7-30-2010

Are Pictures Always Worth a Thousand Words? Interactions Between Reader, Text, and Diagrams in Multimodal Comprehension

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ARE PICTURES ALWAYS WORTH A THOUSAND WORDS? INTERACTIONS BETWEEN READER, TEXT, AND DIAGRAMS IN MULTIMODAL COMPREHENSION

by

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A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

Major: Psychology

The University of Memphis

August 2010

Dedication

This work is dedicated to those who have provided me roots, especially my parents, Burk and Roberta Renner, who loved, supported, and believed in me unconditionally; to all my family, including my grandparents, aunts, and uncles; and to my friends, including my faith family at St. Luke Lutheran Church, for all of their support over the years. Without the love and encouragement of each of them, my life would never have been so blessed – the completion of a humble thesis such as this cannot compare. I cannot say enough, but only that they have my utmost gratitude, and my pledge to always aim high and true. Thanks be to God for the gift of life, and for all of its joys, challenges, and grace for growth.

Love takes up where knowledge leaves off.

-- Saint Thomas Aquinas

Acknowledgements

I wish to sincerely thank my committee, Professors Danielle McNamara, Randy Floyd, and Loel Kim for all their very kind guidance and encouragement. Danielle continually raised the bar of what I could achieve, allowing me to swim on my own without letting me stray too far, and gladly listening to both the ideas that needed to be abandoned as well as those that showed promise. Most notably, I would like to thank her for granting me an assistantship, for going out of her way to make it possible for students to attend conferences, and for her remarkable commitment to her students. Thanks to Randy Floyd for the practical guidance he gave about the steps to come and for his interest and enthusiasm in my future. Thanks to Loel Kim for her enlightening collaboration, and for eagerly sharing knowledge of perspectives outside of psychology. Besides the committee, I would also like to thank Professor Wolfgang Schnotz for imparting further insight and expertise, and also Professor Philip McCarthy for recruiting me to the IIS and for his frequent graces as taskmaster and proofreader.

Many others have been integral in this project. My parents, Burk and Roberta Renner, inspired me to achieve and to never be complacent, and supported me financially much longer than is socially acceptable. Many professors at the Psychology Department provided crucial guidance and training. The staff of the Psychology Department helped untiringly in time of need or crisis. A special thanks to my lab mates for all the moral support and camaraderie even when I was reluctant to come out of my shell. Thanks to fellow students Natalie Davis, Judith Wilson, and Amanda Abbott for their involvement in the project. Lastly, I would like to especially thank friends Jim and Deanna, who bore the brunt of keeping me emotionally anchored during this long journey.

Abstract

Renner, Adam Marshall. M. S. The University of Memphis. August 2010. Are Pictures Always Worth a Thousand Words? Interactions between Reader, Text, and Diagram in Multimodal Comprehension. Major Professor: Danielle S. McNamara.

This study investigates the influence of diagrams and spatial layout on interactive effects of text cohesion, domain knowledge, and reading skill on the comprehension of multimodal science text. College undergraduates read either a low or high-cohesion text about cell mitosis that was or was not augmented with diagrams, and then answered text-based and bridging-inference comprehension questions. Results showed overall effects of diagrams and cohesion, but these effects largely depended on an integrated configuration as well as on ability level. Low-knowledge and less-skilled readers benefited from cohesion when the text did not contain diagrams, and only benefited from diagrams when presented with a low-cohesion text in an integrated configuration. In contrast, high-knowledge and skilled readers benefited from high-cohesion text accompanied by diagrams, but only skilled readers benefited independently of configuration. Results offer support for a linear contiguity effect and a text cohesion effect as either new multimedia design principles or as extensions of existing principles.

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Introduction

This thesis project is intended to examine interactions between reader, text, and diagrams in multimodal reading comprehension. The study investigates how separate and interactive effects of static diagrams and text cohesion may be moderated by students' prior knowledge or reading strategy use. Specifically, the thesis examines the ability of undergraduate students of different levels of reading skill and domain knowledge to comprehend two versions of a difficult cell mitosis text, whereupon the cohesiveness of the text is revised. In addition, the added support of depictive diagrams is compared to text-only versions, as is the influence of spatial configuration of the diagram relative to the text. The general theoretical approach incorporates research perspectives from the areas of text comprehension, multimedia learning, and text-picture integration.

For decades, researchers in cognitive psychology and discourse processing have strived to unravel the intricacies of learning from text-based documents. Undoubtedly, the ability to extract important information from written text is an essential function and property of the human cognitive system. Many theories and models have emerged to explain how readers process and understand text, from how readers decode and parse individual words and sentence structure, to how readers relate individual constituents to one another, to how these associations constrain the reader's active engagement with the text according to their preexisting knowledge base. Indeed, one of the most significant and consistent findings to emerge is the notion that the knowledge that learners bring to the reading experience is an influential factor in determining what information they attend to (e.g., Reynolds, 1992) and what they can comprehend and remember (e.g., Alexander & Murphy, 1996). While early research emphasized shallow levels of comprehension, investigation has more recently moved towards more integrated models of both shallow and deep levels. It is largely established that comprehension involves the interaction of both bottom-up, automatic text-driven processes and top-down, effortful knowledge-driven processes (Goldman & Rakestraw, 2000; Magliano & McNamara, 2009; Verhoeven & Perfetti, 2008).

More recently, cognitive models of comprehension have attempted to involve the understanding of multimedia documents as well. Comprehension research is now more engaged with the flexible use of different modalities, including the combination of pictorial information with linguistic information. Many genres (e.g., newspapers, magazines, and textbooks) commonly apply a combination of text, photographs, graphics, and other types of nonverbal representations to convey information (Ainsworth & VanLebeke, 2004). Moreover, because multimedia technologies are increasingly utilized in our computer-literate society (e.g., in education), it is now all the more critical to understand how students comprehend multimodal text. In fact, the development of multimedia technologies has great potential to facilitate comprehension (Mayer, 2001) and increase students' motivation and engagement in learning tasks (Rouet, Lowe, & Schnotz, 2008). However, exactly how learners combine information from multiple modalities is not fully understood, and at present this question remains a persistent challenge for researchers from the historically separate disciplines of discourse and multimedia, which must work towards more integrated theories of cognitive architectures that are increasingly global and flexible. According to McNamara and Magliano (2009), a complete theory of comprehension should involve greater focus on the representational nature of separate modalities, the ways in which different media are processed, and the integration of such distinct representations in multimedia messages.

Learning materials generally encompass many arrangements of symbolic as well as static and dynamic graphical representations. While combinations of information from different modalities may be able to optimize learning, these combinations also place particular cognitive demands on learners. For example, learners must select and organize information from dissimilar kinds of representation, create associations and consider interactions with these representations, and integrate the information from multiple sources to construct coherent mental models (Tversky, Morrison, & Betrancourt, 2002). However, quite commonly, some learners are not capable of meeting these demands, and so the presentation of multimedia may actually impede learning. For instance, previous research has shown that readers often neglect illustrations and rely too much on textual information (e.g., Tabachneck-Schijf, Leonardo, & Simon, 1997). This may be especially true for learners with low prior knowledge in the given domain, who may not be able to determine which aspects of a diagram are relevant. The question then is how we as instructional designers can induce the learner to integrate information by creating inter-representational coherence out of multiple representations, given that they are encoded and processed differently in the mind (e.g., Schnotz, 2005).

In order to contribute to a better understanding of the integrative processes involved in multimodal comprehension, this research project investigates the effects of four factors on college students' text comprehension: prior knowledge, reading strategy skill, text cohesion, and iconic diagrams. This project is intended to contribute to our existing understanding of comprehension by addressing several questions of whether visual aids can facilitate reading comprehension and in which situations they are most effective. For instance, are diagrams helpful for all learners, or only for those with prior domain or strategy knowledge? Additionally, the study examines whether visual aids can compensate for cohesion gaps in less optimal text. The results of the experiment are examined with regard to prominent theories of cognitive processing during multimedia and text-based learning. Ultimately, this project aims to contribute to a better understanding of the underlying integration processes that take place during learning with multimodal text and the factors that facilitate comprehension for a range of learners.

Related Research

Text Comprehension vs. Multimedia Research

Integration of textual and graphical representations involves a complex interplay between the learner and the learning materials. As such, the embedded agents engaged in these sorts of interactions are often an individual learners attempting to comprehend the materials on their own, but can also include pairs or groups of learners, and may incorporate a more knowledgeable domain expert such as a tutor or teacher who facilitates the learner(s)' interactions with materials and/or each other. The focus of this project is on *individual learning with text and static graphics*.

Although people comprehend information conveyed through a wide variety of media (e.g., pictures, video, conversations, reading), research of multimodal processing has typically diverged into separate fields that deal with one aspect or another. For instance, the research of *comprehension* proper has primarily centered on the specific processes related to understanding *text* and *discourse* (i.e., written or oral text; e.g., Graesser, Millis, & Zwaan, 1997). The main reason for this finer concentration is often attributed to the efficacy of written text in experiments, in that it is a media that is more easily controlled, manipulated, and analyzed. Unfortunately, this tapered focus also means that comprehension theorists have largely ignored issues surrounding text-picture integration and multimedia learning (McNamara & Magliano, 2009). Likewise, there have been a number of theoretical perspectives regarding multimedia learning (e.g., Kulhavy, Stock, & Kealy, 1993; Larkin & Simon, 1987; Mayer, 2001; Paivio, 1990; Sweller, van Merrienboer, & Paas, 1998) and more specifically text-picture integration (Schnotz, 2005), but these fields developed largely independent from the discourse research. As such, research in multimedia learning has in turn grossly overlooked many theoretical tenets that are central to text comprehension models. Ultimately, there are some dimensions that overlap between models of the two disciplines, some dimensions that vary across models, and yet many more that stand in opposition to one another. With recent technological advancements for studying visual processes (e.g., eye-tracking), the time is ripe for research camps to resolve and solidify their theories.

