A Web-based Reading Environment Designed to Fundamentally Extend Readers' Interaction with Informational Texts

Abstract: Given that text (the word "text" is used to refer to both verbal only and multimedia text) is a primary means of acquiring and communicating knowledge, development of effective reading skills is crucial to the success of any society in a global knowledge-based economy. The research being reported led to the design of a Web-based reading environment that fundamentally extends the ways in which readers interact with text. This research had two purposes: (a) to design and develop a Web-based reading environment that supports the use of a set of reading strategies, and (b) to investigate the impact of this Web-based reading environment on readers' memory and understanding of an instructional unit on the human heart.

Introduction

Students, particularly those in Science, Technology, Engineering, and Mathematics (STEM) fields, are faced with a situation in which they are expected to develop mastery of substantial and ever-growing bodies of knowledge in a limited time (Yore, Bisanz, & Hand, 2003). This requires adeptness with text which unfortunately is lacking in many US students. A report by the RAND Reading Study Group (Snow, 2002) noted that US students' lack of proficiency in reading puts them at a clear disadvantage with regard to learning from informational texts when compared with their peers in other countries. In fact, 11^{th} grade students in the US were placed close to the bottom of all industrialized countries in a comparison on reading achievement. This deficiency in reading skills leads many students to drop out of STEM fields. There is also substantial evidence of an achievement gap in reading between low-economic status, at-risk students and their more privileged peers (NCES, 2000). At the same time, the RAND Reading Study group (Snow, 2002) noted that our knowledge of cognitive processes and strategies related to reading comprehension is inadequate to sufficiently reform comprehension instruction. This state of affairs has motivated work on a Web-based reading environment that is designed to extend the ways in which readers engage with informational text (Kidwai, 2009).

Reading Comprehension

Reading for understanding is a non-trivial task, particularly when the reader is unfamiliar with the material being read. Even if readers can understand individual words in a text, they may not be able to link meanings of these words so as to be able to derive an understanding of larger chunks of text (Kintsch, 1988; van Dijk & Kintsch, 1983). Comprehension, defined as the ability to understand the ideas conveyed in a text, involves the creation of a mental representation of the text being read. The representation that is generated is a function of the information contained in the text and the reader's prior knowledge, which includes the reader's knowledge of the subject matter as well as the strategies for comprehension that the reader applies on the text (Mannes & George, 1996).

The quality of the reader's memory and understanding of a text is a function of the quality of the mental knowledge representations that are generated upon reading the text (Kintsch, 1988; van Oostendorp & Goldman, 1999). Higher quality knowledge representations directly impact an individual's ability to apply knowledge in novel situations. For example, the quality of knowledge representations is a known indicator of the probability of success in problem-solving situations (McNamara, E. Kintsch, Songer, & W. Kintsch, 1996).

The Technology of Text

Humankind has witnessed revolutionary advances in technologies in the past centuries, yet the "technology of text" (the form in which text is presented to readers) has remained more or less unchanged (with few exceptions such as hyperlinks and animation) since the time of the handwritten scrolls and the invention of the printing press. Research on comprehension processes demonstrates a dissonance between the form in which text is presented to readers and the cognitive processes that successful readers engage in when they read (DeStefano & LeFevre, 2007; Bannert, 2004; Gervais, 2007, Zumbach & Mohraz, 2008). For example, instead of attempting to understand a large amount of text all at once, skilled readers use a "divide and conquer" strategy which leads them to identify and tackle smaller sections of text. Only when they are comfortable with their understanding of smaller sections of the text do these readers begin to integrate their understanding of the smaller pieces into a larger whole. Even though successful readers routinely engage in such bottom-up processes, the current technology of text does not allow readers to "manipulate" text in ways that support such processing. That is, even though readers mentally break up, reorganize, and reassemble sections of text that they read, they are not able to manipulate printed text, on paper or online, in ways that reflect these operations.

