Article

Journal of Educational Computing Research
2019, Vol. 57(1) 170–200

DOI: 10.1177/0735633117746748
journals.sagepub.com/home/jec
SAGE

Development of an Innovative Dual-Coded Multimedia Application to Improve Reading Comprehension of Students With Imagery Deficit

Ling Wang[1] and Jiang Li[2]

Abstract

This study describes the development of an innovative multimedia application and examines teacher perceptions of its usefulness in assisting students with imagery deficit to visualize the reading comprehension. Students with good reading skills can easily create mental representations from oral or written language, and their sensory system quickly brings parts to whole through imagery. Students with deficiency may have trouble creating images due to their sensory information from imagery is slow and dull, and they often get stuck on parts and pieces. Those unable to image what they read usually cannot understand and remember what they read, which is consistent with the referential connection between the verbal and visual symbolic systems according to the Dual-Coding Theory. This application helps students to develop the capacity to build mental images sentence by sentence. The students engage a touch screen to draw a picture associated with the meaning of each sentence. With the sentences hidden or pictures shuffled, they select and describe each picture in sequence to retell the story. Pictures can be saved to analyze students' learning outcomes and needs. Teacher perceptions indicate their

[1]Department of Teaching and Learning, Austin Peay State University, Clarksville, TN, USA
[2]Department of Computer Science and Information Technology, Austin Peay State University, Clarksville, TN, USA

Corresponding Author:
Ling Wang, Department of Teaching and Learning, College of Education, Austin Peay State University, Clarksville, TN 37044, USA.
Email: wangl@apsu.edu

willingness to integrate this application into reading instruction to help improve reading comprehension of students with imagery deficit.

Keywords
dual coded, multimedia, reading comprehension, imagery, teacher perceptions

Reading teachers often hear their students saying "If I can't picture it, I can't understand it.", indicating the students may have a gestalt visualization deficit. During the process of reading comprehension, a gestalt is a complex organized unit created by the visualization of the "whole" more than the sum of its "parts" (Bell, 1991). Students with gestalt imagery deficit may have to read the same piece of text information numerous times due to their struggle in accessing and integrating old information with new by only processing parts of what has been read. If students cannot image what they see or hear from the text information, they usually struggle to remember what they read. In general, if a student has one or more of the following symptoms, then he or she may have a gestalt imagery deficit.

- During or after reading, he or she cannot create a mental picture of what has been read to show the understanding of a chunk piece of text information.
- During or after reading, he or she may be able to create a mental picture of what has been read but cannot create a mental "movie" to show the understanding of consecutive pieces of text information.
- During or after reading, he or she can hardly remember what has been read due to the difficulty of imaging what has been read.
- During or after reading, he or she may image and understand what has been read by repeated reading, for example, a sentence, but get lost when moving to the next sentence.
- When summarizing, he or she can only include partial details of a story.
- When retelling, he or she may miss the major points or events of a story.
- When retelling, he or she may get the wrong sequence of the events of a story.

This study describes the development of an innovative multimedia application and examines teacher perceptions of its usefulness in helping students with gestalt imagery deficit through visualization of the process of reading comprehension. Dual-Coding Theory suggests that our mental information representation and processing in cognitive tasks rely on two functionally independent but structurally interconnected systems: one for verbal units/texts and the other for visual objects/images (Paivio, 1990; Sadoski & Paivio, 2013). Information is processed more efficiently and stored in long-term memory more successfully when presented both verbally and visually (Baddeley, 1992). Teachers may use this application to create short self-contained passages and guide their students to generate concept imagery sentence by sentence via a touch screen user interface (UI). Students develop the capacity to build mental images by drawing pictures associated with the meaning of each sentence in the passage, as well as verbalizing a summary of each picture in the correct order to retell the story. In addition, the application offers oral narration of each sentence so that students can select visual text input, audio text input, or both when reading the target passage and drawing pictures. Teachers can examine the learning process and isolate specific problems of each individual student using pictures saved at the end of a lesson.

Dual-Coding in Reading Comprehension

Dual-Coding Theory defines three levels of information processing in cognitive tasks: representational, associative, and referential (see Figure 1). Representational processing refers to recognizing familiar objects through direct stimuli, either verbal or nonverbal. For instance, seeing the printed word *house* or hearing the word *house* activates it in the verbal system, while seeing a picture of a *house* will activate its image in the nonverbal system.

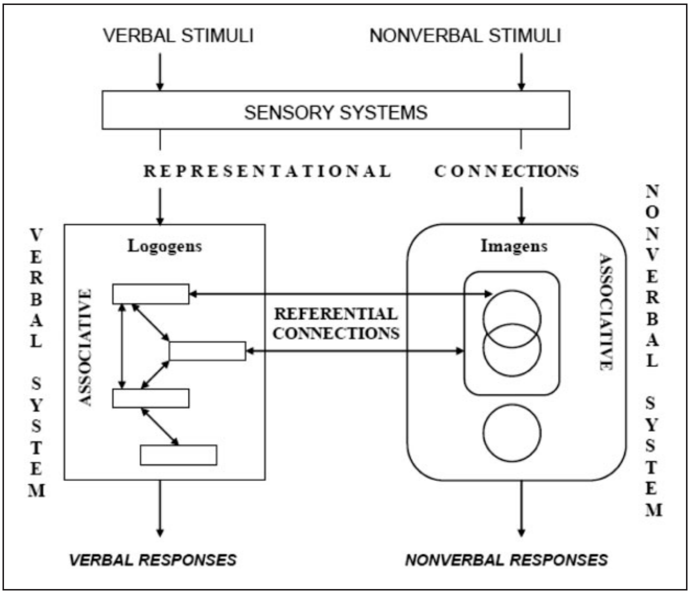

Figure 1. Model of Dual Coding Theory (Paivio, 1990).

Associative processing means representations that can be activated by other representations within the same system. For example, the word *vehicle* may activate other words such as *car* and *bus*, while picture of a *basketball court* may activate an associated image of *basketball*. Referential processing refers to one-to-many or many-to-many correspondence between verbal and nonverbal symbols. For instance, the word *zoo* could activate mental images of animals, while picture of a zoo may activate the word *animal*, and so on. Referential processing is related to associative processing as the word *animal* activated by the picture of a zoo may activate other associated words such as *tiger* and *monkey*, which in turn, can activate the nonverbal system to recall the pictures of these animals in memory.

In reading comprehension, students who are unable to image what they see or hear are often not able to remember what they read, and they may also have difficulty with higher order thinking skills (Bell, 2015). This is consistent with the referential connection between the verbal and visual symbolic systems. Students with good language comprehension, expression, and critical thinking skills can easily create mental representations from oral or written language, and their sensory system quickly brings parts to whole through imagery. In contrast, students with deficiency may have trouble creating gestalt images due to their sensory information from imagery is slow and dull, and they often get stuck on bits, parts, and pieces.

Sentence comprehension. Studies investigating the dual-coded instructions for language learning have shown positive effects using images together with text definitions in vocabulary acquisition and sentence comprehension (Cohen & Johnson, 2011; Glenberg & Langston, 1992; Plass et al., 1998). Generally speaking, abstract sentences are stored primarily as verbal units in memory while concrete sentences are stored more likely as nonverbal images, which retain the meaning instead of the wording of the sentence (Begg & Paivio, 1969). Given the same sentence meaning, semantic changes are recognized more often than wording changes for concrete sentences, but wording changes are more noticeable than semantic changes for abstract sentences (Begg & Paivio, 1969).

The effects of sentence concreteness on comprehension and the connection between concrete sentence and imagery have been discussed in numerous studies (Eddy & Glass, 1981; Holyoak, 1974; Holmes & Langford, 1976; Jorgensen & Kintsch, 1973; O'Neil & Paivio, 1978; Sadoski, Goetz, & Fritz, 1993). The reaction time of sentence evaluation in terms of the rating of how easy to form an image of the sentence has revealed that sentences rated as easy to imagine are evaluated more quickly than sentences rated as difficult to image, indicating imagery may facilitate the comprehension process (Jorgensen & Kintsch, 1973). An extended study on the effects of semantic relatedness and semantic complexity in addition to the effects of rated imagery on reaction time also supports this conclusion (Holyoak, 1974). Concrete sentences have been found to be classified much faster than abstract sentences in a sentence meaning classification task and more words are recalled from concrete sentences than from abstract sentences in a free recall task (Holmes & Langford, 1976). Findings from sentence-rating experiments based on imagery and recall have suggested that concrete sentences receive higher imagery ratings and higher recall scores than abstract sentences (O'Neil & Paivio, 1978), and imagery has played a significant role in sentence understanding in verification and comprehension tasks given high-imagery sentences and low-imagery sentences (Eddy & Glass, 1981). Moreover, results have indicated that using the rating norms as predictors, easy-to-image concrete sentences are recalled twice more than abstract sentences with respect to the comprehensibility, interestingness, and familiarity of concrete and abstract sentences in rating and recall tasks (Sadoski, Goetz, & Fritz, 1993).