Although it is not evident how contemporary views in text comprehension would readily integrate with multimedia perspectives, an interactive model of text comprehension may provide the best initial framework for the study of multimodal comprehension as well. One reason is because reading comprehension, and likewise comprehension in general, is generally agreed to involve the interaction of several lower and higher level processes (e.g., Verhoeven & Perfetti, 2008). In other words, there is a dynamic two-way flow of information between our senses and our memory as we construct meaning about our environment (Rumelhart & McClelland, 1986). Text comprehension research has motivated much investigation into such interactive processing. In contrast, multimedia research has focused more on the static limitations of working memory capacity, which is often misunderstood as a cause of learning instead of an effect of other factors such as prior knowledge (e.g., Ericsson & Kintsch, 1995). Moreover, multimedia research has often limited itself to characteristics of the visual aids and has largely ignored anything to do with text, whereas there is evidence that visual representations in isolation do little to improve learning and are best used when combined with text (Ainsworth & VanLebeke, 2004). Thus, any investigation of multimodal comprehension must include text comprehension as a key element. Following this rationale, the theoretical foundation of this study follows the Construction- Integration model proposed by Kintsch (1998), considered to be one of the most inclusive and complete of text comprehension theories (McNamara & Magliano, 2009).

Although many of the processes identified in the comprehension literature may be unique to reading of text, other processes may be pertinent to comprehension of other media (Magliano, Radvansky, & Copeland, 2007). That is, even though the majority of comprehension research has been limited to the realm of discourse, some research suggests that a common set of higher order cognitive mechanisms may operate across a variety of events that are experienced (Gernsbacher, Varner, & Faust, 1990). Such a notion is generally supported by findings in neuroscience, in which there is distribution of labor between the cortex and hippocampus. The cortex is accountable for slow learning that assimilates input over multiple experiences to extract generalities, while the hippocampus carries out the rapid learning of the subjective contents of perceptual experiences (O'Reilly & Rudy, 2001). Thus, it seems likely that some of the processes involved in text comprehension may be appropriate to the understanding of other media, including visuospatial representations. Accordingly, a number of multimedia learning frameworks also have the potential to lend interpretation to this research. Such theories include Schnotz's (2005) model of text-picture integration, a multimedia learning theory that includes the investigation of textual features. Thus, a fundamental goal of the current research is to promote integration of concurrent dimensions from both fields. In the following sections, the principal theories that have exhibited influence on the research in each discipline are reviewed.

Construction-Integration (CI) Model of Text Comprehension

Overview. The hypotheses and expectations made in this proposal find their roots in the Construction-Integration (CI) model of text comprehension (Kintsch, 1988, 1998). It is a hybrid model that combines symbolic representations with a connectionist architecture, emphasizing the interaction between lower and higher level processes. That is, effective text comprehension is constrained both by automatic and active thinking, in which the reader interacts with the text on lower levels (e.g., decoding and parsing) and on higher levels (e.g., integrating the text with prior knowledge). According to this theory and most other theories of text comprehension (e.g., Albrecht & O'Brien, 1993; Graesser, Singer, & Trabasso, 1994; van den Broek, Rapp, & Kendeou, 2005; Zwaan & Radvansky, 1998), one critical process of successful comprehension is that readers purposely compare the ideas represented in the text with their existing knowledge and experiences. As such, the CI model was the first to support the idea that deep comprehension involves an understanding of not just explicit content, but of referenced and implied situations also (e.g., inferences). It is largely the influence of the CI framework that led most theories of text comprehension to include as a critical process the activation of knowledge that is not explicitly stated in the text.

According to the CI model, comprehension encompasses three levels of representation. These are the *surface code***,** the *propositional textbase***,** and the *situation model*. First, the *surface code* transmits the meaning of each word in the text as well as their syntactic relations. This representation neurologically resides in perceptual memory, and decays quickly as the reader continues to read and more incoming text replaces it. Hence, the surface structure is often unexamined in most comprehension research (including the present study), because perceptual level processes such as decoding and syntactic parsing are generally assumed to be automatic and implicit during the higher level comprehension processes that are described by the models. Next, the *textbase level* is encoded in terms of *propositions*, which preserve the meaning but not the precise words and syntax of the text being read (Best, Floyd, & McNamara, 2008). A central principle of the CI model is that the proposition is the fundamental unit of processing (McNamara & Magliano, 2009). A proposition essentially represents one complete idea, and comprises a predicate and its argument(s). It represents the essential meaning or gist of the information explicitly stated in the text.

Finally, the *situation model* comprises information in the surface structure and textbase, as well as the inferences generated by the reader that are beyond the ideas given in the text. The term situation model is particular to discourse processing, whereas the term *mental* model is applied more broadly. A person's mental model is essentially their internal representation of the external environment as it is compared to contents in memory (e.g., Johnson-Laird, 1983), whereas the situation model is the specific mental representation of what a text is about as it is integrated with prior knowledge. The situation model and the textbase are considered to be related dimensions of the same episodic memory, rather than completely separate and partitioned representations (Kintsch, 1988; McNamara & Magliano, 2009). The situation model comprises information from the text (currently or previously read), inferences derived from propositions or ideas in the text, related prior knowledge, and inferences derived from the text and prior knowledge (Graesser et al., 1994; Kintsch, 1998).

Inferences. Inferences are the new ideas created by the reader that help to build up a reader's situation model when the information available is limited or not entirely explicit. Inferencing is quite a unique phenomenon in human cognition, as this creative process is a fundamental part of our ability to learn in general. This process is important for reading comprehension because texts cannot include all the information needed to understand them (van Dijk & Kintsch, 1983). For instance, texts usually leave out common world knowledge. Kintsch (1998) classifies inferences by whether they are *automatic* vs. *controlled* and whether they are *retrieved* vs. *generated*. The first distinction concerns inferences that are triggered by the text (i.e., automatic) as opposed to inferences that are primed consciously. For example, *bridging* inferences are made when information between two separate ideas imply something that is not explicitly stated in the text. The second dichotomy regards information that is gleaned from the text as opposed to information that is generated beyond the text from prior knowledge (i.e., *elaborative* inferencing). Although both bridging and elaborative inferences may be either automatic or controlled, bridging inferences are reliant on the current context whereas elaborations go beyond the given information.

Because no text is ever completely explicit, the reader has many opportunities to make inferences. The number of opportunities is constrained by prior knowledge. However, *coherence* "gaps" can occur if the reader cannot find a means to create such a connection. When readers encounter such gaps, they may resolve them either by making inferences that allow the seemingly inconsistent information to fit within the established representation (e.g., van Dijk & Kintsch, 1983), or by rereading, reinterpreting, and reorganizing previously represented information (e.g., Goldman & Saul, 1990). Consequently, if a reader is less active and stimulates little outside knowledge, the resulting situation model is less coherent, limiting the reader to a primarily shallow (i.e., textbase) level of comprehension.

Cohesion. As previously discussed, a coherent understanding of a text depends on the reader connecting information between propositions in the textbase representation and prior knowledge in order to construct the situation model. Although these processes are usually engaged with relatively little effort, research has shown that holes in the discourse (i.e., *cohesion* gaps) force the reader to make inferences to understand the relationship between sentences (O'Reilly & McNamara, 2007). Poor readers or readers who do not have prior knowledge of the material may not be able to generate inferences successfully. Numerous studies have shown that repairing expository texts by adding cohesive devices and increasing referential overlap improves clarity (e.g., Britton & Gülgöz, 1991; McNamara, 2001; McNamara, Kintsch, Songer, & Kintsch, 1996). Increasing cohesion provides signals for the reader that tell them how to form coherent representations, which results in improved comprehension. As we will discuss, successful inference generation not only depends on the cohesive features of the text, but also depends on the reader's comprehension skill and prior knowledge.

Prior knowledge. As first demonstrated by McNamara, Kintsch, Songer, and Kintsch (1996), several studies have shown that an individual's knowledge interacts with the cohesion of a text (see also McNamara, 2001; McNamara & Kintsch, 1996; O'Reilly & McNamara, 2007; Ozuru, Dempsey, & McNamara, 2009). Domain-specific knowledge has a large influence on reading comprehension because explicit information is often not enough to produce a coherent situation model, which compels the reader to retrieve pertinent information in long-term memory (Kintsch, 1998). Readers activate and rely on their knowledge to fill in encountered cohesion gaps, to the extent that it is available. Low-knowledge readers benefit from higher cohesion because they do not possess the necessary prior knowledge to generate inferences. When cohesion is lacking, effortful inferential processes may improve the reader's understanding of the textbase, which improves the situation model for individual sentences, but generally the reader cannot make the knowledge-based inferences needed to connect separate concepts in the text. As such, improving a text's cohesion facilitates coherence for low-knowledge readers. Conversely, if high-knowledge readers are able to utilize cohesive devices to make connections between propositions automatically, then less prior knowledge is activated. Indeed, there is substantial evidence that high-knowledge readers gain from lower cohesion because the gaps in the text necessitate the activation of knowledge in order to create a coherent mental model (McNamara, 2001; McNamara & Kintsch, 1996; McNamara et al., 1996). Thus, high cohesion text benefits low-knowledge readers, whereas low cohesion text benefits high-knowledge readers. This interaction is termed the *reverse cohesion effect* (O'Reilly & McNamara, 2007). When the reader activates more prior knowledge and makes more connections within the representation, then a deeper level of comprehension can be accomplished and the resulting situation model is likely to have a stronger and more stable representation in long-term memory.

Reading comprehension skill. In addition to a knowledge-based account of inference generation, a large body of research has shown that inference making is also a large component of skilled reading (e.g., Cain & Oakhill, 1999; Graesser et al., 1994; Long, Oppy, & Seely, 1994; McNamara, 2001; O'Reilly & McNamara, 2007; Voss & Silfies, 1996). Reading skill refers to the cognitive abilities associated with the reading process in general and includes perceptual processes such as decoding and syntactic knowledge (Oakhill & Yuill, 1996). However, higher level processes for connecting various concepts contained in the text in a coherent manner (i.e., comprehension skill) is one of the most essential elements of this overall reading skill (Ozuru et al., 2009). For the purposes of this study, we use the term reading skill to denote the more specific construct of comprehension skill.