Design of Web-based Reading Environment

The research being reported led to the design of a Web-based reading environment that fundamentally extends the technology of text by allowing readers to manipulate text in unique ways (Kidwai, 2009, see also AlAgha & Burd, 2009; Triantafillou, Pomportsis, & Demetriadis, 2003; Wolf, 2003). The design of the reading environment was informed by Kintsch's Construction-Integration (CI) model (Kintsch, 1988; van Dijk & Kintsch, 1983); Paivio's dual coding theory (Sadoski & Paivio, 2004; see also Ainsworth, 1999); research on the role of metacognitive processes such as comprehension monitoring (Palincsar & Brown, 1984; Pressley & Ghatala, 1990; Pressley & Harris, 2006), note-taking (Kiewra, DuBois, Christian, McShane, Meyerhoffer, & Roskelley, 1991) and summarization strategies (Armbruster, Anderson, & Ostertag, 1987; Pressley, Johnson, Symons, McGoldrick, & Kurita, 1989). Theories in human-computer interaction (Carroll, 2003) informed the design of the user-interface of the Web-based reading environment. In particular, five reading strategies were designed in the reading environment:

(a) *Text-macrostructure (chunking) strategy*: A reader can chunk the instructional unit on the human heart into smaller sections by moving elements that make up the instructional unit into *tabs* that they create on the interface of the Web-based learning environment. A reader can also label these tabs. In this way each tab on the user interface corresponds to a reader-generated *section* of instructional unit. An example of a sequence of steps that a reader would take in executing this strategy is provided below (see Figure 1, Figure 2, Figure 3). It is expected that in the process of reorganizing the instructional unit at the macro-level, the reader would begin to develop a macro-level understanding of the text—the "big picture." Being able to *customize* the instructional unit in this way should also motivate the reader to engage with it deeply.

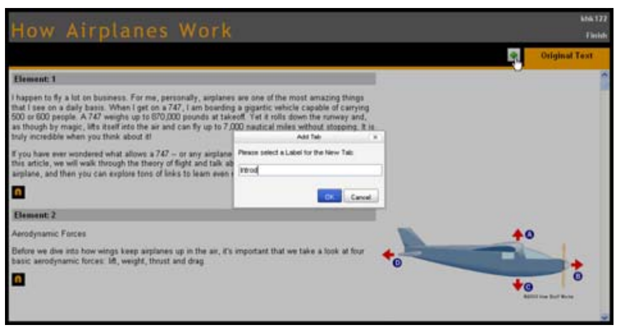

Figure 1. Text-macrostructure strategy: Creating a new section (tab on the interface).

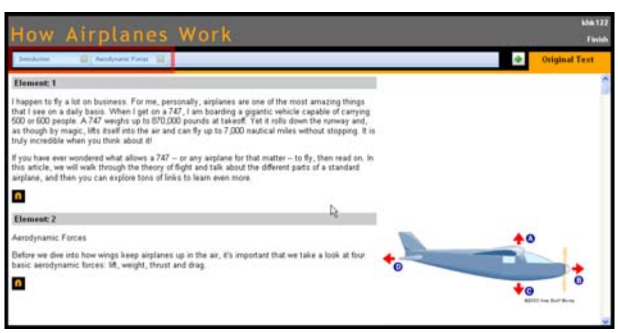

Figure 2. Text-macrostructure strategy: Two new sections are created (top-left hand corner).