Text comprehension. Both children and adults may benefit from self-generated pictures or provided images as discussed in a review of psychological research on the role of imagery processes in prose comprehension (Denis, 1984). Results from experiments on the use of images in the comprehension tasks involving technical content by high school students have revealed that technical material may be comprehended better in the form of illustrations than as text and may be comprehended best if presented in both forms (Purnell & Solman, 1991). Furthermore, Glenberg and Langston (1992) conducted experiments to test how pictures may help adults in a text comprehension task involving sequential steps. Participants were given a text about a four-step procedure in which the middle two steps occurred simultaneously. It was found that participants who were given the text accompanied by appropriate pictures tended to mentally represent the procedures, while they tended to remember the text itself if it was presented alone.

Images may also help on memory for information presented orally in classrooms. For instance, experiments were conducted with elementary students on recall of stories from information recorded on the tape (Levin & Berry, 1980). The researchers designed single pictures to illustrate only the main idea of newspaper articles as well as a group of pictures, each illustrating a sentence in the passage. The results indicated that students who only heard the stories on tape recalled less than those who heard the story on tape and viewed related images at the same time.

Multimedia Learning

Instructional technologies involving computer multimedia have been widely used to teach languages given the great capability of computers in presenting, organizing, and integrating information through multisensory, such as text, picture, audio, video, and animation (Beatty, 2013; Chuang & Ku, 2011; Levy, 1997; Warschauer & Healey, 1998). Multimedia annotations have shown positive effects in learning language vocabulary (Al-Seghayer, 2001; Chun & Plass, 1996; Davis & Lyman-Hager, 1997; Kuo & Hooper, 2004). For instance, the visuospatial properties of Chinese characters have inspired the development of instructional methods for teaching Chinese vocabulary using both verbal and visual information (Chuang & Ku, 2011; Kuo & Hooper, 2004; Wang, 2014). Computer animations using dual-coded multimedia methods have transformed an image symbolizing the etymology of a Chinese character to the modern format of the character, which can assist students to construct a referential connection between the image and the character (Wang & Blackwell, 2015).

According to Generative Theory of Multimedia Learning, information is better memorized when presented both verbally and visually because learners can receive information through both verbal and nonverbal sensors and utilize corresponding working memories to process the target information (Mayer, 2001). Figure 2 illustrates the information and memory paths in multimedia learning. When the text is presented through narration, the picture and narration coding are processed through visual and auditory channels, respectively,

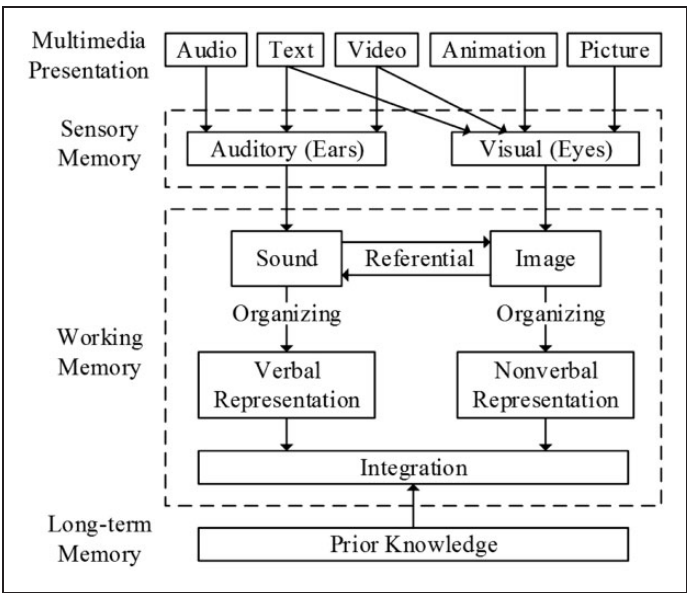

Figure 2. Information and memory paths in multimedia learning (adapted from Chen, 2006).

which should yield better results than the method using picture with on screen text that are processed in the same visual channel.

The development of an educational multimedia application demands a joint effort from both educators and computer scientists. In this study, the requirement analysis of the application gained tremendous help from teachers who has had experience in teaching reading comprehension to students with reading deficiency. Meanwhile, the design and implementation of this application involved computer professionals with strong programming skills, knowledge of software engineering, and ability to apply software development models to real-world projects (Ghezzi, Jazayeri, & Mandrioli, 2002). Before being released as a learning tool in real teaching environments, the application was evaluated by classroom teachers who did not participate in the development process. Likert scale questionnaires were created to investigate (a) whether the classroom teachers confirm functionality and practicability of this application, (b) the classroom teachers' perception of its usefulness in improving reading comprehension of students with imagery difficulty, and (c) the classroom teachers' attitude toward integrating it into their daily reading instruction.

Method

The main purpose of this application is to assist students with gestalt visualization deficit so that they can visualize and verbalize the process of language comprehension and thinking. As aforementioned, a gestalt is a complex organized unit created by visualizing the "whole" more than the sum of its "parts" during reading comprehension. When students only process "parts" of what they see or hear, it is hard for them to create such a gestalt. Linguistic competence and performance are based on a substrate of imager, which includes not only static representations of objects but also dynamic representations of action sequences and relationships between objects and events (Bell & Lindamood, 1991).

To improve the students' ability to image a gestalt in reading comprehension, this application is designed to guide them through a series of steps:

1. A short self-contained paragraph is presented, with each sentence shown on screen one at a time in order.
2. Students engage a touch screen UI to draw a picture to represent the meaning of each sentence they read.
3. With the sentences hidden or shuffled, students verbalize a summary by selecting and describing each picture in the correct sequence to retell the story.
4. The gestalt image is formed as students develop the capacity to build mental images sentence by sentence.

Unified Process Model

The architecture and components of the application were created using Unified Process software development model, which adapts to the change of requirements and project goals better than many traditional models (Lenz & Moeller, 2004; Maciaszek & Liong, 2004). Based on the Unified Modeling Language (UML), the development cycle of the Unified Process model consists of four phases: Inception, Elaboration, Construction, and Transition. Meanwhile, each phase consists of five workflows: Requirement, Analysis, Design, Implementation, and Test (Esposito & Saltarello, 2014; Kruchten, 2004). The following subsections discuss each phase in detail with emphasis on different workflows.

Inception phase. The inception phase is to achieve agreement between the user and the developer on requirements, expectations of the functionality, and procedural approach that is to be taken to implement the application (Windle & Abreo, 2003). After consulting classroom teachers and completing an initial requirement analysis, the application was divided into three major components: presentation module, data module, and logic module.

Besides offering a touch screen interface with a simple layout, large and intuitive image buttons, and support for a digitizer, the presentation module provide the following features:

- Customize size and color of the pen
- Create a new picture box for drawing
- Copy the previous picture to resume drawing
- Draw complex smooth curves besides simple line segments
- Resize a picture box to provide larger drawing space
- Use eraser to modify the picture
- Clear the entire picture and start over
- Show or hide individual sentences in a passage
- Present the sentences orally through an auditory component

The data module employs plain text format for lesson files that consist of sentences, which can be conveniently created and edited using any text editor. The pictures with associated sentences can be saved to give the teacher valuable information on the learning process and assessment of the students. These saved pictures can also be dragged and dropped to the picture box directly if the teacher observes that the students have got stuck on a certain sentence.

The logic module serves as a middle layer between the presentation module and the data module. Once data are read from a lesson file in data module, they are sent to the logic module to populate a list of sentences, which are put into the corresponding textboxes on screen in the presentation module. Similarly, when saving the pictures, the presentation module is coded to take a full screenshot of all the pictures and sentences, as well as individual pictures from the corresponding picture box. The logic module then validates and formats these data before forwarding it to the data module to save the screenshot and each picture as image files. The story retelling is another main feature in the logic module. After students finish their drawings for all the sentences, they can hide all the sentences and verbalize a summary of each picture to retell the story, or they can shuffle the pictures and retell the story by matching each picture in the correct sequence with the corresponding sentence.

Beside requirement analysis, use cases were created in the inception phase. The UML defines a use case as an objective user who wants to achieve with an application, which aims at describing a system from external usage viewpoint, rather than from developer's perspective (Kruchten, 2004). The UML use case diagram in Figure 3 demonstrates the actions the user may take, such as loading a lesson, picking up a pen and its color, drawing pictures, and so on. Note that some actions will not take place until the prerequisite actions have been completed. For instance, the user may start drawing only after a pen is selected and a new picture box is created, an existing picture is copied, or a previously saved picture is loaded.

Elaboration phase. The elaboration phase provides an architectural baseline that implements a working application with limited functionality and formulates a project agreement with the user (Li, 2009). The requirements and use cases were refined in this phase. The analysis workflow describes what the application is supposed to do without defining how it is done given that how to implement the application will be specified in the design workflow of the construction phase (Arlow & Neustadt, 2005; Esposito & Saltarello, 2014).