Currently, research on expository text comprehension is inconclusive regarding the causes that underlie a readers' ability to integrate textual information coherently. However, skilled readers can generally be said to be more active processors of information than less skilled readers. For instance, Cain and Oakhill (1999) found that poor readers' difficulties with bridging ideas between sentences are caused by their sentence-level comprehension problems, even though their vocabulary and decoding skills may be adequate. Whereas skilled readers are readily capable of making inferences to close conceptual gaps, less skilled readers are likely to overlook gaps and fail to generate inferences (Long et al., 1994; Oakhill & Yuill, 1996). Less skilled readers are prone to learn in a passive or less receptive manner, whereas skilled readers are more adept at monitoring and self-regulating their thoughts and behavior (Azevedo, 2008; Winne, 2001). Skilled readers are also more likely than less skilled readers to engage in successful metacognitive strategies that promote inference generation (Long et al., 1994; Oakhill & Yuill, 1996). Therefore, skilled readers more actively process the information given in the text, which thus triggers greater activation of relevant knowledge, which leads to deeper and more stable comprehension (McNamara, 2001).

Although prior knowledge and reading skill may not be completely independent constructs, they are believed to contribute to reading comprehension in distinctive ways (Hannon & Daneman, 2001; Walker, 1987). As previously discussed, prior knowledge helps readers compensate for partially explicit text when cohesion gaps induce retrieval of related information in long-term memory. Such retrieval is immediate and relatively effortless (Ozuru et al., 2009). In contrast, reading skill helps readers connect ideas and concepts from different parts of a text in a more effortful manner (Danenman & Hannon, 2001). This process of associating multiple ideas helps readers obtain a fuller grasp of the text content even when prior knowledge is lacking. Given the distinct functions of prior knowledge and reading skill in reading comprehension, the relative involvement of prior knowledge and reading skill should change as a function of textual elements and the level of comprehension measured (i.e., the types of questions used to assess comprehension).

In the present study, reading skill is expected to interact with text cohesion differently than prior knowledge. Evidence from previous studies has shown that less skilled readers may not benefit as much as skilled readers from a high-cohesion text

(Beck, McKeown, Sinatra, & Loxterman, 1991). Increasing a text's cohesion often means increasing the total amount of information, such as by adding connectives, longer explanations, or increasing referent overlap. Consequently, having to process larger amounts of information may require a higher level of reading skill, implying that less skilled readers may not benefit from a high-cohesion text as much as skilled readers.

The relationship between text cohesion, prior knowledge, and reading skill was investigated by O'Reilly and McNamara (2007) using the same biology text as in the present study. Taking into account the different ways in which prior knowledge and reading skill are thought to contribute to reading comprehension, the researchers expected that the reverse cohesion effect of prior knowledge would only apply to those high-knowledge participants who were also less skilled readers. Results showed a high-cohesion text improved comprehension for low-knowledge readers regardless of their reading skill level. They also found that high-knowledge learners only benefitted from low-cohesion text if they were less skilled readers (confirming a reverse cohesion effect). Conversely, skilled high-knowledge readers' comprehension was better for a high-cohesion text. The advantage of high cohesion was restricted to performance on text-based questions, whereas there was no effect of cohesion on bridging-inference questions. Thus, high-knowledge readers may be more affected by cohesion if they happen to lack sufficient reading skill, because reading skill, by definition, entails more active processing. A highly cohesive text can inhibit active processing for less skilled readers because it is more self-sufficient, requiring less activation of prior knowledge to maintain the text's coherence. In contrast, the non-effect on bridging-inference questions may also be regarded as a reverse cohesion effect, as skilled high-knowledge readers will make inferences regardless of the cohesion of the text because they activate their prior knowledge endogenously (i.e., there is a greater role of top-down activation). In other words, their coherence-making processing is efficient in spite of the characteristics of the text. It is active processing that facilitates surface comprehension of a high cohesion text without inhibiting deeper comprehension as for less skilled readers.

In sum, the theoretical account of cohesion effects for readers of different levels of prior knowledge relies on the notion that comprehension is largely governed by the coherence of the reader’s situation model, and this coherence is influenced by both the cohesion of the text and the inferences made by the reader according to their prior knowledge, their reading skill, or both. This assumption is generally supported by contemporary models of text and discourse.

Theories of Multimedia Learning and Text-Picture Integration

Overview. Early reviews of multimedia research concluded that work conducted prior to the 1990s had documented the benefits of visual displays but had failed to provide a theoretical framework to explain how visual displays benefit learners (e.g., Hegarty, Carpenter, & Just, 1991; Kozma, 1991; Levin, Anglin, & Carney, 1987; Winn, 1987). Reviews of more recent studies show that during the past two decades researchers have gained a better understanding of this process (e.g., Höffler & Leutner, 2007; Tversky et al., 2002; Vekiri, 2002). Findings from this discipline converge into consistent patterns that show how learner and graphic characteristics may affect learning with graphics. However, as Höffler and Leutner (2007) and Tversky et al. (2002) revealed, many of these studies contained differences in experimental conditions with regard to the content of learning material, as well as vast differences in experimental procedure across studies. Additionally, the theoretical perspectives that have guided research in multimedia learning are essentially rooted in a serial information processing framework (as opposed to connectionism or neurodynamics) and are largely more descriptive than explanatory in focus (e.g., Chandler & Sweller, 1991; Mayer, 2005; Schnotz, 2002). Moreover, researchers have focused mainly on graphical attributes (and not the text) and on working memory limitations related to human factors problems, rather than on the cognitive processes involved in integrating multimodal information. Likewise, the disregard of multimedia issues in comprehension models clearly necessitates more inclusive research. One goal of the present study is to address this need.

Dual-coding theory. First advanced by Paivio (1986), dual-coding theory is an established theory of general cognition that has been directly applied to literacy and reading comprehension. The theory's basic assumption is that human cognition is specialized for processing and representing verbal and nonverbal (imagery) information in two distinct but interconnected channels. The theory is comparable to Baddeley's (1986) two-part model of working memory, which emphasizes separate channels for visual and auditory information. Experiments based on dual-coding theory have consistently demonstrated that concurrent processing of related information in both systems can increase recall, compared to information processed in either the verbal or nonverbal system alone.

Dual-coding theory provides a basic framework for reading and comprehending multimodal documents. According to Paivio (1986), mental images are processed and represented in analogue codes (*imagens*), which preserve the main structural features of the perceived stimuli. Conversely, verbal information is processed and represented as symbolic code that arbitrarily represents real objects or their properties (*logogens*). The two types of representations differ not only in their structure but also in their organization. Visual information is organized in a synchronous manner. That is, a mental image may relay aspects of its structural features and their relationships simultaneously, and hence those components may be operated on in parallel. In contrast, verbal information is organized in semantic units and is processed in a sequential fashion. Although they are functionally distinct, the two cognitive systems are interconnected. Concurrent verbal and visual representations can form associative connections, enabling the transformation of each type of information into the other. For instance, people can mentally connect the word "cup" to a picture of a cup. Thus, listening to a word may provoke a mental image of the object or vice versa.

Dual-coding theory has several implications for education and instructional design (Clark & Paivio, 1991). Presenting both text and illustrations contiguously in instructional material enables students to store the same material in two forms of memory representations, and associations between visual and verbal representations may form during encoding. These interrelationships may increase the number of paths that learners can take to retrieve information because verbal stimuli may activate both verbal and visual representations (Clark & Paivio, 1991).

Another implication of the theory relates to the finding that people are more capable of remembering concrete rather than abstract information (Paivio, Clark, & Khan, 1988). According to Paivio and colleagues, concrete information is remembered better because it can evoke mental images and, therefore, encourage people to encode the same information in both modalities. Hence, another way visual displays may contribute to learning is by increasing the concreteness of instruction when the material is abstract (Clark & Paivio, 1991). Also, providing many visual experiences may enrich students' mental representations and increase their ability to generate mental images when they learn with text (Clark & Paivio, 1991; Kosslyn, 1988).

As discussed earlier, dual-coding theory attributes the advantages of visual displays to two factors: the existence of two representation codes in long-term memory and the structural characteristics of visual displays. However, dual-coding theory does not address some critical issues that concern the ways in which learners integrate verbal and visual information. One such issue is that the theory (and existing models of working memory) cannot adequately explain how the separate cognitive systems work together (Miyake & Shah, 1999). Second, there is no consensus among researchers on the number of cognitive systems, their limitations, and the nature of information and tasks for which they are specialized. And, finally, it is not clear how individual differences affect performance in complex tasks that require integration of verbal and nonverbal information (Miyake & Shah, 1999). These issues continue to provide questions for the research paradigms that have emerged from dual-coding theory.

Cognitive load theory. First introduced by Sweller (1988), Cognitive Load Theory is a capacity theory that describes how limited working memory resources constrain the processing of information and subsequent development of mental models. Although the theory attempts to differentiate between three types of cognitive load (i.e., intrinsic, germane, extraneous), analyses in the present study may only be interpreted with regard to total cognitive load. That is, because we do not measure cognitive load directly, by necessity we may only refer to cognitive load in general as it relates to learners' prior knowledge. Cognitive load research suggests several principles for optimizing the use and design of visual displays, which will be discussed later in this section. Such principles are particularly important in tasks that may inflict high cognitive load, such as when the learned material is of high complexity, when the materials give instruction on a time-based system, or when the processing of multiple modalities involves great mental effort by the learner (Mayer, 2005). That is, the amount of cognitive load in any given task is influenced by both the interaction of task features (e.g., layout, number of elements) with learner characteristics (e.g., prior knowledge, visuospatial skills).

As previously discussed, comprehension of a complicated text may require a higher level of reading skill because reading such a text involves processing larger amounts of information. According to Cognitive Load Theory, reading comprehension is likely to be affected not only by the amount of readers' prior knowledge but also by information-processing demands determined by the text features. In the present study, such features include both the cohesion level of the text as well as the presence and characteristics of the visual aids accompanying the text.

Cognitive theory of multimedia learning. First proposed by Mayer and colleagues (2001), the Cognitive Theory of Multimedia Learning describes how learners *select*, *organize*, and *integrate* information from different modalities into coherent mental models. That is, learners must first select relevant information from the visual and verbal external representations, coordinate that information into rational verbal and visual internal representations, and then incorporate the separate representations with one another and with prior knowledge (Mayer, 2002). The theory also advocates several principles that describe how learning is affected by redundancy, modality, and the spatial and temporal features of verbal and visual information. Several of these principles are akin to effects demonstrated in cognitive load theory.

