were monitored and controlled by the researcher to help the teachers pay attention and execute their tasks without interruption. After the task session, the teachers were given the post-task session, asked to complete the post-task questions for 10 min, and had an opportunity to discuss their responses to *Math Explorer* with the researcher. The same procedures were repeated in the second usability testing with the students.

4.4. Usability testing questionnaire

The usability testing questionnaire consisted of two parts including the task and post-task questionnaires. Appendix B presents the usability testing questionnaire.

Table 3
Usability Testing: Questions on Post-Task Questionnaire.

Questions
Task experience
Q1: What is the most attractive feature or function in *Math Explorer?*
Q2: What is the most unattractive feature or function in *Math Explorer*?
Q3: Do you want to use *Math Explorer* again? Why?
Suggestions
Q1: If there is anything you could change in *Math Explorer*, what would it be?
Q2: Do you have suggestions for *Math Explorer*? For example, is there function or feature that you would like to see in *Math Explorer*?

Table 4
Usability testing: average rating scores for tasks 1 and 2.

	Questions	Q1	Q2	Q3	Q4	Q5	Q6	Q 7	Q8	Q9	Q10	Average
Teachers	Task 1	4.8	4.4	5	4.2	5	5	4.8	4.6	5	5	4.78
	Task 2	4.4	5	4.6	5	5	5	4.8	4.4	5	5	4.82
Students	Task 1	5	5	5	4.3	5	5	4.7	5	5	5	4.9
	Task 2	4.7	5	5	5	5	5	4.8	4.6	5	5	4.91

4.4.1. Task questionnaire

The task questionnaire containing two usability tasks was developed by the researcher based on the examples provided in Nielsen et al.'s (2000) usability study. The participants were asked to execute two usability tasks and complete the questionnaire. Specifically, for task 1, the participants were asked to work on *Math Explorer* in order to obtain their overall impression of *Math Explorer*. For task 2, the participants were asked to review one instructional modeling session and solve three guided and three independent practice problems. For each task, the participants were asked to assign a rating from 1 to 5 points (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree) based on the extent to which they agreed or disagreed with each statement on the questionnaire. When the participants were not able to understand the statements on the questionnaire, the researcher explained them, checked their understanding, and then asked the participants to assign a rating. Table 2 summarizes the tasks and questions on the task questionnaire.

While the participants executed the tasks, the researcher took notes on their behaviors and actions. Upon the occurrence of particular events of interest (e.g., clicking a wrong button), the participants' thoughts were asked about to gather specific information regarding the factors that guided their decisions. If the participant had questions or difficulties with the tasks, the researcher provided minimal hints and guidance to help them proceed. Notes were constantly taken on the participants' comments (e.g. things they liked and did not), behaviors, and actions during the process of task execution. These were summarized and considered for use in a revision of *Math Explorer*.

4.4.2. Post-task questionnaire

The post-task questionnaire was also developed by the researcher based on the examples provided in Nielsen et al.'s (2000) usability study. The participants were asked to answer five open-ended questions. The questions asked about the participants' overall experiences and impressions of *Math Explorer*'s usability and value such as, "What was the most attractive feature or function in *Math Explorer*?" and "If there is anything you could change in *Math Explorer*, what would it be like?" The participants had the opportunity to discuss their responses and suggestions for *Math Explorer* with the researcher. The participants' responses and suggestions were considered when revising *Math Explorer*. Table 3 summarizes the questions on the post-task questionnaire.

5. Results

The scores for each usability task question for tasks 1 and 2 were collected, summed and averaged. Table 4 shows that the teachers' average rating scores for tasks 1 and 2 in the first usability testing were 4.78 and 4.82, respectively. Given the fact that 5.0 was a maximum average score, the results for tasks 1 and 2 indicated that the teachers were satisfied with the overall interface design features of *Math Explorer* and able to execute the instructional activities successfully. Table 4 also shows that the students' average rating scores for tasks 1 and 2 in the second usability testing were 4.9 and 4.91, respectively. The students' average rating scores were higher than the teachers' ones indicating that the students were more satisfied with the program than the teachers and did not perceive the problems that teachers points out in the first usability testing.