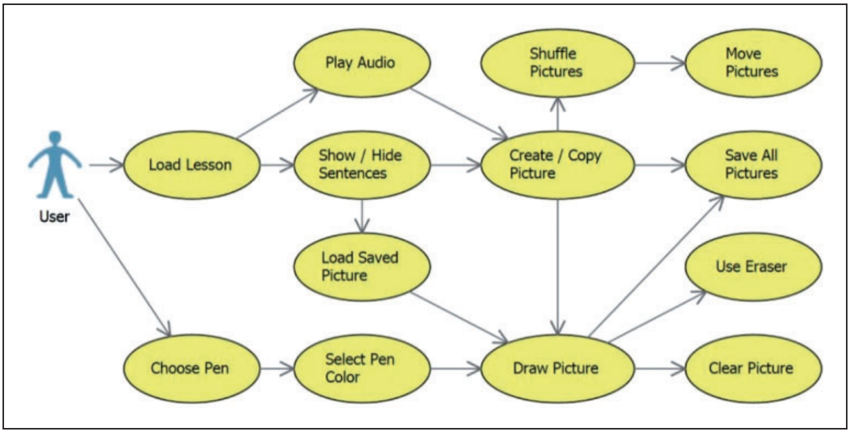

Figure 3. UML use cases diagram describing the system from external usage viewpoint.

The design task in this phase is to develop a stable architecture using UML activity diagrams and sequence diagrams. An activity diagram describes procedural logic, business process, and work flow, which is like a flowchart that allows the user to choose the order in which to do things and supports parallel behavior (Kruchten, 2004). The UML activity diagram in Figure 4 decomposes user actions captured in the use cases into detailed activities involving conditional branches and concurrent flows. For instance, after loading a lesson, the user may

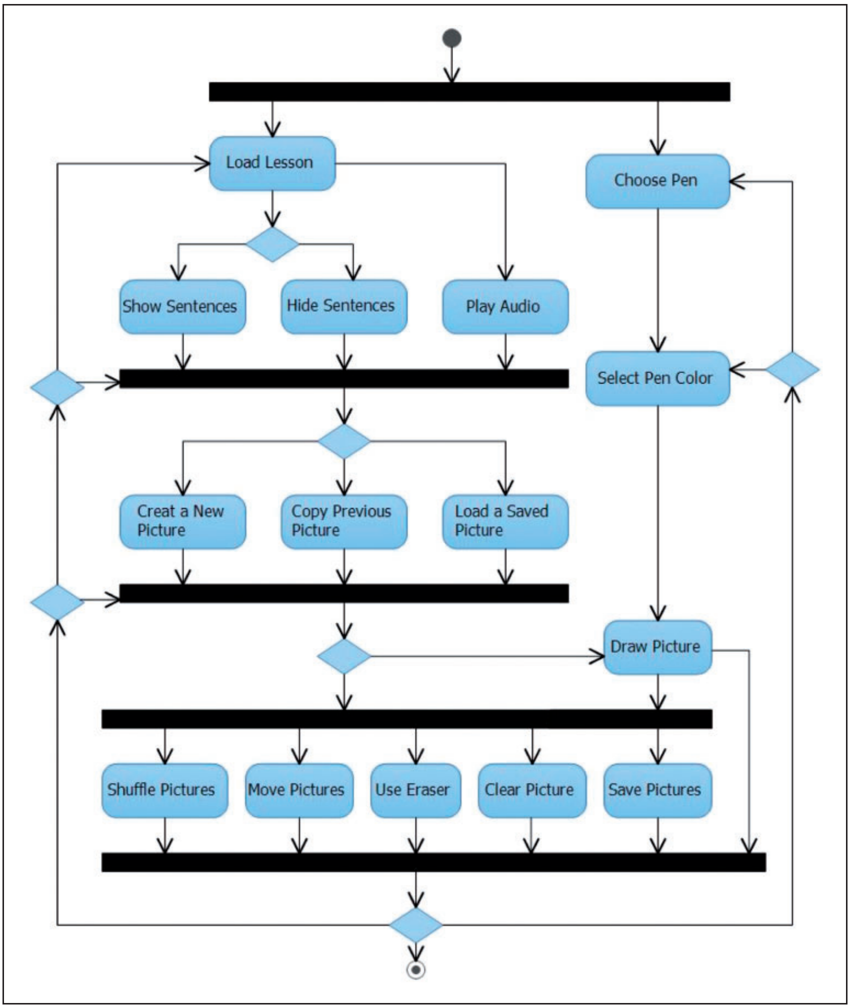

Figure 4. UML activity diagram describing a flowchart and parallel behavior.

either show or hide a sentence by toggling the visibility property of the sentence textbox.

A sequence diagram describes how groups of objects collaborate in some behavior. It usually shows a number of example objects and the messages passed between these objects within the use case (Kruchten, 2004). Figure 5 gives a good representation about which objects are doing which processing by illustrating the messages passed among lesson, sentence, and picture, as well as the interactions and messages passed among the objects of pen and eraser.

Construction phase. The construction phase reveals and analyzes any requirement that has been missed, refines the requirements that have been implemented, and finishes the design of UML class diagrams for coding (Arlow & Neustadt, 2005). The functions were grouped and implemented in three iterations using

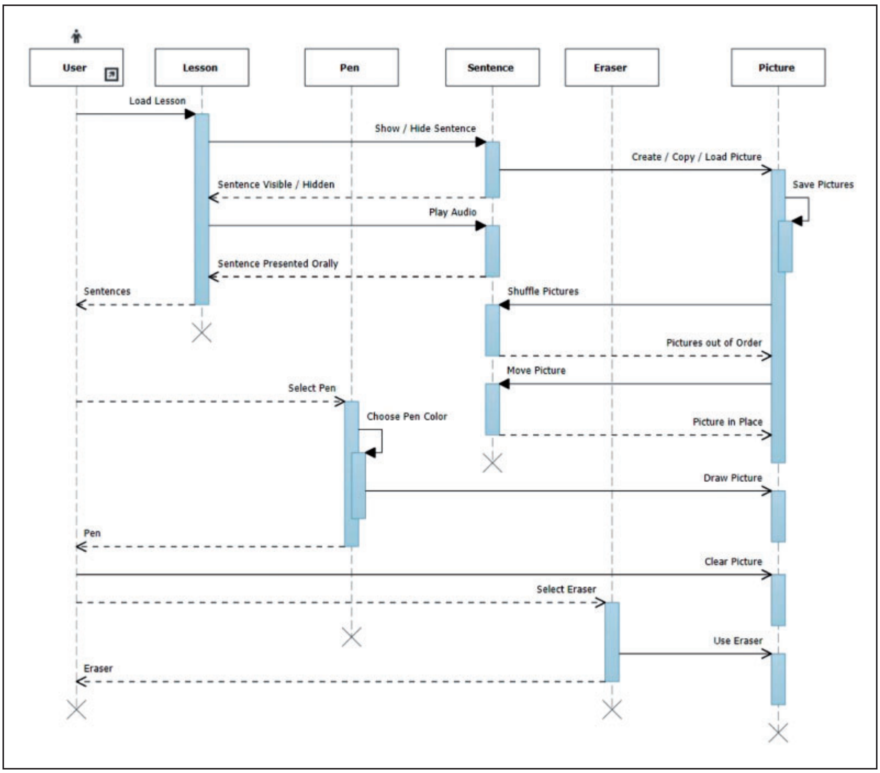

Figure 5. UML sequence diagram describing messages passed between objects within use cases.

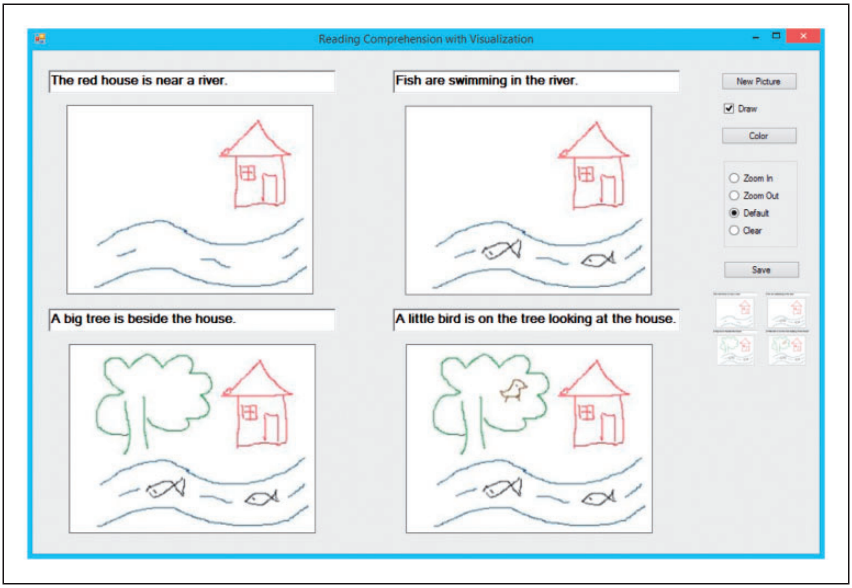

Figure 6. Initial prototype after the first iteration in the Construction Phase.