Integrated model of text and picture comprehension. The model of integrative comprehension by Schnotz and Bannert (2003) is to a very large extent the most appropriate of multimedia learning theories to the present study. It is an extension of Paivio's dual-coding theory that more fully accounts for comprehension processes in text as well as graphics. Schnotz follows the basic idea of dual-coding theory that cognitive processing depends on dual interactive working memory systems with limited capacity, as well as separate subsystems for processing and storing information from different mediums. Schnotz's model also attempts to explain the assumed but unexplained mapping process between visual and verbal representations in Mayer's framework. According to the theory, texts and graphics are based on separate *sign systems*. *Descriptive* representations consist of symbolic signs that are based on the arbitrary relationship with the content they represent, whereas *depictive* representations consist of iconic signs that are based on the structural features with the content they represent. Depictive representations do not contain signs for relationships like symbols do; instead the relationships are captured inherently in the structural characteristics of the visual image (Kosslyn, 1994). Text comprehension is conducted via symbol processing, generating the surface structure and propositional textbase. Task-relevant information is selected and prior knowledge retrieved by means of top-down activation, which prompts the construction of a mental model based on semantic organization of the lower level representations. Picture comprehension is conducted primarily by means of low level perceptual processing (e.g., Ullman, 1984), generating a perceptual image because perception and imagery are derived from the same cognitive mechanisms (Kosslyn, 1994). However, in order to comprehend the picture, some level of semantic processing is required. Thus, picture comprehension involves not only construction of a mental model but also of a propositional representation in which semantic associations are mapped onto spatial and structural associations (see Figure 1). This rationale supports the hypothesis (relevant to the present study); namely, that learners with a high amount of prior knowledge may be better able to organize the information from their low level perceptual processing, whereas low prior knowledge learners who rely exclusively on perceptual processing may only form for themselves the illusion of having understood. In sum, learners incorporate text with their existing knowledge base to create a propositional model of the text and a distinct mental model that includes related visualizations of the information. Similarly, they also construct both types of internal representations when engaged in iconic processing (Graesser et al., 1997; Schnotz, 2005). Lastly, descriptive representations are more influential in representing propositional forms (i.e., the textbase), but depictive representations are better for drawing inferences (i.e., the mental model).

Display characteristics. In general, research has shown that diagrams can provide a valuable contribution to students' learning, but their effects are contingent upon two important factors: the characteristics of the displays themselves and the characteristics of the learners who use them (i.e., individual differences). This section describes a few principles developed from the various multimedia frameworks that are relevant to this study, many of which have common characteristics across theories.

Task relevance. As Levin et al. (1987) noted, only some displays must meet the demands of the learning task in order to be effective. For example, when the goal is to help students understand cause–effect relations or how systems behave, diagrams need to show not only the components of the systems but also how they interact and interrelate (Mayer & Gallini, 1990). When the task involves learning about dynamic phenomena, animated diagrams might be better than static displays because they depict motion and trajectory more effectively (Rieber, 1990). On the other hand, students may be able to infer motion from multiple static displays. For instance, Hegarty, Kriz, and Kate (2003) contend that people may internally represent dynamic phenomena as sequences of static images and infer motion based on their knowledge of the system. Of course, it is quite debatable whether animations are ever more effective than static media (Tversky et al., 2002) or which requisites must be met first. Indeed, an animation's utility is dependent on a large number of factors, including levels of element interactivity (Sweller et al., 1998), repleteness (i.e., similarity to the real object or system; Westelinck, Valcke, Craene, & Kirschner, 2004), control (i.e., system-paced or user-paced; Mayer, 2005), and learners' prior knowledge or visuospatial ability (Höffler & Leutner, 2007).

Spatial and temporal contiguity. Dual-coding theory predicts that providing material in both visual and verbal format enhances learning (Clark & Paivio, 1991). Additional studies coming from multimedia learning theories show that visual displays must be provided in spatial and timely coordination with the verbal information in order to be effective (Mayer, 2005). Mayer and Anderson (1992) called this effect the *spatial contiguity principle*. When learners interact with multimedia materials, they have to scan the image and read the text, process both to acquire meaning, and locate the referents between them to incorporate information from both sources. These activities can be cognitively difficult if the text and picture are placed far apart from each other (i.e., a *split-attention* format). Physical integration of verbal and visual material can help learners develop richer and more coherent mental models because they can form connections between what is presented in graphics and text. Recent studies show how different formats and spatial layouts affect viewing behavior, which thus influences learning (Holsanova, Holmquist, & Holberg, 2008).

Cueing effects. Adding visual aids to verbal material has the potential to improve comprehension, but this is contingent upon whether the display includes guidance or directional features. Rieber (1991) found that graphics only contributed to learning when students were aided by cueing devices or prompts that encouraged interaction with the graphics. Such prompts include labels and arrows, which enable readers to select relevant information and integrate it with the information in a text. According to this *signaling* principle, cues can also facilitate the mental association of elements in a diagram, including their spatial relations and interactivity (Mayer, 2005).

Avoiding redundancy. This guideline is referred to by Mayer as the *coherence* principle (Clark & Mayer, 2003), but coherence does not carry the same meaning as previously discussed. Essentially, students learn better when irrelevant material is kept out. For this reason, this study utilizes simplified *iconic* diagrams, which retain the abstracted structural and functional relationships of the object represented but eliminate unnecessary detail. Several investigations have demonstrated that increased realism can hinder learning outcomes, particularly in learners with low prior knowledge (e.g., Butcher, 2006; Parkhurst & Dwyer, 1983; Winn, 1987).

Learner characteristics. As discussed earlier in this review, reading comprehension is affected not only by the characteristics within the textual material, but also by the individual's knowledge, skills, and abilities. The same principle is also supported in multimedia learning, because design features that are optimal for some learners may not be beneficial for others.

Prior knowledge. In their studies, Hegarty and colleagues (e.g., Hegarty et al., 1991; Hegarty et al., 2003) found that individual differences in prior knowledge affected comprehension of diagrams and the quality of readers' understanding. High-knowledge participants were more capable of locating the relevant information in a diagram and extracting information more selectively (Hegarty & Just, 1989). Also, they were able to form a representation of the system even when the text did not provide all the relevant information. In contrast, low-knowledge readers did not know what parts of the system were relevant to its functioning and required direction from the text to locate and encode information from the diagram (Hegarty & Just, 1989). Another difference was that low-knowledge readers had more difficulty in comprehending parts of the system and integrating information from the text and the diagram (Hegarty & Just, 1993). As one may expect, high-knowledge readers had superior comprehension of the configuration of system components and developed a better understanding of their movement (Hegarty & Just, 1993). Altogether, these studies showed that high prior knowledge enabled readers to make more strategic use of text and diagrams and integrate information successfully from the two sources using less mental effort. This suggests that, because of the difficulties associated with information integration, the design of instructional materials should compensate for low-knowledge readers' lack of strategies. The Hegarty studies show that this can be accomplished by breaking down the information in multiple displays and by using cues (such as arrows or descriptors embedded in the display) and labels that direct readers to the parts of the display that are important (e.g., Hegarty et al., 1991; Hegarty & Just, 1993).

Visuospatial ability. Visuospatial ability is the ability to mentally produce and transform visual representations and to reason with these imagery transformations (Carroll, 1993). Although research suggests that visuospatial ability influences graphic processing, understanding of its role is limited. Mayer and Sims (1994) found that diagrams had a lower effect on students with low spatial ability. They speculated that visual displays require low-ability students to dedicate more cognitive resources to the formation of a visual representation in working memory, which reduces the resources they can allocate for building connections between verbal and visual information. Thus, it appears that diagrams may be more demanding to process, and thus less beneficial, when students have lower visuospatial ability. Although visuospatial ability is not measured in this study, several studies have shown that the relationship between visuospatial ability and text-picture integration is unclear (Miyake & Shah, 1999). In addition, a wealth of evidence supports the notion that visuospatial ability is not directly related to reading comprehension (see Floyd, Bergeron, & Alfonso, 2006). In contrast, skill differences in reading comprehension have reliably been demonstrated to relate to integration processes. Nonetheless, learners with low visuospatial ability are likely to experience difficulties in processing visual information and therefore may not benefit from graphical representations. To this end, we use iconic diagrams in this study, which have been shown to be better understood by students with low visuospatial ability.

The Present Study / Hypotheses

This thesis project examines the role of six factors on college students' comprehension of a science lesson: text cohesion, diagrams, page layout, comprehension level, prior knowledge, and reading skill. Participants learned about cell mitosis from one of eight versions of a printed text. Participants were randomly assigned to one of eight between-subjects conditions that result from the factorial combination of illustration (present, not present) text cohesion (high, low), and the page configuration (i.e., the text was presented on the left side or right side). Additionally, the participants were classified into the between-subjects individual difference groups of prior domain knowledge (high, low) and reading skill (high, low). Comprehension of the lesson is assessed using textbase and bridging-inference questions. This experiment investigates the conditions under which cohesion and diagrams benefit comprehension. Given that text cohesion and static diagrams influence learners' building of text coherence, learners' prior knowledge and reading skill should interact with text cohesion and diagrams in different ways in influencing comprehension. Thus, this study examines the extent to which prior knowledge and reading skill moderate the effect of cohesion and diagrams on both the textbase and mental model levels of comprehension. This section provides the specific research questions we want to answer as well as corresponding hypotheses and rationale.

