Informing the Design of Future Literacy Technologies with Theories of Cognitive Science

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INTRODUCTION

Textual information is increasingly disseminated via virtual media such as the World Wide Web or mobile applications, as opposed to physical media like books or newspapers (Goldman, Braasch, Wiley, Graesser, & Brodowinska, 2011). These new media offer numerous potential advantages over paper-based media; however, there are no commonly recognized guidelines for how these new literacy technologies can be designed to support comprehension and learning. Thankfully, cognitive theories of how humans comprehend and learn from texts can help to inform the development, implementation, and evaluation of literacy technologies, now and in the future (Rohrer & Pashler, 2010; Sparks & Rapp, 2011). In this article, we discuss developments from basic and applied research in cognitive psychology that can help inform the design of new literacy technologies. New technologies simultaneously present exciting new possibilities (e.g., the ability to dynamically tailor texts) as well as new obstacles to learning (e.g., the facilitation of distracting task-switching). In this article, we discuss empirically derived evidence from cognitive research that can help inform design decisions that will maximize comprehension and learning while overcoming potential threats to understanding that are associated with new technologies.

BACKGROUND

The Human Cognitive System and Text Comprehension

In order to consider how new literacy technologies can be designed to best support human comprehension and learning, it is important to understand the basic workings of the human cognitive system. Two components of the cognitive system that are critical to text comprehension are working memory (WM) and long term memory (LTM). WM is what allows readers to hold onto information for a brief period of time and to perform operations on it. One of the most important aspects of WM is that it is extremely limited. We all confront the short-term storage limitations of WM when we struggle to remember a long list of items that we have never encountered before. During reading, this limited capacity to hold onto information for the short term is even more constrained because it must be shared with other operations like parsing the syntactic structure of a sentence or determining what a pronoun refers to (Just & Carpenter, 1992). This means that readers often develop a very "minimal" or "local" understanding of a text that is the product of information from the current sentence and a small amount of

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information that they have been able to hold in WM from previous sentences (McKoon & Ratcliff, 1992).

In addition to WM, readers must also recruit their LTM during reading. LTM is our capacity to store information for the long term. LTM plays several vital roles in text comprehension. One of these roles is as the repository of information that readers encode from a text. When you recall something that you read minutes, hours, or years earlier, you are recalling information that you encoded in LTM. One of the goals for designing digital reading platforms that increase learning is to increase the likelihood that readers encode and can subsequently recall relevant information from LTM.

A second key role for LTM is to provide readers with relevant background knowledge for understanding a text. For example, consider the following short passage:

John was feeling very hungry as he entered the restaurant. He settled himself at a table and noticed that the waiter was nearby. Suddenly, however he realized that he'd forgotten his glasses. (adapted from Abelson, 1981, p. 715)

If someone asked you why John suddenly realized that he had forgotten his glasses, you might answer that he was going to try to read the menu. This information was never explicitly stated, but you were able to produce this answer because you recruited your prior knowledge about restaurant visits. Possessing and recruiting relevant prior knowledge is key to comprehending and learning from texts (Bransford & Johnson, 1972; Recht & Leslie, 1988). Therefore, another design goal for digital reading platforms is to help readers recruit the relevant prior knowledge that they do have. When readers do not have relevant prior knowledge for understanding a text, digital texts can also be designed to provide missing background knowledge.

A third key role for LTM is to provide readers with relevant information from earlier in a text. For example, when you read a novel, you may interpret the actions of a character in light of motivations and goals established much earlier in a text (Graesser, Singer, & Trabasso, 1994). Unfortunately, retrieving information from LTM can be too slow to facilitate real-time comprehension; and when retrieval from LTM is fast, it can be sloppy (O'Brien & Myers, 1999). Because of this sloppiness, readers may not retrieve information that is relevant for understanding the current part of a text.

In order to design virtual texts that help readers maximize comprehension and learning, it is important to be aware of these limitations. At a bare minimum, virtual texts should *do no harm*. That is, they should not impose additional limitations on the reading process. Because readers are already limited in the amount of information that they can hold in their WM and how quickly and precisely they can retrieve information from LTM, the design of virtual texts should not place additional restrictions on their access to relevant information from earlier in a text. Ideally, properly designed texts should even help readers overcome the limitations inherent to the human cognitive system. For example, properly designed texts should increase readers' access to relevant information and increase the likelihood that they encode new information in LTM.

Theories of Dynamic Text Comprehension

The process of comprehending and understanding textual information is one of the most complicated mental processes engaged in by humans (van den Broek, 2010; van den Broek & Kremer, 2000). Indeed, the ability to read is unique to our species. Theories of dynamic text comprehension posit that the ability to comprehend a text arises from a complex interaction between the reader, the text, and the reading situation (Rapp & van den Broek, 2005). In this section, we provide a brief overview of this model.

Every reader brings a host of individual characteristics that may influence the mental processes that occur during reading as well as the final memory product that is stored in long term memory after reading. At the most basic levels, readers vary in their ability to decode word meaning and comprehend oral language (Kendeou, Savage, & van den Broek, 2009). Generally, when readers are deficient in one or more of these major areas, comprehension for any given text will suffer. In addition, readers also differ across a multitude of other cognitive factors, such as working memory capacity, need for cognition, metacognitive ability, topic interest, and task motivation (Johnston, Barnes, & Desrochers, 2008; van den Broek, 2012).

These important reader factors interact with textual factors to influence the processes and products of text comprehension. Textual aspects such as genre, topic, or document structure can cause drastic changes in the