C# programming language and Visual Studio .NET (Esposito & Saltarello, 2014; Troelsen, 2012).

The first iteration primarily implemented drawing functions that include creating a new picture, copying the previous picture, choosing pen color, and so on. The zoom in function doubles the picture box size to provide more space, while the zoom out function reduces its size to half for a better fit below the associated sentence. The default option resets the picture box to its original size, and the clear option deletes the entire drawing. The user may save a screenshot of the sentences and pictures as well. Figure 6 gives an example of reading comprehension of four sentences. Note that the UI created with standard Windows controls such as checkboxes and radio buttons was primitive and not yet suitable for a touch screen presentation.

The second iteration implemented the eraser function to modify the drawing and greatly refined the UI by using large image buttons to facilitate touch screen operations (see Figure 7). The copy option allows the user to resume drawing on the picture for the previous sentence instead of redrawing everything from the scratch. Furthermore, the saving function was updated to save each individual picture besides an overall screenshot.

The functions of showing/hiding sentences and shuffling pictures for story retelling were realized in the third iteration (see Figure 8). This iteration also implemented the auditory narration feature using the Text-to-Speech Engines on the Microsoft Speech Platform (Troelsen, 2012). UI was further improved by

Figure 7. Evolved prototype after the second iteration in the Construction Phase.

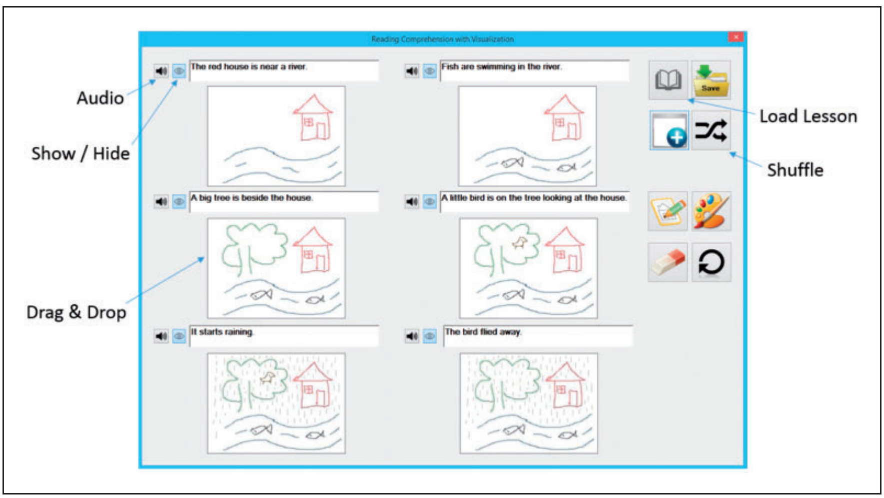

Figure 8. Final product after the third iteration in the Construction Phase.

consolidating zoom in and zoom out functions into a single resizing action. The user may simply double click on the picture to toggle the default and double size. Another requirement change is that picture associated with the previous sentence is automatically copied to the current picture box. The user can easily clear the picture if he or she wants to draw from the scratch instead. Finally, this iteration implemented the drag and drop feature that let the user drag a previously saved picture onto a picture box so that he or she can use it as is or modify it for the current sentence.

Transition phase. Transition phase starts after all the tests have been completed, and the application is prepared for release (Arlow & Neustadt, 2005; Li, Wang, Williams, & Allan, 2015). The defects on the remaining components were analyzed, and all the errors discovered during testing were fixed. Installation packages, which include executable binary code along with supporting libraries and files such as user manual, were created using the built-in setup utilities and deployment tools in Visual Studio .NET. In addition, all the documents including requirements, use case diagram, activity diagram, sequence diagram, and class diagrams, and so on were collected and archived. Keeping these development documents is important for code reuse, software maintenance, new release, and future training.

Application Testing

Throughout the construction phase and the transition phase, a variety of tests including UI testing, unit testing, and integration testing were created and run to validate the application is working as expected.

UI testing. A typical experience for software developers is to manually click through the UI controls, such as textboxes, command buttons, radio buttons, and checkboxes, and so on, to verify that things are working correctly for the end user. UI tests were created to automatically verify that code dealing with user interactions does not impact the functionality of the application. This is particularly useful where there is validation or other logic in the UI. For example, the show/hide sentences button should be inactive until the lesson is loaded.

Unit testing. Unit testing verifies whether all the required functionalities across the logic module are implemented, and the various components are working in isolation (Troelsen, 2012). Unit testing has the greatest effect on the quality of coding when it is an integral part of the software development workflow. The application is broken down into discrete behaviors that can be tested as individual units. As soon as a function or other block of application code is written, unit tests may be created to verify the behavior of the code in response to standard, boundary, and incorrect cases of input data, and check any explicit or implicit assumptions made by the code. For instance, unit tests were created to verify that previously saved pictures can be successfully loaded into the picture boxes later.

Integration testing. Integration testing combines individual units into components and test them as a group, which usually happens after the unit testing (Esposito & Saltarello, 2014). For instance, testing of the story retelling function depends on the completion of unit testing of shuffling pictures, moving pictures, and showing/hiding sentences. A final integration test was performed during the transition phase to verify the interactions among the presentation module, the logic module, and the data module work properly.

Evaluation of the Application

Because the end users of this application are classroom reading teachers and students with reading difficulties, it is imperative to let the teachers who may use it in their lesson preparations, classroom teaching, and students' learning outcome analysis, to evaluate its functionality, and to validate whether all the requirements defined in the inception phase and elaboration phase have been met and the application works as expected.

Participants. Twenty reading teachers who have taught from kindergarten to fifth grade in public elementary schools volunteered to evaluate this application and provide feedback through the Likert scale questionnaires (Appendix). All of these teachers have had experiences of using computer applications on tablets, and they are currently enrolled in the Master of Education in Reading program in a southern state university.

Procedure. The teachers were given instructions to install the application on their own computers. After reading the user manual and watching a 5-minute video tutorial, they went through all the features of the application before posting their responses to the questionnaires in a discussion forum. The results were collected and saved electronically into Excel spreadsheets.

Results

The Likert scale questionnaires aim to investigate classroom teachers' perception of the application's usefulness in improving the reading comprehension of students with imagery deficit, their attitude toward integrating it into daily reading instructions, and the value of its functionality and simplicity of use in four aspects: data management, gestalt visualization, story retelling, and auditory narration.

Table 1 illustrates the descriptive analysis of classroom teachers' overall perception of the application's usefulness in guiding students to create mental images of the sentences they read, retain the meaning of these sentences, and retell the story. The majority (80%) of the participants strongly agree and 20% of the participants agree with the statement "Overall I think this application is

Table 1. Descriptive Analysis of Teachers' Perception of the Application's Usefulness.

Item 1	Frequency	Percent	Valid percent	Cumulative percent
1 Strongly disagree	0	0.0	0.0	0.0
2 Disagree	0	0.0	0.0	0.0
3 Neutral	0	0.0	0.0	0.0
4 Agree	4	20.0	20.0	20.0
5 Strongly agree	16	80.0	80.0	100.0
Total	20	100.0	100.0	

effective in helping students with difficulty imaging/retaining/retelling what has been read." None of them holds attitudes of strongly disagree, disagree, or neutral.

Data management

To use this application in classrooms, the teacher only needs to set up a few things beforehand. Lessons are in plain text format so that the teacher can create them using any text editor they are familiar with. No additional software or training is needed. The only thing the teacher should pay attention to is writing only one sentence per line so that the application can recognize individual sentences and put them into the corresponding textboxes. The number of textboxes updates automatically in accordance with the number of sentences in the lesson. Figure 9 demonstrates a screenshot of loading a lesson in text format.

Upon completion of the lesson, the student will save a screenshot of all the pictures with associated sentences (see Figure 10) as well as each picture as a separate JPEG or PNG file to a folder specified by the teacher. If these pictures demonstrate the student's good understanding of sentences, they can be used as examples to assist other students who may have difficulty drawing pictures for these sentences. The teacher may encourage these students to drag and drop previously saved pictures directly into the picture boxes below the sentences they are having trouble with. The students can continue drawing on this picture for the current sentence or take it as is and move onto the next sentence. Moreover, if the saved pictures reveal that the student misunderstand some sentences, the teacher can accurately locate which part of the passage the student needs more help and therefore adjust their instructions.