The first set of research questions is straightforward. The literature reviewed in this proposal has shown that cohesion, prior knowledge, and reading skill are beneficial to comprehension. Therefore, we expect separate main effects for cohesion as well as for both individual difference measures. Conversely, the literature concerning the effectiveness of diagrams is inconclusive. This lack of overall consensus is not surprising, given that visual aids can vary greatly on many dimensions such as level of complexity and presence of cues. One goal of this experiment is to investigate the effectiveness of *iconic*, *simplified* diagrams that do not contain a high degree of natural detail. According to previous studies, such clear and explicit types of representations are more beneficial for low-knowledge learners than more complex visual aids (e.g., Butcher, 2006). Given that the diagrams in this experiment have the best chance to facilitate comprehension in low-knowledge learners, and presumably moreso in high-knowledge learners, it is predicted that the presence of diagrams will significantly benefit overall comprehension. Finally, all participants completed both textbase and bridging inference questions, hence a within-subjects main effect of question type on comprehension is expected.

Moving on to interaction between factors, it can be anticipated that it may be difficult to interpret between-subjects interaction effects without also considering the influence of the within-subjects factor of question type (i.e., level of comprehension measured). For instance, previous work by McNamara and colleagues has demonstrated that the benefit of cohesive text differs according to prior knowledge and reading skill, but such effects also often depend on the level of comprehension measured. One of the primary questions addressed by this research is to *what extent* does cohesive text improve comprehension? First, it is predicted that cohesion benefits comprehension for both the textbase and situation model, but that the effect is greatest for the textbase level. Because text by its nature is *descriptive* (see Schnotz, 2005), cohesion is expected to be more beneficial for the textbase representation. This hypothesis also reflects the notion that low-knowledge learners' comprehension is restricted to shallow textbase representations. Second, the effect of cohesion is not expected to depend on the presence (or absence) of diagrams overall, although it is expected that the two will be mutually beneficial. In other words, participants should perform best when both cohesion is high and diagrams are present. Third, the effect of cohesion is expected to depend on prior knowledge, such that the benefit of cohesion should be more apparent for learners with less knowledge. Whereas low-knowledge learners may benefit from high cohesion, high-knowledge learners should be induced to activate their knowledge via the gaps in a less cohesive text (i.e., the reverse cohesion effect). However, question type is expected to interact with this predicted reverse cohesion effect. That is, cohesion may be beneficial for textbase comprehension in high-knowledge learners, but it should not have an effect on their situation model comprehension. The reverse cohesion effect is likely to manifest as either an advantage of low cohesion on bridging inference questions, or have no effect (i.e., a *reverse* cohesion effect or a *non*-cohesion effect). Finally, the effect of cohesion is predicted to depend on reading skill, but in a different way. A high-cohesion text may be less beneficial for learners with less reading skill because increasing text cohesion often involves adding more information and complexity (Beck et al., 1991), requiring a higher level of reading skill to comprehend. Thus, less skilled readers are not expected to benefit from cohesion on either level of comprehension, but skilled readers may benefit on both levels. As we will discuss further however, a direct interaction between cohesion and reading skill may be difficult to interpret without also explaining the different moderating effects of reading skill for varying levels of prior knowledge.

The second primary question addressed by this research is to *what extent* do static diagrams improve comprehension? First, it is predicted that diagrams benefit comprehension for both the textbase and situation model, but that the effect is greatest for the situation model level. Because diagrams are *depictive* in nature, they are expected to be more useful for generating inferences about relationships between structural features, therefore helping learners form a situation model. Second, the effect of diagrams is not expected to interact with text cohesion because generally speaking they deal with divergent levels of comprehension, although again it is expected that comprehension may be best when both cohesion is high and diagrams are available. Third, the influence of diagrams is expected to depend on knowledge, reading skill, or on an interaction of the two. The body of previous research on prior knowledge and the optimal format of learning materials suggests that the usefulness of certain diagrams depends on a learner's background knowledge, with low-knowledge learners having difficulty knowing what features of a diagram are relevant to the text (e.g., Tabachneck-Schiff et al., 1997). Because participants are given texts both with and without diagrams, they are offered no specific instructions on what they should pay attention to. Accordingly, it can be assumed that their reading behavior is what they naturally would do. Thus, it is hypothesized that high-knowledge participants will benefit most from the diagram, either because they spend more time studying the diagram overall, or because they draw on their knowledge to select relevant features from it. However, low-knowledge learners may benefit from diagrams if they happen to be skilled readers, as they may be able to draw some basic inferences from the structural features of the diagrams. Likewise, high-knowledge learners who are also skilled readers are expected to benefit from diagrams moreso than less skilled readers. Finally, reading skill may facilitate comprehension at the textbase level as well as the situation model level when diagrams are present, because there will be a valuable amount of overlapping information for skilled readers to process.

Although the large number of independent variables can make it difficult to formulate comprehensible research questions and hypotheses, it may be helpful to reiterate potential interactions for meaningful groups separately. Indeed, the body of research on individual differences indicates that learners process information differently according to their preexisting knowledge base. The overall question can then be asked, do the effects of cohesion and diagrams vary as a function of reading skill and question type, for both low and high-knowledge learners? For learners with low domain knowledge, it is expected that cohesion helps low-knowledge learners on textbase questions only, but not on bridging-inference questions. Conversely, diagrams should not facilitate comprehension for low-knowledge learners, unless they happen to be skilled readers. The specific hypothesis is that skilled learners will make some inferences from the diagrams, but less skilled learners will likely not benefit. Actually, they may even be hurt by the presence of diagrams. As discussed earlier, low-knowledge learners may not process diagrams effectively, either because they do not know what information is relevant, or because they do not know how to integrate information from multiple sources. If the less skilled low-knowledge learners attempt to integrate information across text and diagram, it could result in overloaded working memory (i.e., cognitive overload). In general, cohesion is expected to benefit low-knowledge learners more than high-knowledge learners, but cohesion could be detrimental when combined with diagrams unless they happen to be skilled readers.

Previous research has illustrated a reverse cohesion effect for high-knowledge learners. The reverse cohesion effect will likely manifest itself in the both the unimodal conditions as a non-significant effect. That is, high-knowledge learners are expected to have equal outcomes regardless of cohesion. However, skilled readers may gain maximum benefit from the combination of high cohesion and diagrams because there is more information available to them overall. This prediction is consistent with the findings of McNamara and O'Reilly (2007), who found that only less skilled, high-knowledge learners exhibit a reverse cohesion effect. Thus, the reverse cohesion effect is not expected to depend on the influence of diagrams. The reverse cohesion effect is also expected to manifest on both question types, except that when diagrams are present, cohesion may be beneficial to the textbase comprehension for skilled readers. The notion that cohesion gaps induce high-knowledge learners into active processing provides some rationale for this prediction, but it is also likely that skilled readers will activate their knowledge equally across cohesion conditions while benefitting from the total increase in information.

In summary, it is difficult to predict precisely how cohesion will benefit comprehension when accompanied by static diagrams, although we can anticipate some interactions. While main effects should be clear, between-subjects interactions may be nonsignificant due to the influence of moderating variables and also the influence of comprehension level. Reading skill is expected to facilitate comprehension for both low and high-knowledge learners, but only at the textbase level. The exception to this prediction is when diagrams are present for low-knowledge learners, who may utilize their reading skill to draw some inferences from them. In addition, there may be a reverse cohesion effect (or a non-cohesion effect) for high-knowledge learners regardless of when diagrams are available, although they may still benefit from the diagrams. Finally, it is predicted that knowledge and reading skill facilitate comprehension of diagrams, and that their effects will be additive (i.e., skilled high-knowledge learners will outperform all other groups).

Method

Participants

Participants included 179 college undergraduate students from the University of Memphis, Tennessee. The mean age of the sample was 21.01 years (*SD* = 4.98), with a range of 17 to 50 years of age. 130 of the participants were women and 49 were men. The mean number of years enrolled in a university was 1.85 years (*SD* = 1.07), with a range of 1 to 6 years. The students enrolled in the experiment through the psychology department's subject pool system and were awarded class credit for their participation. Informed consent was obtained prior to participation.

Materials

Mitosis text. One of two versions of a difficult science text on cell mitosis was presented in the experiment. As explained in McNamara (2001), the two texts comprise an original passage taken from a high-school biology textbook measured as rather low in cohesion (see Appendix A), and a high-cohesion adaptation of the original (see Appendix B). The high-cohesion version was produced by furnishing information previously omitted in possible cohesion gaps. Seven modifications were made to the original text to increase cohesion: (a) replacing pronouns with noun phrases, (b) inserting details and elaborative information, (c) adding sentence connectives (e.g., nevertheless, additionally, before, etc.), (d) increasing semantic overlap by adding or replacing words, (e) adding headings, (f) adding global sentences, and (g) rearranging sentences or portions of sentences.

Both texts described the same content and contained all the essential information needed to respond to the open-ended comprehension questions. Traditional readability measures indicated that the low-cohesion text was 650 words in length and had a Flesch Reading Ease of 53 and a Flesch-Kincaid Grade Level of 9.2 (see Table 1). The high-cohesion adaptation was 901 words in length and had a Flesch Reading Ease of 48 and a Flesch-Kincaid Grade Level of 10.5. As cohesion increases, reading ease decreases and grade level estimates increase. These customary indices of reading difficulty indicate that the low-cohesion text may be less difficult to comprehend than the high-cohesion text. On the contrary, there is usually an inverse association between cohesion and conventional readability indices (Graesser et al., 2004). This trend generally occurs because traditional indices include sentence length as a key measure to calculate the readability value, and increasing cohesion generally produces longer sentences, thus increasing text difficulty as assessed by conventional measures. Hence, additional text cohesion measures are offered to balance the customary readability indices.

Table 1 presents the auxiliary set of cohesion indicators that were acquired with Coh-Metrix Version 2.0, a language software program used to automatically assess linguistic features of text such as cohesion (Graesser et al., 2004). The four additional measures shown in Table 1 offer a variety of reliable techniques for determining text cohesion. Causal cohesion is the degree to which sentences are linked by causal associations, and is assessed by the ratio of causal verbs to causal particles (e.g., *because*, *so that*). This ratio was higher for the high-cohesion text, suggesting that the causal relations are more explicit than in the low-cohesion text. Latent Semantic Analysis (LSA; Landauer, McNamara, Dennis, & Kintsch, 2007) is a statistical technique that has been widely successful for computationally assessing textual similarity. It is based on co-occurrences of lexical items within a large corpus of text. LSA applies singular value decomposition, a type of factor analysis, to calculate a vector *cosine* value of a high-dimensional space between two pairs of texts to represent their degree of conceptual overlap. LSA can evaluate similarity between sentences, paragraphs, or entire texts, but in the current study LSA is used to calculate the semantic relations of every sentence to each of the other sentences in the text. The high-cohesion version of the mitosis text has a higher average cosine than the low-cohesion text, thus indicating a greater amount of overall semantic connections between the concepts in the high-cohesion text.