Table 5 summarizes the teachers' responses for each post-task question in the first usability testing. All teachers agreed that *Math Explorer* was well-designed, and would be attractive for students as well as effective for enhancing students' word problem-solving performance. However, they pointed out several features that should be changed to make *Math Explorer* more helpful for students' learning. Based on their suggestions, the researcher revised *Math Explorer* by having a bigger font size for problem texts, shorter instructional texts on each screen, easier button functions of the computing tool, and more words for the dictionary tool. Table 5 also summarizes the students' responses for each post-task question in the second usability testing. Overall, the students were very excited to use the computing tool, dictionary tool, voice buttons, and drawing tool in *Math Explorer*. The students expressed that *Math Explorer* was very easy and fun to study with. Several suggestions for revising *Math Explorer*, such as having more animations and sounds, emerged.

Table 5
Usability testing: responses for post-task questions.

Tasks	Questions	Responses	
		Teachers	Students
Task experience	Q1	• Dictionary tool • Drawing tool • Computing tool • Computing strategies	• Drawing tool • Voice button • Computing tool • Gold fish
	Q2	• Computing tool • None	• More animations • None
	Q3	• It will be helpful for students to learn word problem-solving • It is much more attractive than any other math software • Students will enjoy studying with this!	• It's fun to use • I want to solve more problems • It's easy and fun to use • I love math!
Suggestions	Q1	• Computing tool is not simple to use • Instructions are too long • Font size for problem texts should be bigger	• More animations in the drawing tool • None
	Q2	• Highlight words when the words are read • Include more words in the dictionary tool • Include sound when I click the buttons	• I want to see more animations on the screen • None

6. Discussion

6.1. Conclusions

In the field of special education, the instructional features of mathematics CAI programs have been emphasized and considered as critical factors to improve the mathematical performance of students with LD (Seo & Bryant, 2009). Beyond the instructional features, the user interface design features of mathematics CAI programs are also critical because the instructional features can be effectively delivered depending on how the interface of mathematics CAI programs is designed. However, there is a lack of systematic identification of the critical user interface design features of mathematics CAI programs for students with LD. Given the fact that students with LD are frequent users of CAI programs in schools (Banes & Walter, 1997; Becker & Sterling, 1987; Johnson & Hegarty, 2003; Lewis, 1998; Okolo, 1991), identifying the critical user interface design features and developing CAI programs incorporating those features are imperative to facilitating their mathematical learning through CAI. Therefore, it is noteworthy that this study identified the critical user interface design features of mathematics CAI programs for students with LD by analyzing the relationship between the performance and biological characteristics of students with LD, and the instructional features for these students. The three critical user interface design features were identified as *instruction-driven*, *manifest structure*, and *adaptive interaction interfaces*. Each of the features was further specified with seven implementation guidelines for example, *controlling the amount of mathematics instruction*, *using visual representations, animations, and graphics*, and *selecting appropriate fonts and colors*. In addition, this study designed and developed *Math Explorer* to demonstrate how the identified features and guidelines could be practically and successfully embedded in mathematics CAI programs. Finally, this study conducted usability testing to assess whether the interface of *Math Explorer* was well-designed for students with LD to facilitate their mathematical word problem-solving performance. In response to the special education teachers' feedback in the first usability testing, this study revised *Math Explorer* and conducted the second usability testing with the students who were identified as having LD or were in the LD identification process in grades 2–3. The results of the second usability testing demonstrated that the students' satisfaction was rated quite high (i.e., 4.9 and 4.91 out of 5.0) indicating that the interface of *Math Explorer* was improved and that *Math Explorer* would foster the mathematical word problem-solving performance of students with LD. Taken together, this study corroborated the fact that the critical user interface design features in mathematics CAI programs would be essential for facilitating the mathematical learning of students with LD and added further evidence that a CAI program with the identified features and guidelines, for example, *Math Explorer*, would be a potentially effective method for improving the mathematical performance of students with LD.