Items 2 and 3 in the questionnaires investigate whether the teachers think data management functions are useful and easy to use in their classroom. Given the scale that range from "*strongly disagree*" to "*strongly agree*" (i.e., *Strongly disagree* = 1, *Disagree* = 2, *Neutral* = 3, *Agree* = 4, *Strongly agree* = 5), the larger

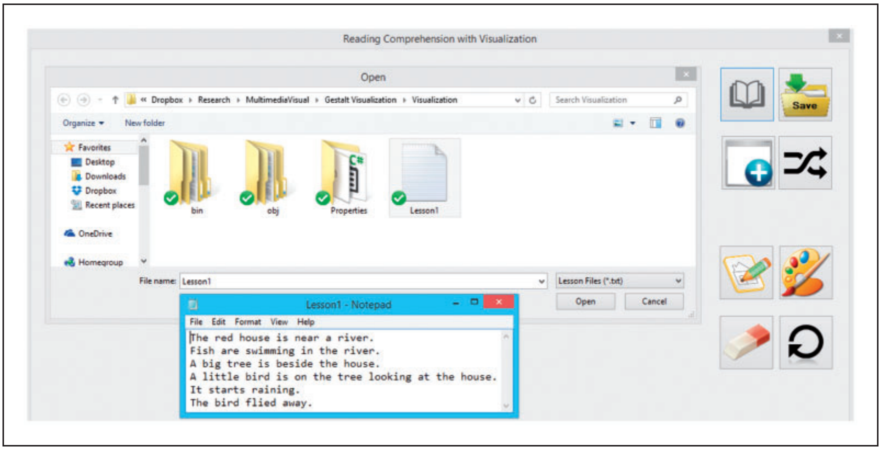

Figure 9. Loading a lesson in text format.

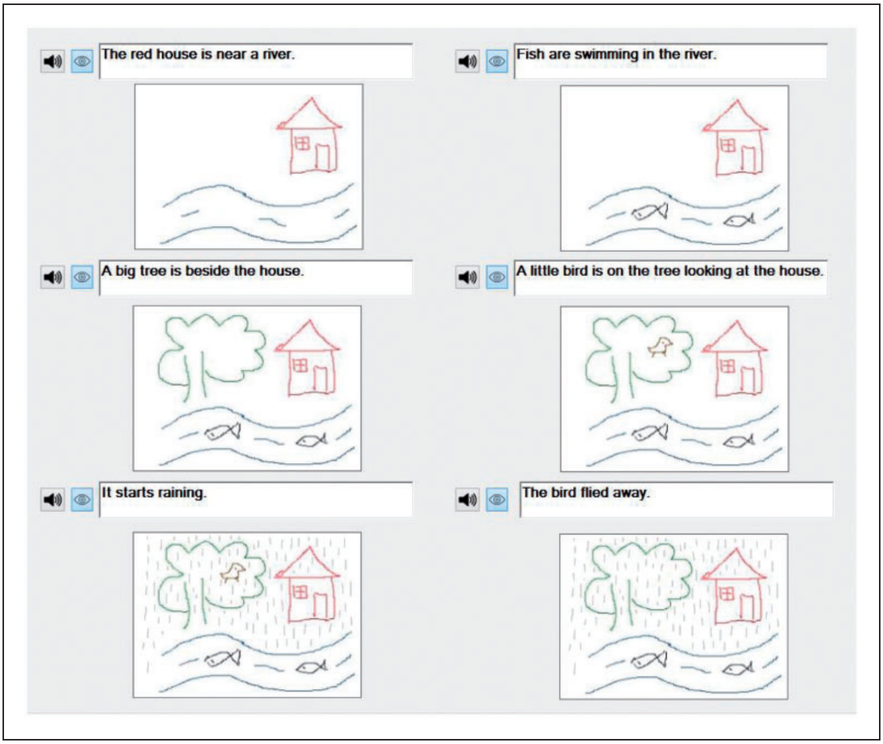

Figure 10. Saving results after the completion of a lesson.

value the mean of teachers' responses, the more strongly they agree with the statements. The means of Item 2 (4.75) and Item 3 (4.60) demonstrate that most teachers agree that data management functions are useful and easy to use (see Table 2).

The descriptive analysis in Figure 11 reveals that 75% of the participants strongly agree that the data management functions are useful and 25% of them agree. None of them holds neutral or negative attitude toward the usefulness of these functions. When asked whether these functions are easy to use, 65% of participants strongly agree, 30% agree, 5% are neutral, and none feels these functions are difficult to use. These results indicate the usefulness of the data management functions from the teachers' perspective.

Gestalt visualization. One of the most significant features of this application is to assist students with reading difficulties to generate mental images in reading comprehension. Students will draw a sequence of pictures associated with each sentence based on their understanding. The picture for the previous

Table 2. Descriptive Statistics of Teachers' Feedback on Data Management Functions.

Questions	*N*	Minimum	Maximum	Mean	*SD*
Item 2 (usefulness)	20	4	5	4.75	.444
Item 3 (easiness of use)	20	3	5	4.60	.598

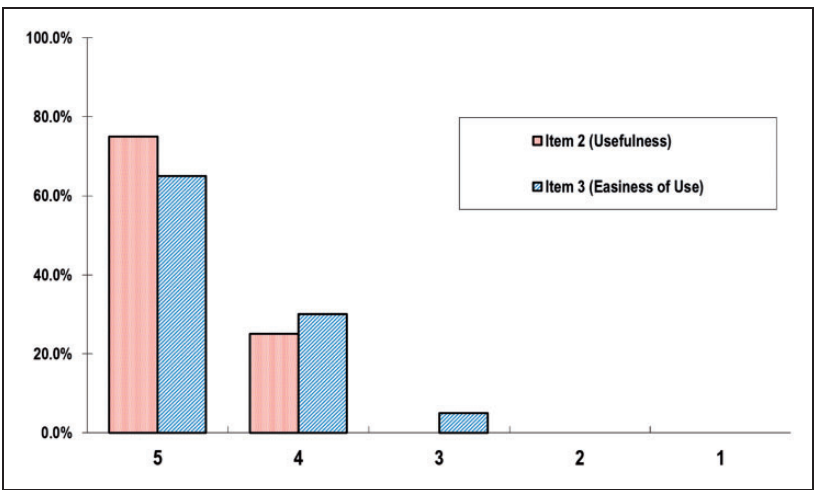

Figure 11. Descriptive analysis of teachers' feedback on data management functions.

sentence is automatically copied for the current sentence so that the student can continue drawing new objects or making changes. Not only does this avoid drawing the same thing over again, which saves valuable class time, but also helps the student remember what was previously going on and preserves how the story unfolds, a key factor in the story retelling activity the student practice later.

Figure 12 demonstrates the student keeps adding objects, for example, fish, tree, bird, rain, until the picture for the final sentence "The bird flied away," which requires using the eraser to remove the bird and draw more rain drops at the spot where the bird was standing.

Items 4 and 5 in the questionnaires examine whether the teachers think gestalt visualization functions are useful and easy to use in practical reading classroom. The high values of the means of Item 4 (4.90) and Item 5 (4.30) revealed that most of the participants hold positive attitudes on the usefulness and simplicity of use of the gestalt visualization functions (see Table 3).

The descriptive analysis in Figure 13 demonstrates that 90% of the participants strongly agree that the gestalt visualization functions are useful and 10% of them agree with the statement. None of them holds neutral or negative attitudes toward the usefulness of these functions. When the participants were asked whether they feel these functions are easy and convenient to use, 50%

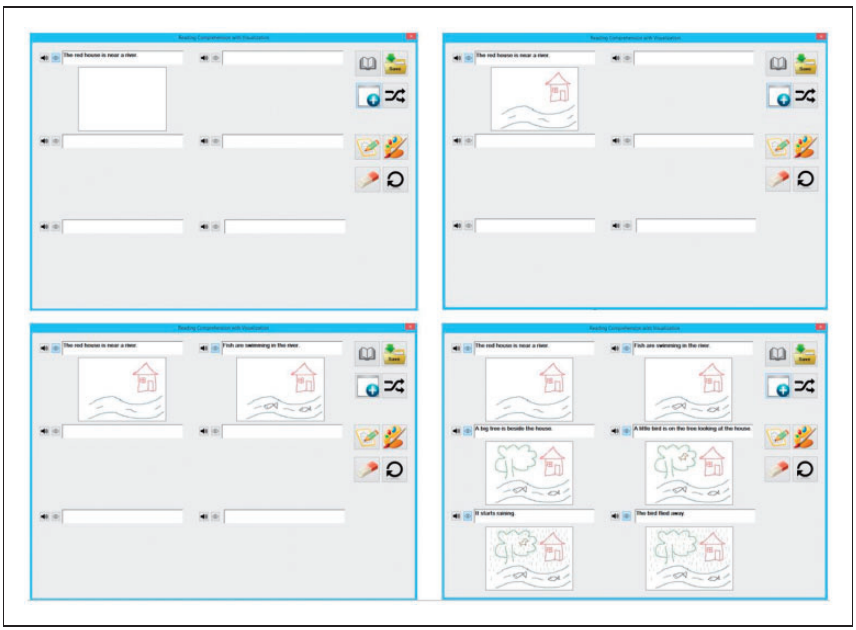

Figure 12. Generating concept imagery by building mental images sentence by sentence.

Table 3. Descriptive Statistics of Teachers' Feedback on Gestalt Visualization Functions.