The type-token ratio is the ratio of unique words in a text to the number of tokens of those words, or how frequently those words occur (Graesser et al. 2004). The closer the type-token ratio is to a value of 1, the less frequently each word occurs in the text (i.e., a value of 1 indicates that each word occurs only once); comprehension would be comparatively difficult because many unique words need to be processed with no repetition in the text. The high-cohesion mitosis text had a lower type-token ratio, indicating that more concepts were reiterated than in the low-cohesion text. Lastly, the connectives index is a measure of how well words and phrases are connected to one another (e.g., *because*, *as a result*, *such as*, *therefore*). As shown in Table 1, there were more connectives in the high-cohesion text than the low-cohesion text, indicating that the relationships between concepts were more explicit in the high-cohesion text.

Diagrams. Static diagrams were produced that depicted concepts from the experimental text. The illustrations comprise one circular diagram that depicts the sequence of cell division within the cell cycle, and five iconic diagrams that portray each phase of mitosis and cytokinesis. The iconic diagrams were created by taking screenshots of an animation at the point in each phase that corresponds to the text (see Appendix C). Iconic diagrams represent concrete objects, such that the structural and relational information between components is closely preserved (e.g., Koedinger & Anderson, 1990; Larkin & Simon, 1987). The diagrams were *schematized* or *simplified*, in accordance with *coherence* principles of multimedia learning (Clark & Mayer, 2003). That is, simplistic diagrams are often more supportive of learning because they leave out extraneous details and facilitate the representation of structural relations necessary for mental model development (Butcher, 2006). Lastly, labels were added to each diagram for each part of the cell that was mentioned in the corresponding text, and arrows were drawn from the labels to each component.

Comprehension questions. Participants' understanding of the mitosis lesson was determined by their responses to 14 open-ended questions (i.e., the participant had to generate the answer); seven of the questions are classified as *text-based* and seven as *bridging-inference* (see Table 2). These two question types are used to measure the textbase and situation model levels of comprehension, respectively. The question type category is established by whether the answer could be remembered from a single sentence in the text, or whether the answer had to be recalled by bridging information from across two or more sentences. In other words, answers to text-based items are contained within a single sentence in the text, whereas answers to the bridging-inference questions necessitate that the reader remember and integrate information from two or more sentences by making inferences as to how concepts are related. The questions included 10 of the 12 used in O'Reilly and McNamara (2007). Two questions were eliminated after a pilot study indicated that participants performed particularly poorly on them, and four new questions were added for a total set of 14 questions. A reliability of items analysis for the complete set of mitosis questions found a Cronbach's alpha of α = .84 for 14 items, with corrected item-total correlations ranging from .32 to .63. For the text-based questions only, Cronbach's alpha was α = .71 for 7 items, with corrected item-total correlations ranging from .34 to .55. Finally, for the bridging-inference questions, Cronbach's alpha was α = .78 for 7 items, with corrected-item total correlations ranging from .35 to .64. It was expected that the alphas for the separate question sets would be lower than the alpha for the total set because of the lower number of items, but all of the results indicate an acceptable reliability above a threshold value of .7.

A specific scoring rubric was constructed that included all the components required to score a full point. Each question is valued one point, with partial credit given for a partially correct answer (in increments of .25). That is, participants were given full credit for a question if they provided all of the necessary information required to get the full point; alternatively they were given fractional credit in quarter point increments if they only provided a part of the fully correct response. The responses were evaluated and scored by the experimenter, who was blind to condition, and twenty percent of the responses were also independently scored by an additional grader, who was also blind to condition. The experimenter and independent grader achieved an agreement of Kappa = .91, indicating that the scoring key was reliable.

Comprehension skill assessment. Participants' reading skill was evaluated with the comprehension subtest of the Nelson-Denny Adult Reading Comprehension test, Form H (Brown, Fishco, & Hanna, 1993). The test comprises 38 multiple-choice questions designed to assess reading comprehension of seven short passages, which are drawn from high school and college textbooks. The test has been found to be a reliable measure of reading comprehension ability for both high school and college students. The participants were instructed to read each passage and then answer comprehension questions about each passage, and were permitted to refer back to the text to help answer the questions. The time allotted to complete the assessment was 15 minutes. Performance is measured by the proportion answered correctly out of the total number of questions. Reliability for the reading comprehension section was $\alpha = .77$.

Participants also completed a portion of the Metacognitive Strategy Index (MSI; Schmitt, 1990). The MSI subset consists of nine multiple-choice questions that ask participants to reflect on and report their usual activities when reading. Responses are intended to uncover the participants' knowledge and use of metacognitive reading strategies, such as previewing, purpose setting, question asking, drawing from background knowledge, summarizing, predicting and verifying, and self-monitoring of comprehension. The original scale was originally built for use with narrative texts but was modified to be used with expository texts by Forget (1999). Cronbach's alpha for the MSI was $\alpha = .45$ for 9 items, indicating it was not a reliable measure in this study.

Prior knowledge assessment. Participants' science domain knowledge and general prior knowledge was assessed by a combination of open-ended and multiple-choice questions. The multiple-choice portion consists of 54 items that encompass biology ($n = 29$), the humanities ($n = 19$), and general science knowledge ($n = 6$). Each question on the multiple-choice is worth one point. Cronbach's alpha for all 54 items of the multiple choice test was $\alpha = .79$. Cronbach's alpha for the biology, humanities, and science questions was $\alpha = .69$, .59, and .22, respectively. Only the biology portion of the multiple-choice questions was used to form the domain knowledge measure.

The open-ended portion comprises eight items that especially query participants' knowledge about living cells (see Table 3). This more specific measure contains questions that are relevant to understanding the mitosis passage, but the answers to the questions are not provided in the passage. Four questions from O'Reilly and McNamara (2007) were eliminated during creation of the item set because it was found prior to the study that responses to those questions could have potentially been remembered or inferred from information in the mitosis passage. Thus, four new questions were created. Cronbach's alpha for eight questions was $\alpha = .76$ with corrected item-total correlations ranging from .23 to .63. A specific scoring rubric was constructed that included all the elements necessary for a fully correct answer. Each of these questions is worth one point, with partial credit given for portions of the correct answer (in increments of .25). Twenty percent of the cell knowledge responses was evaluated and scored by the experimenter as well as an independent grader, who were both blind to condition. The experimenter and independent grader achieved an agreement of Kappa = .93, indicating the scoring key was reliable. The experimenter then scored the remaining data.

The biology multiple-choice questions and the cell knowledge questions were converted to z-scores and averaged together to generate a composite biology domain prior knowledge score. Previous work in our lab has confirmed the appropriateness of this combination technique as a measure of domain prior knowledge (see O'Reilly & McNamara, 2007). The time allotted to answer the open-ended portion was 10 minutes, and for the multiple-choice portion 15 minutes.

Procedure

The complete set of materials was presented in a single printed 8 ½ x 11-inch booklet with "stop" pages interleaved between sections. This procedure was to prevent participants from proceeding to the following section if they finished the current section before the allotted time had elapsed. Participants were told that they could recheck their answers but could not advance to the next section if they finished early. In addition, an experimenter was in close proximity to the participants and actively monitored their progress.

Participants were randomly assigned to one of eight conditions that resulted from the factorial combination of the following experimental manipulations: diagram (present, not present), text cohesion (high, low), and the page configuration (text-left, text-right). To control the arrangement of views on each page, alternate versions of the lesson were designed; that is, one with the text on the left and the adjacent diagram on the right side of the page and one with the two views in the opposite positions. Thus, the no-illustration conditions viewed the text with the opposite half of the page blank. This positioning of the text relative to the graphics was counterbalanced so as to accommodate a possible confound of linear configuration. Linear configuration conforms to conventional patterns of reading verbal language in western cultures (e.g., left to right), and in fact, research has demonstrated that generally people adopt verbal reading direction to follow pictorial sequences (Spinillo & Dyson, 2001). Thus, it was expected that participants who viewed the diagram on the left side could have potentially performed better than those who viewed the diagram on the right side because they would have involuntarily dedicated more time and attention to the diagram. In addition, presenting the associated visual and verbal information as closely as possible in space is consistent with *contiguity* and *temporal* principles of multimedia learning (Mayer & Gallini, 1990).

The participants were tested in small groups of one to six students per session, and the experiment was completed in a single 90-minute session, although the time varied slightly according to the pace of the untimed sections. Participants' study of the lesson was self-paced, although they were asked to log their start and stop times by looking at a digital clock. Participants were instructed to study the lesson carefully and told that they would be asked to answer a set of open-ended short answer questions about the lesson afterward. They were also told that they were not permitted to refer back to the lesson upon beginning the questions. Following the text, participants completed the comprehension questions followed by several assessment batteries, each with a time limit. The experiment was carried out in the following order and time frame: mitosis text (self-paced), comprehension questions (15 min), Nelson-Denny (15 min), cell knowledge (10 min), general and biology prior knowledge (15 min), and demographics/MSI skill self-report (untimed). After completing the experiment the participants were debriefed, thanked, and dismissed.

Prior knowledge was assessed after the main experimental portion with the mitosis test so as to prevent any potential influence on the answers to the mitosis questions. Introducing items about biology and cell knowledge was anticipated to prime knowledge applicable to the mitosis passage, which could possible diminish the effect of reading skill. If reading skill is assumed to be a mediating factor in the retrieval and use of knowledge, then prompting participants with a knowledge assessment could reduce the impact of reading skill when reading the mitosis passage and answering the comprehension questions. For high-knowledge participants, priming could lessen the variation between skilled and less skilled readers' knowledge activation and use of knowledge. Although low-knowledge participants have relatively less knowledge to activate, presenting a knowledge assessment prior to the mitosis passage could also affect the results by inadvertently producing frustration or lack of interest in the study. That is, participants would struggle on the test because they lack prior knowledge, and would consequently anticipate further difficulties on subsequent sections (see, e.g., McNamara & Kintsch, 1996). In a resolute effort to make certain that none of the cell knowledge questions could be correctly answered from the mitosis passage, four questions from the O'Reilly and McNamara (2007) cell knowledge test were replaced because of possible connections between the mitosis passage and the cell knowledge questions.