6.2. Limitations of the study

There are several limitations that need to be considered when interpreting the results of this study. First, in contrast with the instructional design features of mathematics CAI programs for students with LD, the interface design features were not adequately addressed in the field of special education (Seo & Bryant, 2009). Therefore, the critical user interface design features of mathematics CAI programs for students with LD identified in this study could not be validated by many other studies. More mathematics CAI studies are necessary for a more accurate identification of the critical user interface design features of mathematics CAI programs for students with LD.

Second, a limitation related to external validity of the usability testing of this study is noted. The usability testing occurred twice for one and a half hours. Only five special education teachers and 17 students participated in the first and second usability testing, respectively. Therefore, even though the usability testing showed positive responses from the participants, caution is necessary in interpreting the results of the usability testing. Further testing with larger groups of special education teachers and students with LD is suggested.

Additionally, the teachers and students individually participated in the usability testing under the researcher's supervision and monitoring. Therefore, there is a possibility that the researcher's considerable attention in the individual testing influenced the participants' performance and responses. Therefore, the results of the usability testing should be interpreted cautiously.

Lastly, the results of the usability testing showed that *Math Explorer* would be helpful for students with LD to improve their word problem-solving skills, but the empirical evidence regarding the effects of *Math Explorer* on the mathematics learning performance of students with LD was not established in this study. An experimental study with *Math Explorer* that covers this issue is necessary in future.

6.3. Implications for practice

Based on the results of this study, future CAI researchers and software designers who are interested in improving the mathematical learning of students with LD can develop effective mathematics CAI programs by including the critical user interface design features identified in this study. The software designers can initiate and develop ideas regarding how the interface design features can be incorporated into the CAI programs by reviewing the interface of *Math Explorer* presented in the study.

Another implication of this study is that teachers or other educators can be aware of the critical interface design features identified in this study when they evaluate or purchase mathematics CAI programs for their students with LD. Moreover, teachers can become familiar with the critical interface design features and apply them when they prepare mathematics instructions and materials for students with LD. In this way, teachers can become more competent in providing mathematics instructions that are effective for enhancing the mathematical learning outcomes of students with LD.

6.4. Implications for future research

Based on the limitations of this study, several suggestions for future research have emerged. First, due to a limited number of studies addressing the user interface design features of mathematics CAI programs for students with LD, several interface design features such as an appropriate amount of mathematics instruction (e.g., how many instructional lines and words per screen) and font size and styles for students with LD could not be specified in this study. More studies in this area are necessary.

Second, although this study identified the critical user interface design features of mathematics CAI programs for students with LD and developed *Math Explorer* with those interface design features, empirical evidence that *Math Explorer* is helpful in leading students' positive learning outcomes has not yet been established. Therefore, there is a need to conduct an experimental study with *Math Explorer* to prove its effectiveness in improving the mathematical performance of students with LD. Further, more studies that develop mathematics CAI programs with the identified user interface design features in various mathematical areas and evaluate the programs' effectiveness must be conducted in future.

The last area that warrants further research is that of designing and developing more mathematics CAI programs which incorporate the critical interface design features identified in the study with advanced technology, such as hypermedia, virtual reality, and networking, to assist students with LD. In general, several studies in the field of educational technology identified the critical hypermedia interface features depending on the students' characteristics (i.e., passive or active learner and with or without prior experience of CAI) and discovered that well-designed hypermedia interface features were crucial to facilitate their learning (Lee & Lai, 2005; Lee & Lehman, 1993; Liaw, Huang, & Chen, 2007). However, there is a lack of such studies in mathematics with particular attention to the learning characteristics of students with LD. Therefore, studies in this area are necessary to ensure that the mathematics CAI programs with advanced technology can efficiently incorporate the critical interface design features and therefore make a positive contribution to the successful mathematical learning outcomes of students with LD.