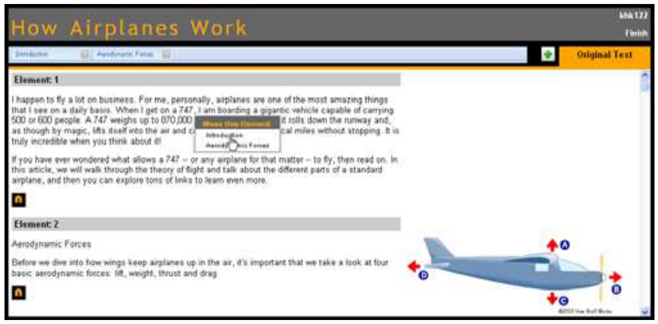

Figure 3. Text-macrostructure strategy: An element is moved to a section (tab).

b. *Summarization strategy*: A reader can write summaries for each section (tab) that she creates (see Figure 4). It is expected that in the process of writing summaries the reader would access her *macro-level understanding* of the instructional unit. In the process of writing summaries, gaps in macro-level understanding, if any, would be exposed. In the event the reader found gaps in understanding, she could take action—for example, rereading a particular section of the instructional unit (Armbruster, Anderson, & Ostertag, 1987).

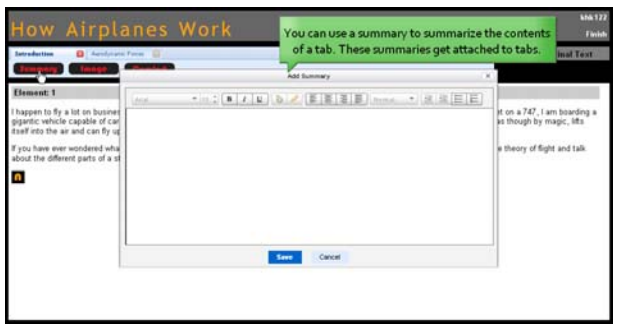

Figure 4. Summarization strategy.

c. *Imagery strategy*: A reader can select an image from a library of images that is most representative of the contents of a given section (see Figure 5). This strategy is expected to encourage readers to integrate knowledge across modalities, which in turn should lead to creation of well integrated and robust knowledge representations (Sadoski & Paivio, 2004; see also Ainsworth, 1999).

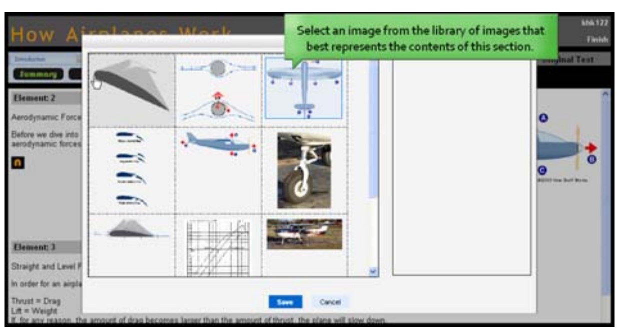

Figure 5. Imagery strategy.

d. *Reading self-assessment (comfort-meter) strategy*: A reader can mark on a scale of 1-5 how comfortable she feels with her understanding of each section of the instructional unit (see Figure 6). It is expected that a metacognitively aware reader would realize that not all sections of the instructional unit are equally challenging. On the basis of this knowledge, the reader could decide to allocate cognitive resources to the more difficult sections, for example by choosing to revisit and reread them (Pressley & Harris, 2006; Pressley & Ghatala, 1990).

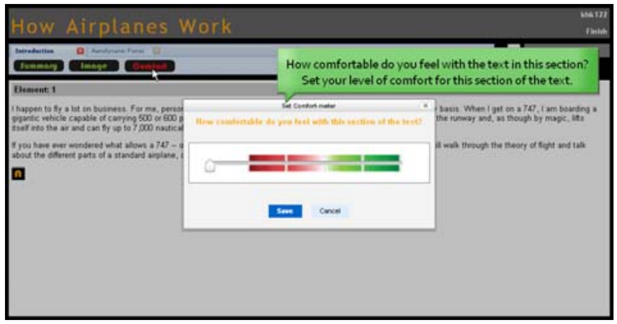

Figure 6. Reading self-assessment (comfort-meter) strategy.

e. *Note-taking strategy*: A reader can take notes on an *element-by-element* basis—these notes are attached to the elements that make up the instructional text (see Figure 7). It is expected that note-taking will support comprehension by allowing the reader to externalize her understanding, maintain attention, and provide a summary of the main points for a given element in the instructional unit (DiVesta & Gray, 1972; Peper & Mayer, 1986; see also Kiewra et al., 1991).