Results

The alpha level for all analyses was set at .05, but results of marginal significance below .10 are also reported. The dependent measure was the proportion correct on the text-based and bridging-inference questions.

General Descriptive Statistics and Correlations

Table 4 presents the means and standard deviations as well as the minimum and maximum scores for the individual difference measures and the dependent measures, along with those from O'Reilly and McNamara (2007). On average, participants in the present study performed poorer compared to those in O'Reilly and McNamara (2007). Participants were particularly unsuccessful in answering the bridging-inference and cell knowledge questions, further indicating that the lesson and assessment materials were quite challenging.

Table 5 presents correlations between the measures. The correlations of the individual difference assessments indicate that the Nelson-Denny best correlated with general humanities knowledge but also correlated considerably well with biology and cell knowledge. This result is not surprising because performance on a comprehension skill test involves some degree of general knowledge use, and the themes covered in the Nelson-Denny tend to be general and unrelated to science topics. The correlations between the individual difference measures and the comprehension measures indicate that the measures of domain knowledge (biology, cell, and combined) correlate more highly with comprehension than does the reading skill, as assessed by the Nelson-Denny. The MSI did not correlate highly with any measures and due to its low reliability reported earlier is not included in the main analysis as an indication of reading skill.

Prior Domain Knowledge

The proportion of correct answers on the 29 biology multiple-choice questions and the 8 open-ended cell knowledge measures were converted to z scores and averaged to create a composite domain knowledge score. Participants were categorized as high-knowledge (n = 88; M = .70; SD = .71; minimum = -.17; maximum = 2.87) or low-knowledge (n = 91; M = -.68; SD = .31; minimum = -1.60; maximum = -.20) based on a median split of the composite scores. The difference between the two groups on the combined domain knowledge score was reliable, $t(177) = 16.76$, Cohen's $d = 2.54$.

An analysis of variance was conducted to inspect the relationship between the experimental factors and the prior knowledge factor. Results indicated that there was a marginally significant difference between the conditions in terms of prior knowledge, such that by chance, those in the diagram condition performed better on the prior knowledge test ($M_{\text{z-score}}$ = .12, *SE* = .094) than did those in the condition without diagrams ($M_{\text{z-score}}$ = -.11, *SE* = .092), *F*(1, 171) = 2.93, *p* = .089, Cohen's *d* = .26. No other effects or interactions between experimental conditions were found.

Comprehension Skill

As discussed earlier, only the Nelson-Denny was used as a measure of reading skill, rather than a combination of the Nelson-Denny and the MSI, because of the low reliability of the MSI and the low correlations between the MSI and performance on the comprehension questions. Participants were categorized as skilled and less-skilled readers based on the proportion correct out of the total number of questions on the Nelson-Denny test. In keeping with the prior-knowledge analysis, scores on the Nelson-Denny test was converted to z scores. Participants were classified as skilled readers (*n* = 92; *M* = .80; *SD* = .68; minimum = -.08; maximum = 2.19) or less skilled readers (*n* = 87; *M* = -.84; *SD* = .42; minimum = -.2.09; maximum = -.21) based on a median split. The z score means translate to the following proportion scores on the Nelson-Denny: M_{skilled} = .70; *SD* = .13; minimum = .53; maximum = .97; $M_{\text{less skilled}}$ = .38; *SD* = .08; minimum = .13; maximum = .50. The difference between the two groups on the reading comprehension skill score was reliable, *t*(177) = 19.17, Cohen's *d* = 2.88. An analysis of variance was performed to examine the relation between the experimental factors and reading skill factor. Results indicated no differences between the experimental conditions in terms of reading skill.

Effects of All Conditions on Time on Task

A univariate analysis of variance was conducted on reading time as a function of the between-subjects factors of page configuration (text-left, text-right), text type (low cohesion, high cohesion) and diagrams (present, not present). The means and standard deviations as a function of page configuration, text type, and diagrams are presented in Table 6. As previously discussed, participants' study of the mitosis lesson was self-paced; participants were allowed to study the lesson for as long as they liked, but they were asked to record what time they started reading and what time they finished. The time on task measure is the difference between the logged stop time and the start time, divided by the number of words in the text (as a function of the participants' text type condition). For instance, the low-cohesion text comprised 650 words, so the total number of seconds was divided by that number. Results show a significant main effect of cohesion on reading time, $F(1, 171) = 4.70$, $p = .032$, $d = .33$, indicating that participants took longer to study the lesson when given a low-cohesion text ($M = .63$ seconds per word, $SE = .025$) than when they were given a high-cohesion text ($M = .55$ seconds per word, $SE = .025$). A significant two-way interaction also emerged between cohesion and page configuration, $F(1, 171) = 4.25$, $p = .041$, indicating that the effect of cohesion was significant in the text-left configuration, $F(1, 86) = 9.89$, $p = .002$, $d = .66$ ($M_{\text{low cohesion}} = .69$ seconds per word, $SE = .033$; $M_{\text{high cohesion}} = .54$ seconds per word, $SE = .034$), but did not have an effect in the text-right configuration, $F(1, 85) < 1$. Separate analyses for the diagram and no-diagram conditions revealed that this interaction was only significant when diagrams were not available, $F(1, 87) = 3.62$, $p = .061$. There was also a marginally significant main effect for the no-diagram condition, $F(1, 87) = 3.33$, $p = .072$, $d = .29$. There were no effects or interactions for the diagram condition.

A separate analysis of covariance was then conducted in which prior knowledge was added as a between-subjects factor (high, low) and reading skill was added as a covariate. Results showed that the main effect of cohesion was still significant, $F(1, 162)$

= 5.08, p = .026, d = 33. The interaction between cohesion and page configuration was marginally significant, $F(1, 162) = 3.02$, $p = .084$. There was no main effect of prior knowledge, $F(1, 162) < 1$, but reading skill was significant as a covariate, $F(1, 162) = 6.54$, $p = .011$. Separate analyses for the diagram and no-diagram conditions found again that the interaction between cohesion and configuration was only significant when diagrams were absent, $F(1, 82) = 2.89$, $p = .093$, but was not significant when diagrams were present, $F(1, 79) < 1$. There was also a marginally significant two-way interaction between cohesion and prior knowledge when diagrams were present, $F(1, 79) = 3.11$, $p = .081$, indicating that low-knowledge readers took longer to read the low-cohesion text.

A final analysis of covariance was then performed in which reading skill was included as the between-subjects factor (high, low) with prior knowledge as the covariate. This analysis replicated the previous results, in which cohesion had a significant main effect, $F(1, 162) = 4.90$, $p = .028$, $d = .33$, and the interaction between cohesion and page configuration was marginally significant, $F(1, 162) = 3.10$, $p = .080$. Likewise, there was a marginally significant effect of reading skill, $F(1, 162) = 2.97$, $p = .087$, $d = .25$, indicating that less-skilled readers took longer to process the text ($M = .63$ seconds per word, $SE = .027$) than skilled readers ($M = .56$ seconds per word, $SE = .026$). Prior knowledge was not significant as a covariate, $F(1, 162) < 1$. Separate analyses for the diagram and no-diagram conditions found a marginally significant two-way interaction between cohesion and reading skill when diagrams were absent, $F(1, 82) = 2.95$, $p = .090$, indicating that less-skilled readers took longer to read the low-cohesion text.

Taken together, these results indicate that the low-cohesion text took longer to process than the high-cohesion text, but only when the text was positioned on the left side of the page when diagrams were absent. Low-knowledge readers took longer to read the low-cohesion text, but only when diagrams were presented along with it. In contrast, less-skilled readers only took longer to read the low-cohesion text when it was configured without diagrams and only on the left side of the page. Although there was a difference in reading time as a function of these experimental variables, results of the main analysis did not differ as function of whether reading time was included or excluded as a covariate. Consequently, it was excluded from the main analysis for greater simplicity and in order to maximize power.

Full Analysis: Reading Comprehension with Experimental Factors

A mixed 2 x 2 x 2 analysis of variance was performed on the proportion of correct responses on the mitosis passage. The analysis included the within-subjects factor of question type (text-based or bridging) and the between-subjects factors of text type (high cohesion, low cohesion), diagram (present, not present), and page configuration (text-left, text-right). The means and standard deviations as a function of text type, diagram, page configuration, and question type are provided in Table 7, with graphed data presented in Figure 2. Overall, participants correctly answered more text-based questions (M = .42, SE = .018) than bridging questions (M = .19, SE = .015), $F(1, 171) = 36.02$, $p < .001$, d = 1.07. There was a significant main effect for cohesion, $F(1, 171) = 5.39$, $p = .021$, d = .35, indicating that participants scored higher on the comprehension questions when presented with a high cohesion text (M = .34, SE = .021) than when they were presented with a low cohesion text (M = .26, SE = .021). Additionally, there was a significant two-way interaction between cohesion and question type, $F(1, 171) = 7.72$, $p = .006$, indicating that the high-cohesion text benefited participants more on text-based questions,

$F(1, 171) = 8.84$, $p = .003$, $d = .32$ ($M_{\text{high cohesion}} = .48$, $SE = .025$; $M_{\text{low cohesion}} = .37$, $SE = .025$), than on bridging questions, $F(1, 171) = 1.30$, $p = .256$ ($M_{\text{high cohesion}} = .20$, $SE = .021$; $M_{\text{low cohesion}} = .17$, $SE = .021$). There was also a main effect for diagram, $F(1, 171) = 7.69$, $p = .006$, $d = .42$, indicating higher scores on the comprehension questions when the diagrams were present ($M = .35$, $SE = .021$) than when they were absent ($M = .26$, $SE = .021$). Univariate analyses revealed that diagrams were more beneficial for bridging questions, $F(1, 171) = 10.78$, $p = .001$, $d = .62$, than for text-based questions, $F(1, 171) = 3.82$, $p = .052$, $d = .30$.