Appendix A. Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.compedu.2010.02.002.

References

Adydin, E. (2005). The use of computers in mathematics education: A paradigm shift from "computer assisted instruction" towards "students programming". *The Turkish Online Journal of Educational Technology, 4*, 79–83.

Akpinar, A., & Hartley, J. R. (1996). Designing interactive learning environments. *Journal of Computer Assisted Learning, 12*, 33–46.

Anderson-Inman, L., Knox-Quinn, C., & Horney, M. A. (1996). Computer based study strategies for students with learning disabilities: Individual differences associated with adoption level. *Journal of Learning Disabilities, 29*, 461–485.

Babbit, B. C., & Miller, S. P. (1996). Using hypermedia to improve the mathematics problem-solving skills of students with learning disabilities. *Journal of Learning Disabilities, 29*, 391–401, 412.

Babbitt, B. C. (1999). *10 tips for software selection for math instruction*. <http://http://www.ldonline.org/article/6243>. Accessed 05.08.08.

Baki, A., & Güveli, E. (2008). Evaluation of a web based mathematics teaching material on the subject of functions. *Computers & Education, 51*, 854–863.

Banes, D., & Walter, R. (1997). The Internet: A new frontier for pupils with severe learning difficulties. *British Journal of Special Education, 24*, 27–30.

Becker, H. J., & Sterling, C. W. (1987). Equity in school computer use: National data and neglected considerations. *Journal of Educational Computing Research, 3*, 289–311.

Bley, N. S., & Thornton, C. A. (2001). *Teaching mathematics to students with learning disabilities* (4th ed.). Austin, TX: Pro-Ed.

Bryant, B. R., Bryant, D. P., Kethley, C., Kim, S., Pool, C., & Seo, Y. (2008). Preventing mathematics difficulties in the primary grades: The critical features of instruction in textbooks as part of equation. *Learning Disability Quarterly, 31*, 21–35.

Carnine, D. (1997). Instructional design in mathematics for students with learning disabilities. *Journal of Learning Disabilities, 30*, 130–141.

Carnine, D., Dixon, R., & Siberts, J. (1998). Effective strategies for teaching mathematics. In E. Kame'enui & D. Carnine (Eds.), *Effective teaching strategies that accommodate diverse learners* (pp. 92–112). Columbus, OH: Merrill.

Cho, V., Cheng, T. C. E., & Lai, W. M. J. (2009). The role of perceived user-interface design in continued usage intention of self-paced e-learning tools. *Computers & Education, 53*, 216–227.

Chou, C. (2003). Interactivity and interactive functions in web-based learning systems: A technical framework for designers. *British Journal of Educational Technology, 34*, 265–279.

Clark, R. (1983). Reconsidering research on learning from media. *Review of Educational Research, 53*, 445–459.

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.

Davidoff, J. (1987). The role of colour in visual displays. *International Reviews of Ergonomics, 1*, 21–42.

Faiola, T. (1989). Principles and guidelines for screen display interface. *The Videodisc Monitor, 8*, 27–29.

Faiola, T., & Debloois, M. L. (1988). Designing a visual factors-based screen display interface. The new role of the graphic technologist. *Educational Technology, 28*, 12–21.

Ferretti, R. P., & Okolo, C. M. (1996). Authenticity in learning: Multimedia design projects in the social studies for students with disabilities. *Journal of Learning Disabilities, 29*, 450–459.

Fuchs, L. S., Fuchs, D., Powell, S. R., Seethaler, P. M., Cirino, P. T., & Fletcher, J. M. (2008). Intensive intervention for students with mathematics disabilities: Seven principles of effective practice. *Learning Disability Quarterly, 31*, 79–92.