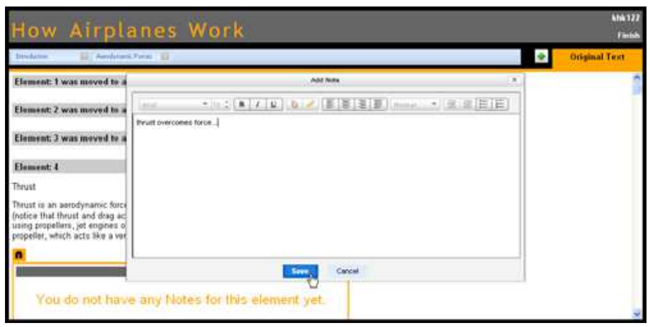

Figure 7. Note-taking strategy.

Research Goals

This research had two purposes: (a) to design and develop a Web-based reading environment that supports the use of a set of reading strategies, and (b) to investigate the impact of this Web-based reading environment on readers' memory and understanding of an instructional unit on the human heart. These purposes led to four major research goals (also see Table 1):

1. Guide the design of a Web-based reading environment that supports the use of a set of five reading strategies.
2. Establish validity and reliability of Web-based measurement instruments that were designed to measure memory and understanding of the instructional unit on the human heart at four levels of knowledge representation—micro-textbase, macro-textbase, micro-situation model and macro-situation model.
3. On the basis of these measurement instruments, determine whether participants who read the instructional unit on the human heart in the Web-based reading environment developed better memory and understanding of the instructional unit when compared with participants who read the same text on a regular Web page.
4. Develop an understanding of participants' use of the five reading strategies in the Web-based reading environment and their experience in the Web-based reading environment.

Table 1. Research goal(s), number of participants, and materials in the four phases of the design-based research investigation

Phase	Research Goals	Number of Participants	Primary Materials
Phase I	Research Goal 1: Guide the design of a Web-based learning environment.	10	Paper prototype of the Web-based learning environment with only the text-macrostructure strategy

Phase II	Research Goal 2: Establish validity and reliability of Web-based instruments that are designed to measure memory and understanding of the instructional unit on the human heart at four levels of knowledge representation—micro-textbase, macro-textbase, micro-situation model and macro-situation model.	57	Web-based human heart tests; instructional unit on the human heart presented on a regular Web-page
Phase III	Research Goal 1: Guide the design of a Web-based learning environment. Research Goal 4: Develop an understanding of readers' use of the five reading strategies in the Web-based learning environment and their experience in the Web-based learning environment.	43	Web-based and paper-form of the Web-based learning environment with all five reading strategies; animated demonstration of the Web-based learning environment; Web-based human heart tests; feedback survey
Phase IV	Research Goal 3: Determine the impact of reading in the Web-based learning environment on readers' memory and understanding of the instructional text on the human heart. Research Goal 4: Develop an understanding of readers' use of the five reading strategies in the Web-based learning environment and their experience in the Web-based learning environment.	685	Web-based learning environment with all five reading strategies; two animated demonstrations of the Web-based learning environment; Web-based human heart tests; feedback survey