Questions	N	Minimum	Maximum	Mean	Standard deviation
Item 4 (usefulness)	20	4	5	4.90	.308
Item 5 (easiness of use)	20	3	5	4.30	.801

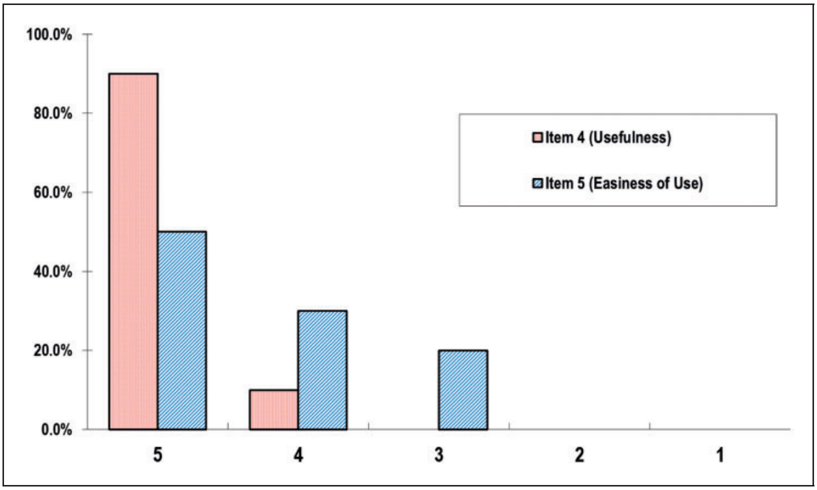

Figure 13. Descriptive analysis of teachers' feedback on gestalt visualization functions.

strongly agree, 30% agree, 20% are neutral, and none feel they are difficult to use. These results indicate the usefulness of the gestalt visualization functions from the teachers' perspective. The neutral responses might come from those teachers who are not used to the operations of dragging and dropping an image file directly onto a picture box.

Story retelling. Story retelling is a popular activity for classroom teachers to check students' comprehension of what has been read. This application offers two distinct ways to help students recall the storyline. The teacher could instruct the student to hide all the sentences and describe the meaning of each picture (see Figure 14). Alternatively, the teacher may ask the student to shuffle the pictures and then sequence them back in order according to the development of the story they just read (see Figure 15).

Items 6 and 7 in the questionnaire investigate whether the teachers think story retelling functions are helpful and easy for reading teachers to use in

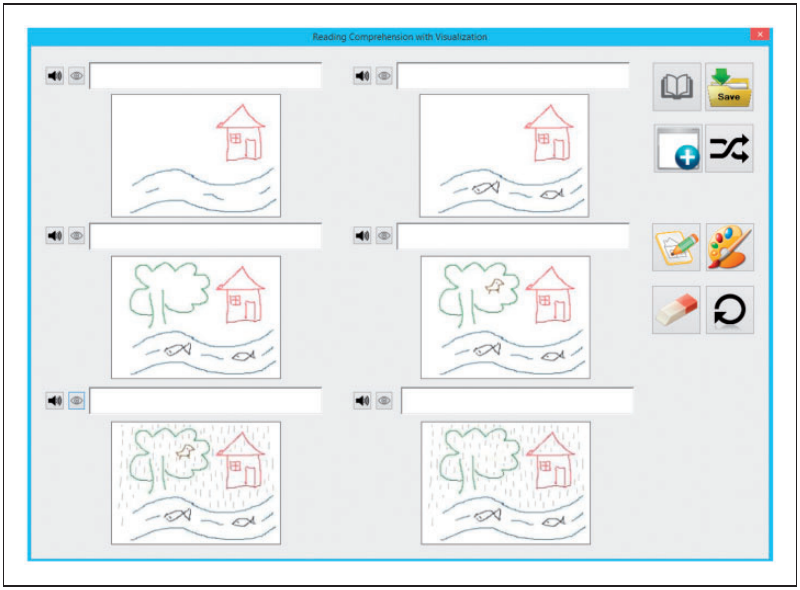

Figure 14. Story retelling with sentences hidden.

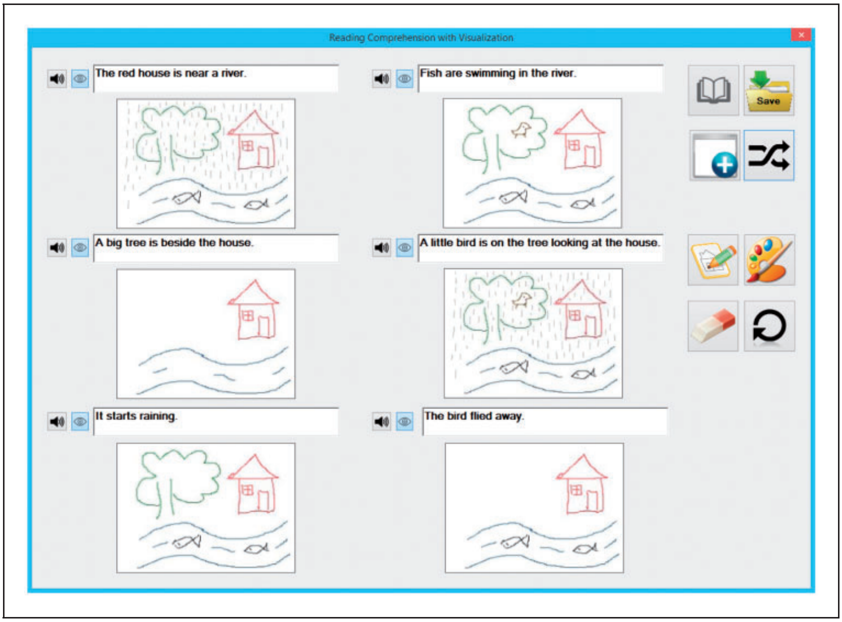

Figure 15. Story retelling through picture reordering.

classrooms. The means of Item 6 (4.80) and Item 7 (4.45) revealed that most participants agree that the story retelling functions are useful and easy to use (see Table 4).

The descriptive analysis in Figure 16 shows that 80% of the participants strongly agree that the story retelling functions are useful and 20% of teachers agree with this statement. None of them holds neutral or negative attitude toward the usefulness of these functions. Fifty-five percent of the participants strongly agree these functions are easy to use, and 35% agree with this statement. Only 10% are neutral, and none feel they are difficult to use. These results indicate the usefulness of the story retelling functions from the teachers' perspective.

Auditory narration. According to Mayer's Generative Theory of Multimedia Learning, the input from both visual and auditory sensors may utilize memories

Table 4. Descriptive Statistics of Teachers' Feedback on Story Retelling Functions.

Questions	N	Minimum	Maximum	Mean	Standard deviation
Item 6 (usefulness)	20	4	5	4.80	.410
Item 7 (easiness of use)	20	3	5	4.45	.686

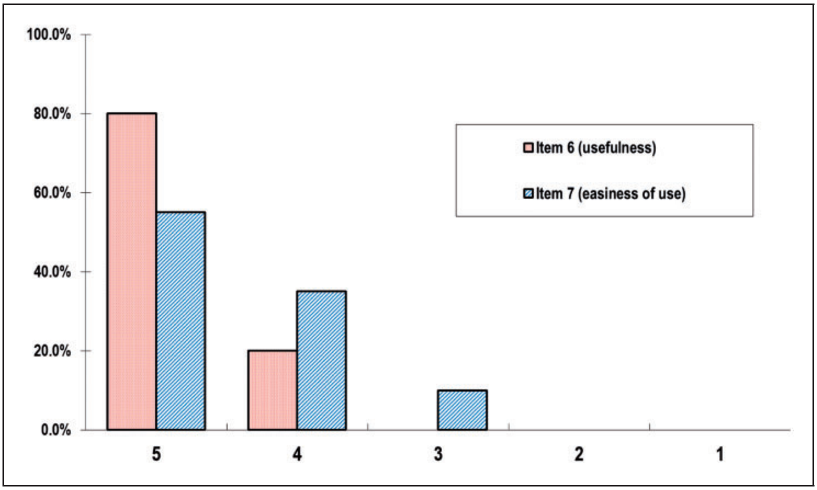

Figure 16. Descriptive analysis of teachers' feedback on story retelling functions.

more efficiently than the input from only one sensor (Mayer, 2001). The auditory narration of the sentences was implemented use Text-to-Speech (TTS) on the Microsoft Speech Platform, which refers to the ability of the operating system to play back printed text as spoken words. An internal driver, called a TTS engine, recognizes the text and uses a synthesized voice chosen from several pregenerated voices to speak the written text.

The auditory narration can be activated when the sentences are either shown or hidden. The student may listen to the oral presentation of the sentence while drawing the picture. During the story retelling, the teacher may ask the students to hide all the sentences before shuffling the pictures, and then request them to rearrange the pictures by listening to the audio playback of the sentences instead. Generative Theory of Multimedia Learning tells us that when the text is presented through narration, it should yield better results than the method using picture with on screen text that are processed in the same visual channel because picture and narration coding are processed through visual and auditory channels, respectively (Mayer, 2001).