Galitz, W. O. (1989). *Handbook of screen format design* (3rd ed.). Wellesley, MA: QED Information Science.

Garner, K. H. (1990). 20 Rules for arranging text on a screen. *CBT Directions, 3*, 13–17.

Geary, D. C. (1990). A componential analysis of an early learning deficit in mathematics. *Journal of Experimental Child Psychology, 49*, 363–383.
Geary, D. C. (1993). Mathematical disabilities: Cognitive, neuropsychological, and genetic components. *Psychological Bulletin, 114*, 345–362.
Geary, D. C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities, 37*, 4–15.
Geary, D. C., Brown, S. C., & Samaranayake, V. A. (1991). Cognitive addition: A short longitudinal study of strategy choice and speed-of-processing differences in normal and mathematically disabled children. *Developmental Psychology, 27*, 787–797.
Geary, D. C., Hamson, C. O., & Hoard, M. K. (2000). Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology, 77*, 236–263.
Geary, D. C., Hoard, M. K., & Hamson, C. O. (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for a mathematical disability. *Journal of Experimental Child Psychology, 74*, 231–239.
Gleason, M., Carnine, D., & Boriero, D. (1990). Improving CAI effectiveness with attention to instructional design in teaching story problems to mildly handicapped students. *Journal of Special Education Technology, 10*, 130–136.
Hasselbring, T. S., Goin, L. I., & Bransford, J. D. (1988). Developing math automaticity in learning handicapped children: The role of computerized drill and practice. *Focus on Exceptional Children, 20*, 1–7.
Higgins, K., Boone, R., & Williams, D. L. (2000). Evaluating educational software for special education. *Intervention in School and Clinic, 26*, 109–115.
Higgins, K., Boone, R., & Pierce, T. B. (2005). *Evaluating software for use by students with disabilities to foster inclusion in general education*. Paper presented at the inclusive and supportive education congress international special education conference. <http://www.isec2005.org.uk/isec/abstracts/papers_h/higgins_k.shtml>. Accessed 03.05.08.
Hinostroza, J. E., & Mellar, H. (2001). Pedagogy embedded in educational software design: Report of a case study. *Computers & Education, 37*, 27–40.
Howell, R., Sidorenko, E., & Jurica, J. (1987). The effects of computer use on the acquisition of multiplication facts by a student with learning disabilities. *Journal of Learning Disabilities, 20*, 336–341.
Hudson, P., & Miller, S. P. (2006). *Designing and implementing mathematics instruction for students with diverse learning needs*. Boston: Pearson Education Inc..
Irish, C. (2002). Using peg- and keyword mnemonics and computer-assisted instruction to enhance basic multiplication performance in elementary students with learning and cognitive disabilities. *Journal of Special Education Technology, 17*, 29–40.
Ittigson, R. J., & Zewe, J. G. (2003). Technology in the mathematics classroom. In L. A. Tomei (Ed.), *Challenges of teaching with technology across the curriculum: Issues and solutions* (pp. 114–133). Hershey, PA: Inormation Science Publishing.
Jerrett, D. (1999). *The inclusive classroom: Math and science instruction for students with learning disabilities*. Portland, Oregon: Northwest Regional Educational Laboratory.
Jitendra, A. K., Salmento, M. M., & Haydt, L. A. (1999). A case analysis of fourth-grade subtraction instruction in basal mathematics programs: Adherence to important instructional design criteria. *Learning Disabilities Research & Practice, 14*, 69–79.
Johnson, R., & Hegarty, J. R. (2003). Websites as educational motivators for adults with learning disability. *British Journal of Educational Technology, 34*, 479–486.
Jonassen, D. H., Howland, J., Moore, J., & Marra, R. (2003). *Learning to solve problems with technology: A constructivist perspective* (2nd ed.). Upper Saddle: Prentice Hall.
Jordan, N., Hanich, L., & Kaplan, D. (2003). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. *Child Development, 74*, 834–850.
Kong, S. C. (2008). The development of a cognitive tool for teaching and learning fractions in the mathematics classroom: A design-based study. *Computers & Education, 51*, 886–899.
Kroesbergen, E., & Van Luit, J. E. H. (2003). Mathematics interventions for children with special educational needs. *Remedial for Children with Special Education, 24*, 97–114.
Lee, K. M., & Lai, J. (2005). Speech versus touch: A comparative study of the use of speech and DTMF keypad for navigation. *International Journal of Human–computer Interaction, 19*, 343–360.
Lee, Y. B., & Lehman, J. D. (1993). Instructional cuing in hypermedia: A study with active and passive learners. *Journal of Educational Multimedia and Hypermedia, 2*, 25–37.
Lerner, J. (2000). *Learning disabilities: Theories, diagnosis, and teaching strategies*. Boston, MA: Houghton.
Lewis, R. B. (1998). Assistive technology and learning disabilities: Today's realities and tomorrow's promises. *Journal of Learning Disabilities, 31*, 16–26.
Lewis, R. B. (1999). Reading software for students with learning disabilities: Hypermedia-based children's literature. <http://www.ldonline.org/ld_indepth/technology/lewis_rdgsftware.html>. Accessed 09.01.09.