Participants in the study were undergraduate students at a large public university in the northeastern United States. Potential benefits of using the strategies in the reading environment include: (a) Cognitive: Strategies such as the text-macrostructure strategy will allow readers to externalize the mental representations that they create as they read and process text. These external representations of the text should free up cognitive resources that would otherwise be used to store and recall these representations from long term memory (Niederhauser, Reynolds, Salmen & Skolmoski, 2000; Paas, Renkl & Sweller, 2004; Paas, Tuovinen, Tabbers & Van Gerven, 2003; Mayer & Moreno, 2003). Cognitive resources that are freed-up could be allocated to comprehension processes. (b) Metacognitive: Writing summaries and setting the comfort-meter will give readers an opportunity to evaluate their understanding of a given section of the instructional text (Schwartz, Andersen, Hong, Howard & McGee, 2004). Metacognitively aware readers could use this opportunity to find gaps in their understanding and take remedial action. (c) Motivational: The ability to customize text can be motivating (Lawless & Brown, 1997; Wigfield, & Guthrie). Strategies such as text-macrostructure, note-taking, summarization, imagery, and reading self-assessment, will allow readers to customize the text to suit their learning style and their level of comfort with particular sections of the instructional text.

Results

A design-based research methodology guided a series of studies that addressed the research goals in the study. These studies were conducted in four phases. Findings from each of the first three phases of the investigation were used to inform and update the design of the Web-based reading environment, the Web-based measurement instruments, and the research design of the subsequent phase. The investigation culminated in a large-scale quasi-experimental study.

In the Phase I study, participants' use of the text-macrostructure or chunking strategy was investigated with the help of an early-stage paper prototype of the Web-based reading environment. Participants' organization of the individual *elements* that made up the instructional unit on the human heart into *sections,* and the labels that participants gave these sections were markedly *different* across the six participants who completed this study. This evidence indicated that participants in the study made use of the text-macrostructure strategy to develop *unique macro-level representations* of the instructional unit on the human heart. Findings from this study provided support for incorporating the text-macrostructure strategy in the Web-based reading environment. This strategy played a key role in the overall design of the Web-based reading environment.

In the Phase II study, Web-based measurement instruments that measured participants' knowledge of the instructional unit on the human heart at four levels of knowledge representation—micro-textbase, macro-textbase, micro-situation model, and macro-situation model—were designed and validated. Technology used to develop the measurement instruments (implementation of the autocomplete design-pattern, drag-and-drop, and AJAX) and online delivery of measurement instruments was tested. The Web-based measurement instruments developed in this study were used in the subsequent phases of the investigation.

One-on-one sessions with 43 participants were conducted in the Phase III study. Participants were found to engage deeply with the reading task in the Web-based reading environment spending nearly twice as much time reading when compared with participants in the Phase II study who read the instructional unit on the human heart on a regular Web page. In preparation for the Phase IV study, an animated demonstration that provided participants an overview of the user interface of the Web-based reading environment was prepared and tested. Feedback questions related to participants' experience in the Web-based reading environment and the Web-based measurement instruments were prepared and tested. On the basis of data collected from interviews with participants, responses to the feedback survey, think-aloud and video data, numerous updates were made to the user interface and the design of the reading strategies in the Web-based reading environment.

On the basis of observations in the Phase III studies, a decision was made to develop two variants of the animated demonstration for the Web-based reading environment. The first demonstration was similar to the demonstration used in the Phase III studies. The objective of this demonstration was to provide participants an orientation of the user interface of the Web-based reading environment. In addition to providing participants an orientation of the user interface of the Web-based reading environment, the second demonstration provided *explicit instruction* on the five reading strategies.

The Phase IV study investigated the impact of the Web-based reading environment on readers' memory and understanding of an instructional unit on the human heart. Two levels of the independent variable—the Web-based reading environment—were set up: (a) Web-based reading environment with demonstration that *did not include* explicit instruction on the reading strategies (T1); and (b) Web-based reading environment with demonstration that *included* explicit instruction on the reading strategies (T2). In the control condition participants read the instructional unit on the human heart on a regular Web page. The six dependent variables in the study included scores on four tests that measured participants' memory and understanding of the instructional unit on the human heart (micro-textbase, macro-textbase, micro-situation model, and macro-situation model), time spent reading the instructional unit on the human heart, and the time spent responding to test questions. Six research questions were pursued: (a) Did the Web-based reading environment help participants develop better *memory* (micro-textbase and macro-textbase) of the instructional unit on the human heart, and was there an effect of the explicit instruction on reading strategies? (b) Did the Web-based reading environment help participants develop better *understanding* (micro-situation model and macro-situation model) of the instructional unit on the human heart, and was there an effect of the explicit instruction on reading strategies? (c) Did participants in the three experimental conditions spend equal amount of time reading the instructional unit on the human heart? (d) Did participants in the three experimental conditions spend equal amount of time responding to Web-based human heart tests? (e) How did participants use the five reading strategies in the Web-based reading environment and what was their experience in the Web-based reading environment? (f) What was participants' experience with the Web-based human heart tests?