Items 8 and 9 in the questionnaire examine whether the teachers feel auditory narration functions are helpful and easy to use in classrooms. The means of Item 8 (4.35) and Item 9 (4.60) revealed that most participants feel that the auditory narration functions are helpful and convenient to use (see Table 5).

The descriptive analysis in Figure 17 illustrates that 45% of the participants strongly agree that the auditory narration functions are useful, 45% of them agree, and 10% are neutral. None of them holds negative attitude toward the usefulness of these functions. When participants were asked whether these functions are easy to use, 60% of them strongly agree, 40% agree, and none holds neutral or negative attitude toward the easiness of use of these functions. These results indicate the usefulness of the auditory narration functions from the teachers' perspective.

The very last item in the questionnaires investigates classroom teachers' attitude toward integrating this application into their daily reading instruction session (see Table 6). All the participants are interested in using this application in their reading lessons, with 85% of them show strong interest and 15% of them willing to utilize it to help their students.

Table 5. Descriptive Statistics of Teachers' Feedback on Auditory Narration Functions.

Questions	N	Minimum	Maximum	Mean	Standard deviation
Item 8 (usefulness)	20	3	5	4.35	.671
Item 9 (easiness of use)	20	3	5	4.60	.503

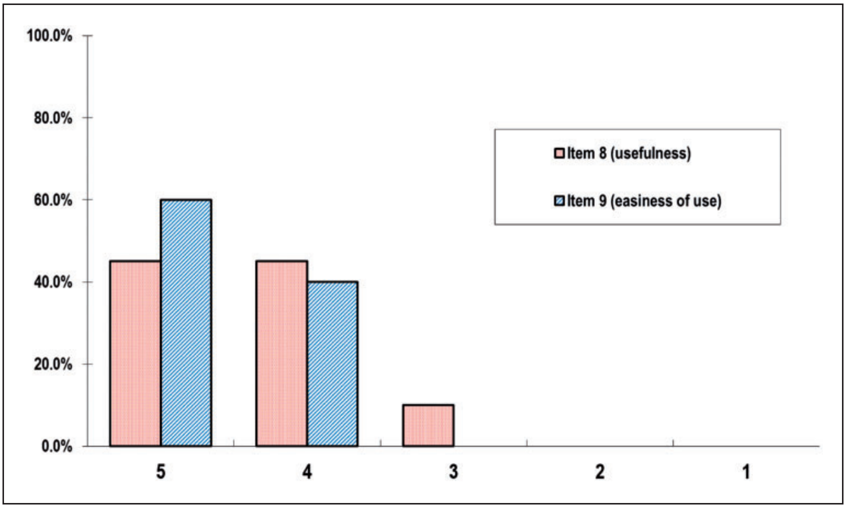

Figure 17. Descriptive analysis of teachers' feedback on auditory narration functions.

Table 6. Descriptive Analysis of Teachers' Attitude Toward Integrating This Application Into Their Daily Reading Instruction Session.

Item 1	Frequency	Percent	Valid percent	Cumulative percent
1 Strongly disagree	0	0.0	0.0	0.0
2 Disagree	0	0.0	0.0	0.0
3 Neutral	0	0.0	0.0	0.0
4 Agree	3	15.0	15.0	15.0
5 Strongly agree	17	85.0	85.0	100.0
Total	20	100.0	100.0	

Discussion

The innovative application developed using Unified Process model is the first computer software aiming to improve reading comprehension of students with gestalt imagery deficit based on dual-coded visual instructions. Its intelligence lies in guiding the students to create their own drawings in sequence to visually present the understanding of a passage sentence by sentence. Not only does it assist the students to generate mental images as a whole of what they are reading, but it also reinforces their memorization of the story by building connections in this series of pictures.

Implications

Feedback from teachers who evaluated the application indicates that it has significant implications in practical teaching. Teachers often encourage students to make pictures in their mind like a movie when they read. However, many students can only "call words" instead of reading words due to the failure of making such mental images when attempting to comprehend what they read. This application, if appropriately integrated into the reading instruction, may help students with difficulty imaging, retaining, and retelling what has been read.

In general, teachers believe if a student can take control of a part of the lesson, he or she can take more away from it (Pearson & Gallagher, 1983). Most students today are used to do activities on computers and tablets. This application allows students to be more engaged but feel less challenging in constructing the meaning of a passage by taking a small step each time, that is, illustrating one sentence at a time with their creativity. The interactive drawing via a touch screen presentation can effectively keep students' attention to the reading activity given the following features: the student needs to click on the button beside each individual textbox to see the sentence, which would prevent them from working ahead or getting confused; the student can have access to predrawn pictures if he or she is struggling to create one of their own; loading previously saved pictures through a simple drag and drop action adds another level of control so that the student will have a better chance to complete the activity, and therefore avoid the frustration when getting stuck on a complex sentence.

Instead of using illustrations copied from the book to help students retell a story they read as some teachers usually do, this application enables students to do retelling with their own drawings, which may help the retention of the details and sequence of the story, because the meaning of the sentences are now represented by their self-created drawings. In addition, the shuffling feature that pictures can be mixed up for students to sort them out offers an alternative practice for sequencing and retelling.

The pictures drawn by students in each lesson would make a great formative assessment for the teacher to accurately locate the exact areas that individual students need extra help. The teacher can also review the saved pictures over a period of time to identify patterns that some students consistently struggle in comprehending certain type of information. With these valuable data, teachers will be able to create corresponding reading instructions for these students.

According to the Dual-Coding Theory, this application should work better on concrete sentences than abstract sentences due to the intrinsic connection between a concrete sentence in the verbal system and its counterpart of image that retains the meaning in the nonverbal system. However, as the reading materials in *K*-5 classrooms and many introductory basic reading passages for English Language Learners (ELL) students include more concrete sentences than abstract information in the most popular genres, this application can be used in a wide range of reading comprehension activities. Moreover, constructing the meaning of concrete sentences by young *K-5* readers can serve as a good starting point for comprehending more complex abstract reading materials when they get older. With the help of this application, young readers with gestalt imagery deficit should have better chance of imaging, understanding and retaining what they read. This will increase their reading interest and motivation, and build positive reading attitudes and habits, which are important factors for a good reader regardless of his or her age and the type of materials they read.

Limitations

Like all computer programs, the current version of the application has its limitations: (a) dragging a picture from another window on a tablet may not be so handy for some students, (b) it would be helpful to have the words highlighted as they were being read, (c) instead of using a standard full color palette, it could have only basic colors to keep students from playing with all of them, and (d) it could have loaded commonly used predrawn objects, such as houses, pets, plants, and so on, for students to drag and drop into the picture box.

Moreover, although the application is very functional, it can be improved if its appearance is more attractive to young readers and its operations can be adapted to the motor skills of younger readers. For instance, the UI could be more aesthetically pleasing to children by using vivid colors and bigger and cute buttons to keep their attention. Pictures could be automatically aligned to the grid below each sentence in the story retell activity so that the student does not need to put them precisely in place.

This study only investigated teacher perceptions of the usefulness of this application in assisting students with imagery deficit during reading. The research on the effectiveness of using this application in practical classrooms to improve the reading comprehension of students with imagery deficit demands a comprehensive empirical study that collects and analyzes student use of the application, and adopts more rigorous statistical methods, such as ANOVA and ANCOVA, as well as a large group of voluntary participants.

Conclusion and Future Work

This study presents a complete cycle of using the Unified Process method to develop a multimedia application for improving reading comprehension of students with gestalt imagery deficit. Both reading teachers and their students can benefit from its novel features based on the Dual-Coding Theory and Generative

Theory of Multimedia Learning. The teacher could efficiently develop reading comprehension lessons, analyze students' learning outcomes, and evaluate students' learning needs, while the students can work on their comprehension and retelling of the target passage/story in an engaging circumstance where the gestalt image of the story is generated through interactive drawings and diversified reading activities. Besides being used to identify students who may have gestalt visualization deficit in *K*-5 classrooms, this application can be easily incorporated into daily reading instruction for ELLs, special education students, or potentially any student having trouble making mental images when they read.

Future development may include predrawn objects and events relevant to the abstract sentences presented in the passage so that the students can apply these predrawn objects to construct a picture instead of creating self-generated pictures from the scratch. Furthermore, although plain text files are satisfactory for managing lessons and convenient to use, we will explore the advantages of using databases to store and retrieve student information, lessons, drawings, and even steps that each student has taken during the story retelling. The database could be a lightweight embedded database management system, for example, SQLite, which has small footprint but offers sufficient functions for this type of educational applications (Lv, Xu, & Li). More importantly, we will seek the opportunity to distribute this application to *K*-5, ELL, and special education classrooms so that an empirical study can be conducted to validate the effectiveness of this innovative multimedia learning tool.

Appendix: Questionnaires for Teachers to Evaluate the Application

	Question	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
1	Overall I think this application is effective in helping students with difficulty imaging/retaining/retelling what has been read.					
2	The data management features are useful and practical.					
3	The data management functions are easy and convenient for me to use.					