Liaw, S. S., Huang, H. M., & Chen, C. D. (2007). An activity – theoretical approach to investigate learners' factors toward e-learning systems. *Computers in Human Behavior, 22*, 1906–1920.
Lin, A., Podell, D. M., & Tournaki-Rein, N. (1994). CAI and the development of automaticity in mathematics skills in students with and without mild mental handicaps. *Computers in the Schools, 11*, 43–59.
Maccini, P., Gagnon, J. C., & Hughes, C. A. (2002). Technology-based practices for secondary students with learning disabilities. *Learning Disability Quarterly, 25*, 247–261.
Macromedia (2006). *Flash professional 8*. San Jose, CA: Macromedia.
Mazzocco, M. M. M., & Myers, G. F. (2003). Complexities in identifying and defining mathematics learning disability in the primary school age years. *Annals of Dyslexia, 53*, 218–253.
Mazzocco, M. M. M., & Thompson, R. (2005). Kindergarten predictors of math learning disability. *Learning Disabilities Research & Practice, 20*, 142–155.
Miller, S. P., Butler, E. M., & Lee, K. (1998). Validated practices for teaching mathematics to students with learning disabilities: A review of literature. *Focus on Exceptional Children, 31*, 24–40.
Miller, S. P., & Hudson, P. (2007). Using evidence-based practices to build mathematics competence related to conceptual, procedural, and declarative knowledge. *Learning Disabilities Research & Practice, 22*, 47–57.
Miller, S. P., & Mercer, C. D. (1993). Using a graduated word problem sequence to promote problem-solving skills. *Learning Disabilities Research & Practice, 8*, 169–174.
Moore, B. M. (1988). Achievement in basic math skills for low performing students: A study of teachers' affect and CAI. *Journal of Experimental Education, 57*, 38–44.
National Council of Teachers of Mathematics. (2000). Principles and standards for school mathematics. Reston, VA: Author.
Nielsen, J., Snyder, C., Molich, R., Farrell, S. (2000). E-commerce user experience: Methodology of the study. <http://www.nngroup.com/reports/ecommerce>. Accessed 11.12.06.
Okamoto, Y., & Case, R. (1996). Exploring the microstructure of children's central conceptual structures in the domain of number. *Monographs of the Society for Research in Child Development, 61*, 27–59.
Okolo, C. M. (1991). Learning and behaviorally handicapped students' perceptions of instructional and motivational features of computer-assisted instruction. *Journal of Research on Computing in Education, 24*, 171–188.
Okolo, C. M. (1992a). The effect of computer-assisted instruction format and initial attitude on the arithmetic facts proficiency and continuing motivation of students with learning disabilities. *Exceptionality, 3*, 195–211.
Okolo, C. M. (1992b). The effects of computer-based attribution retraining on the attributions, persistence, and mathematics computation of students with learning disabilities. *Journal of Learning Disabilities, 25*, 327–334.
Pierce, R., Stacey, K., & Barkatsas, A. N. (2007). A scale for monitoring students' attitudes to learning mathematics with technology. *Computers & Education, 48*, 285–300.
Poncelet, G. M., & Proctor, L. F. (1993). Design and development factors in the production of hypermedia based courseware. *Canadian Journal of Educational Communication, 22*, 91–111.
Reimer, K., & Moyer, P. S. (2005). Third-graders learn about fractions using virtual manipulatives: A classroom study. *Journal of Computers in Mathematics and Science Teaching, 24*, 5–25.
Rhee, K. M. (1997). The effect of hypermedia-based math instruction on the basic whoe number addition skills of children with learning disabilities. Unpublished doctoral dissertation. The Johns Hopkins University, MA.
Robinson, S. L., DePascale, C., & Roberts, F. C. (1989). Computer-delivered feedback in group-based instruction: Effects for learning disabled students in mathematics. *Learning Disabilities Focus, 5*, 28–35.
Sayeski, K. L. (2008). Virtual manipulatives as an assistive technology support for students with high-incidence disabilities. *Journal of Special Education Technology, 23*, 47–53.
Seo, Y., & Bryant, D. P. (2009). Analysis of studies of the effects of computer-assisted instruction on the mathematics performance of students with learning disabilities. *Computers & Education, 53*, 913–928.
Shiah, R., Mastropieri, M. A., Scruggs, T. E., & Fulk, B. J. M. (1994). The effects of computer-assisted instruction on the mathematical problem solving of students with learning disabilities. *Exceptionality, 5*, 131–161.
Steel, M. M. (2002). Strategies of helping students who have learning disabilities in mathematics. *Mathematics Teaching in the Middle School, 8*, 140–143.
Steen, K., Brooks, D., & Lyon, T. (2006). The impact of virtual manipulatives on first grade geometry instruction and learning. *Journal of Computers in Mathematics and Science Teaching, 25*, 373–391.
Steffe, L. P., & Olive, J. (1996). Symbolizing as a constructive activity in a computer micro-world. *Journal of Educational Computing Research, 14*, 113–138.
Swanson, H. L., Hoskyn, M., & Lee, C. (1999). *Interventions for students with learning disabilities*. New York: Guilford.