Participants in the Web-based reading environment group with demonstration that included explicit instructions on the reading strategies (T2) performed significantly better ($p < .10$) than participants in the control group on the macro-textbase, micro-situation model, and macro-situation model tests ($p = .076$, $p = .079$, and $p = .012$ respectively). There was no difference in performance on the micro-textbase test ($p = .274$). Performance of participants in the Web-based reading environment group with demonstration that did not include explicit instructions on the reading strategies (T1) was unexpected; they scored lower than participants in the control group on all four tests.

Participants in the two Web-based reading environment conditions (T1 and T2) spent nearly twice as much time reading the instructional unit on the human heart when compared with participants in the control group who read the instructional unit on the human heart on a regular Web page ($p = .000$ and $p = .000$ respectively).

Participants in the Web-based reading environment group with demonstration that did not include explicit instructions on the reading strategies (T1) spent significantly less time responding to questions on the

Web-based human heart tests when compared with participants in the control group and the Web-based reading environment group with demonstration that included explicit instructions on the reading strategies (T2) (p = .001 and p = .001 respectively).

Feedback from participants in the Web-based reading environment groups indicated that they engaged deeply with the instructional text in the Web-based reading environment; many of the participants were able to use the five reading strategies effectively, several participants thought that they benefited from using these reading strategies. Overall, 87% of the participants noted that they had a favorable experience in the Web-based reading environment. There was a significant difference between the Web-based reading environment group with demonstration that did not include explicit instructions on the reading strategies (T1) and the Web-based reading environment group with demonstration that included explicit instructions on the reading strategies (T2) [χ^2 (1, N = 353) = 8.10, p = .004]; 93% of the participants in Treatment 2 (T2) voted favorably, as compared to 83% of the participants in Treatment 1 (T1). Furthermore, 89% of the participants in Treatment 2 (T2) noted that they would have liked to use the Web-based reading environment in the following semester. In comparison, this percentage was only 75% for participants in Treatment 1 (T1). This difference was statistically significant [χ^2 (1, N = 351) = 13.88, p = .000].

Overall, 82% of the participants found the experience of responding to questions on the Web-based human heart tests to be favorable. There was a significant difference between the three experimental groups [χ^2 (2, N = 545) = 16.62, p = .000]. Participants in the control group and the Web-based reading environment group with demonstration that included explicit instructions on the reading strategies (T2) rated their experience to be more positive (89%, 84% respectively) than participants in the Web-based reading environment group with demonstration that did not include explicit instructions on the reading strategies (T1) (73%).

Conclusion

Reading comprehension is contingent upon the successful execution of a series of cognitive and metacognitive processes. The reading strategies in the Web-based learning environment support a subset of these comprehension processes. Findings from this research stand to inform our understanding of these comprehension processes, and ways in which affordances of current Web technologies can be used to design compelling reading environments and assessments that measure learning that occurs in these environments. The Web-based learning environment also has potential for impacting the practice of reading strategies instruction. According to one participant in the study, "*Yes, I think it [reading environment] not only allowed me to learn a few things about the heart, but it also taught me that I work better when breaking text apart and categorizing the material. It also allows you to actually attach a meaning to the text instead of just reading it.*"

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