(continued)

Continued

	Question	Strongly disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly agree 5
4	The gestalt visualization functions are useful and practical.					
5	The gestalt visualization functions are easy and convenient for me to use.					
6	The story retelling functions are useful and practical.					
7	The story retelling functions are easy and convenient for me to use.					
8	The auditory narration functions are useful and practical.					
9	The auditory narration functions are easy and convenient for me to use.					
10	I am willing to integrate this application into my daily teaching of reading comprehension.					

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was support by our university (Austin Peay State University)'s 2016–2017 Research Support Grant (RSG) Program, which was an institutional internal grant.

References

Al-Seghayer, K. (2001). The effect of multimedia annotation modes on L2 vocabulary acquisition: A comparative study. *Language Learning & Technology*, *5*(1), 202–232.

Arlow, J., & Neustadt, I. (2005). *UML 2 and the unified process: Practical object-oriented analysis and design*. Upper Saddle River, NJ: Pearson Education.

Baddeley, A. (1992). Working memory. *Science*, *255*(5044), 556–559.

Beatty, K. (2013). *Teaching & researching: Computer-assisted language learning*. Abingdon, England: Routledge.

Begg, I., & Paivio, A. (1969). Concreteness and imagery in sentence meaning. *Journal of Verbal Learning and Verbal Behavior*, *8*, 821–827.

Bell, N. (1991). Gestalt imagery: A critical factor in language comprehension. *Annals of Dyslexia*, *41*(1), 246–260.

Bell, N., & Lindamood, P. (1991). *Visualizing and verbalizing: For language comprehension and thinking*. Paso Robles, CA: Academy of Reading Publications.

Bell, N. (2015). *Visualizing and verbalizing program for cognitive development, comprehension, & thinking*. Retrieved from http://www.lindamoodbell.com/programs/visualizing-verbalizing.html

Chen, Z. (2006). *The effects of multimedia annotations on L2 vocabulary immediate recall and reading comprehension: A comparative study of text-picture and audio-picture annotations under incidental and intentional learning conditions* (Doctoral dissertation, DAI-A, 68/01, 170). University of South Florida, Tampa, FL.

Chuang, H. Y., & Ku, H. Y. (2011). The effect of compute-based multimedia instruction with Chinese character recognition. *Educational Media International*, *48*(1), 27–41.

Chun, D. M., & Plass, J. L. (1996). Effects of multimedia annotations on vocabulary acquisition. *The Modern Language Journal*, *80*(2), 183–198.

Cohen, M. T., & Johnson, H. L. (2011). Improving the acquisition of novel vocabulary through the use of imagery interventions. *Early Childhood Education Journal*, *38*(5), 357–366.

Davis, N., & Lyman-Hager, M. (1997). Computers and L2 reading: Student performance, student attitudes. *Foreign Language Annals*, *30*(1), 58–72.

Denis, M. (1984). Imagery and prose: A critical review of research on adults and children. *Text*, *4*(4), 381–401.

Eddy, J., & Glass, A. (1981). Reading and listening to high and low imagery sentences. *Journal of Verbal Learning and Verbal Behavior*, *20*(3), 333–345.

Esposito, D., & Saltarello, A. (2014). *Microsoft. NET – Architecting applications for the enterprise*. Redmond, WA: Microsoft Press.

Ghezzi, C., Jazayeri, M., & Mandrioli, D. (2002). *Fundamentals of software engineering*. Upper Saddle River, NJ: Prentice Hall PTR.

Glenberg, A. M., & Langston, W. E. (1992). Comprehension of illustrated text: Pictures help to build mental models. *Journal of Memory and Language*, *31*(2), 129–131.

Holyoak, K. J. (1974). The role of imagery in the evaluation of sentences: Imagery or semantic factors? *Journal of Verbal Learning and Verbal Behavior*, *13*(2), 163–166.

Holmes, V., & Langford, J. (1976). Comprehension and recall of abstract and concrete sentences. *Journal of Verbal Learning and Verbal Behavior*, *15*(5), 559–566.

Jorgensen, C., & Kintsch, W. (1973). The role of imagery in the evaluation of sentences. *Cognitive Psychology*, *4*(1), 110–116.

Kruchten, P. (2004). *The rational unified process: An introduction*. Boston, MA: Addison-Wesley Professional.

Kuo, M., & Hooper, S. (2004). The effects of visual and verbal coding mnemonics on learning Chinese characters in computer-based instruction. *Educational Technology Research and Development*, *52*(3), 23–38.

Lenz, G., & Moeller, T. (2004). *NET: A complete development cycle*. Boston, MA: Addison-Wesley Professional.

Levin, J. R., & Berry, J. K. (1980). Children's learning of all the news that's fit to picture. *Educational Communication and Technology Journal*, *28*(3), 177–185.

Levy, M. (1997). *Computer-assisted language learning: Context and conceptualization*. Oxford, England: Oxford University Press.

Li, J. (2009). Teaching unified process in software design and development courses: A case study. *Journal of Computing Sciences in Colleges*, *24*(5), 5–11.

Li, J., Wang, L., Williams, L. L., & Allan, C. A. (2015). Development of a novel computer application to teach counting in *K*-2 classroom using the Unified Process method. *International Journal of Modern Education & Computer Science*, *7*(10), 1–11.

Lv, J., Xu, S., & Li, Y. (2009, May). Application research of embedded database SQLite. *International Forum on Information Technology and Applications, 2009. IFITA'09* (Vol. 2, pp. 539–543). Los Alamitos, CA: IEEE.

Maciaszek, L., & Liong, B. L. (2004). *Practical software engineering: An interactive case-study approach to information systems development*. Boston, MA: Pearson Addison Wesley.

Mayer, R. E. (2001). *Multimedia learning*. New York, NY: Cambridge University Press.

O'Neil, B., & Paivio, A. (1978). Some consequences of violating selection restrictions in concrete and abstract sentences. *Canadian Journal of Psychology*, *32*(1), 3–18.

Paivio, A. (1990). *Mental representations: A dual coding approach*. New York, NY: Oxford University Press.

Pearson, P. D., & Gallagher, M. C. (1983). The instruction of reading comprehension. *Contemporary Educational Psychology*, *8*(3), 317–344.

Plass, J. L., Chun, D. M., Mayer, R. E., & Leutner, D. (1998). Supporting visual and verbal learning preferences in a second-language multimedia learning environment. *Journal of Educational Psychology*, *90*(1), 25–36.

Purnell, K. N., & Solman, R. T. (1991). The influence of technical illustrations on students' comprehension in geography. *Reading Research Quarterly*, *26*(3), 277–299.

Sadoski, M., Goetz, E., & Fritz, J. (1993). Impact of concreteness on comprehensibility, interest, and memory for text: Implications for dual coding theory and text design. *Journal of Educational Psychology*, *85*(2), 291–304.

Sadoski, M., & Paivio, A. (2013). *Imagery and text: A dual coding theory of reading and writing*. Abingdon, England: Routledge.

Troelsen, A. (2012). *Pro C# 5.0 and the .NET 4.5 framework*. New York, NY: Apress.

Wang, L. (2014). The effects of single and dual coded multimedia instructional methods on Chinese character learning. *Chinese as a Second Language Research*, *3*(1), 1–25.

Wang, L., & Blackwell, A. (2015). Effects of dual coded multimedia instruction employing image morphing on learning a logographic language. *Journal of Educational Multimedia and Hypermedia*, *24*(3), 281–313.

Warschauer, M., & Healey, D. (1998). Computers and language learning: An overview. *Language Teaching*, *31*(2), 57–71.

Windle, D. R., & Abreo, L. R. (2003). *Software requirements using the unified process: A practical approach*. Upper Saddle River, NJ: Prentice Hall Professional.

Author Biographies

Ling Wang is an associate professor of Reading at Austin Peay State University. She holds a PhD degree in Literacy Studies from the Middle Tennessee State University. She also holds a MA Ed degree in Reading from Austin Peay State

University and a MA degree in Foreign Languages and Applied Linguistics from Shandong University of Finance. Her research interest is in educational multimedia, literacy studies, and foreign language acquisition. She has published multiple refereed journal and conference articles. Dr. Wang is a member of International Literacy Association, and she currently serves on the Editorial Boards of *Journal of Educational Multimedia and Hypermedia* and *Journal of Technology and Teacher Education*.

Jiang Li is a professor of Computer Science at Austin Peay State University. He holds a PhD degree in Engineering and Computer Science from the University of Nebraska–Lincoln. He also holds MS and BS degrees in Electrical Engineering from the Beijing Institute of Technology. Dr. Li's research interest is in Data Mining, Machine Learning, Image Processing, Software Engineering, and Distributed Computing. He has published over 30 refereed articles in international journals and conference proceedings. Dr. Li is a member of ACM and ODBMS.ORG's Panel of Experts. He currently serves as the Editor-in-Chief of *International Journal of Image, Graphics, and Signal Processing (IJIGSP)*.