Symington, L., & Stranger, C. (2000). Math = success: New inclusionary software programs add up to a brighter future. *Teaching Exceptional Children, 32*, 28–33.
Torgesen, J. K., & Barker, T. A. (1995). Computers as aids in the prevention and remediation of reading disabilities. *Learning Disability Quarterly, 18*, 76–88.
Trifiletti, J. J., Frith, G. H., & Armstrong, S. (1984). Microcomputers versus resource rooms for LD students: A preliminary investigation of the effects on math skills. *Learning Disability Quarterly, 7*, 69–76.
Watkins, M. W., & Webb, C. (1981). Computer assisted instruction with learning disabled students. *Educational Computer Magazine, 1*, 24–27.
Wilson, R., Majsterek, D., & Simmons, D. (1996). The effects of computer-assisted versus teacher-directed instruction on the multiplication performance of elementary students with learning disabilities. *Journal of Learning Disabilities, 29*, 382–390.
Woodward, J., & Carnine, D. (1993). Uses of technology for mathematics assessment and instruction: Reflection on a decade of innovations. *Journal of Special Education Technology, 7*, 38–48.
Yook, J. (2000). Effects of reading software on the reading fluency and on-task behavior for students with emotional and behavioral disorders. Unpublished doctoral dissertation, University of South Carolina, South Carolina.