The main effect of page configuration was not reliable, $F(1, 171) = 2.06$, $p = .153$, but there was a significant two-way interaction between configuration and question type, $F(1, 171) = 4.61$, , $p = .033$ (see Figure 3). The two-way interaction indicated that participants scored higher on text-based questions when the text was on the right side of the page ($M = .46$, $SE = .025$) than when the text was on the left side of the page ($M = .39$, $SE = .025$), $F(1, 171) = 3.97$, $p = .048$, $d = .32$, whereas there was no significant benefit of page configuration on bridging questions, $F(1, 171) < 1$. Univariate analyses revealed that the effect of page configuration on text-based questions was marginally significant when diagrams were available, $F(1, 84) = 3.60$, $p = .061$, $d = .40$, but was not significant when diagrams were not available, $F(1, 87) < 1$. This result is to be expected because when the diagram is not present, page configuration should not have an effect. No other significant interactions were found.

To further examine the effects of page configuration, separate mixed 2 x 2 x 2 analyses of variance were conducted for both the text-left and text-right conditions. No significant main effects were found in the text-left condition except question type, *F*(1,

86) = 184.40, $p < .001$, $d = .98$, and a marginally significant interaction between cohesion and question type, $F(1, 86) = 3.52$, $p = .064$, again indicating that the high-cohesion text was beneficial on text-based questions but not bridging-inference questions. However, a separate univariate analysis showed that this benefit was not significant, $F(1, 86) = 1.54$, $p = .218$. In addition, a univariate analysis also revealed a marginally significant effect of diagram on bridging-inference questions, $F(1, 86) = 2.84$, $p = .096$, $d = .36$.

In the text-right condition, there was a significant main effect of question type, $F(1, 85) = 159.44$, $p < .001$, $d = 1.18$, and a significant main effect of diagram, $F(1, 85) = 6.65$, $p = .012$, $d = .55$, and a significant effect of cohesion, $F(1, 85) = 6.51$, $p = .013$, $d = .54$. The interaction between cohesion and question type was significant, $F(1, 85) = 4.26$, $p = .042$, indicating that cohesion had a greater benefit on text-based questions, $F(1, 85) = 8.27$, $p = .005$, $d = .61$, than on bridging questions, $F(1, 85) = 2.51$, $p = .117$. In a univariate analysis for the text-right condition, there was also a marginally significant interaction between cohesion and diagram on bridging-inference questions, $F(1, 85) = 3.40$, $p = .069$, indicating that diagrams were more beneficial when presented with the high-cohesion text ($M_{\text{diagram}} = .33$, $SE = .043$; $M_{\text{no diagram}} = .13$, $SE = .041$), $F(1, 42) = 8.29$, $p = .006$, $d = .87$, than when presented with the low-cohesion text ($M_{\text{diagram}} = .18$, $SE = .042$; $M_{\text{no diagram}} = .14$, $SE = .041$), $F(1, 43) = 1.01$, $p = .321$. Univariate analyses also indicated that cohesion was beneficial for text-based questions when diagrams were available, $F(1, 41) = 7.14$, $p = .011$, $d = .81$, but not when diagrams were absent, $F(1, 44) = 1.95$, $p = .170$.

These results indicate that the main effects of diagram and cohesion may depend on page configuration. First, the text-right configuration had an overall benefit on text-based questions. Second, although there was a main effect of diagrams regardless of page configuration, diagrams seemed to be most effective when they were presented on the left side of the page (i.e., the text-right configuration) and combined with a high-cohesion text. Participants in the text-left condition scored marginally better on bridging-inference questions when diagrams were available, but they scored significantly better on bridging-inference questions in the text-right condition. Moreover, participants in the text-right condition who had diagrams also scored better on text-based questions when presented with a high-cohesion text. Third, although there was a significant main effect of cohesion, this effect was associated more with performance on text-based questions. Finally, there was an interaction between cohesion and diagrams for bridging-inference questions in the text-right configuration. One possible explanation for this interaction is that it may indicate a synergistic effect of cohesion, diagrams, and configuration whereby the text-right/diagram-left configuration facilitated the foundation of a textbase representation, which in turn led to a better mapping and understanding of relations among ideas between the text and the diagrams. In other words, having the better text increased the informational overlap between text and diagram and helped learners to know what to look for in the diagrams. Such an explanation seems reasonable, considering that diagrams showed an effect on text-based questions, but only in the text-right condition. These results support previous research on linear configuration, which found that readers in Western cultures adopt a left-to-right reading pattern for pictorial sequences (see Spinillo & Dyson, 2001). The present study offers a new contribution to this literature because the linear configuration pattern was found in a multimodal format, that is, between visual aids and text. Moreover, results demonstrate how ideal linear configuration and optimal text can facilitate structure mapping as proposed by the integrative model of text-picture comprehension (see Schnotz, 2005).

Although the objective of this first analysis was to demonstrate no effect of text position (so as to demonstrate counterbalancing of linear configuration), the effect of text-right configuration did in fact interact with the two other experimental variables. Unfortunately the implication is that further analyses including the individual differences measures may potentially depend on page configuration, even though there were main effects for both factors across conditions. That is, although cohesion and diagrams were beneficial regardless of page configuration, the larger effects in the text-right configuration was largely accounted for by the high-cohesion text with diagrams (see Figure 2). Overall, diagrams facilitated the construction of a mental model, and likewise cohesion facilitated textbase comprehension. It would be unjustifiable to remove page configuration as a factor in the subsequent investigations that include the individual difference measures, because those outcomes may also be conditional on page configuration. The effect of page configuration also leads to a new question: Does this effect of page configuration depend on prior knowledge or reading skill? Originally the primary objective had been to conduct a full omnibus analysis of variance that included the within-groups factor of question type (text-based, bridging), the experimental factors of cohesion (high, low) and diagram (present, not present), and the quasi-experimental factors of prior domain knowledge (high, low), and reading comprehension skill (high, low). However, a full analysis with both individual difference factors was not feasible because of small cell sizes. Although the total number of participants recruited was appropriate, there were a disproportionate number of high-knowledge less-skilled readers in some cells, as well as a disproportionate number of low-knowledge high-skilled readers. This outcome seems to be a consequence of the moderate correlation between knowledge and reading skill, $r = .44$ as indicated in Table 5. That is, high-knowledge participants tended to also be skilled readers, whereas low-knowledge participants tended to also be less-skilled readers. Thus, the following analyses include one individual difference measure as a between-groups factor and incorporate the other measure as a covariate. In addition, page configuration is also included as a between-groups factor because it significantly interacted with the other experimental variables, and because including it produced sufficient cell sizes.

Full Analysis: Experimental and Quasi-Experimental Factors

Prior Knowledge. A mixed 2 x 2 x 2 x 2 analysis of covariance was conducted, which included the within-subjects factor of question type (text-based, bridging-inference), the between-subjects experimental factors of page configuration (text-left, text-right), diagram (present, not present) and text cohesion (high, low), and the quasi-experimental factor of prior domain knowledge (high, low). In addition, the continuous variable of reading skill was included as a covariate. The means and standard deviations as a function of text type, diagram, page configuration, knowledge, and question type are provided in Table 8.

As reported in the previous analysis, there was a main effect of question type, $F(1, 162) = 320.31$, $p < .001$, $d = 1.31$, as well as a significant main effect of text cohesion, $F(1, 162) = 5.78$, $p = .008$, $d = .30$, and a marginally significant effect of diagram, $F(1, 162) = 5.80$, $p = .051$, $d = .28$. The main effect of page configuration was not reliable, $F(1, 162) < 1$. A two-way interaction was found between question type and cohesion, $F(1, 162) = 6.17$, $p = .014$, as well as a marginally significant two-way interaction between question type and page configuration, $F(1, 162) = 3.70$, $p = .056$.

In addition to replicated results from the first analysis, there was also a main effect for prior domain knowledge, $F(1, 162) = 51.66$, $p < .001$, $d = 1.12$, indicating that high-knowledge learners scored higher ($M = .40$, $SE = .018$) than low-knowledge learners ($M = .20$, $SE = .018$). In addition, a two-way interaction was found between question type and prior knowledge, $F(1, 162) = 9.50$, $p = .002$, indicating that in comparison to low knowledge participants, high-knowledge participants scored higher on both text-based ($M_{\text{high-knowledge}} = .54$, $SE = .022$; $M_{\text{low-knowledge}} = .30$, $SE = .021$), $F(1, 162) = 67.85$, $p < .001$, $d = 1.20$, and bridging questions ($M_{\text{high-knowledge}} = .26$, $SE = .019$; $M_{\text{low-knowledge}} = .11$, $SE = .019$), $F(1, 162) = 36.464$, $p < .001$, $d = .83$. Reading skill was significant as a covariate, $F(1, 162) = 13.146$, $p < .001$.

This analysis also yielded a significant four-way interaction between question type, diagram, cohesion, and prior knowledge, $F(1, 162) = 5.30$, $p = .023$. This interaction is depicted in Figure 4. Univariate analyses revealed that cohesion was beneficial for low-knowledge learners on text-based questions, but only had a significant effect when diagrams were absent, $F(1, 48) = 15.82$, $p < .001$, $d = 1.09$, but was not significant when diagrams were available, $F(1, 33) < 1$. There was no significant effect of diagram on either question type for the low-knowledge learners, $F_{\text{text-based}}(1, 82) < 1$, $F_{\text{bridging}}(1, 82) = 2.02$, $p = .159$. For high-knowledge learners, there was a marginally significant main effect of diagram, $F(1, 79) = 3.16$, $p = .080$, and univariate analyses indicated that this benefit of diagrams was significant for bridging questions, $F(1, 79) = 4.22$, $p = .023$, $d = .46$, but not for text-based questions, $F(1, 79) < 1$. Although the overall effect of cohesion was not significant, $F(1, 79) = 2.59$, $p = .112$, there was a marginally significant effect of cohesion for text-based questions, $F(1, 79) = 3.68$, $p = .059$, $d = .41$. However, univariate analysis revealed that cohesion only helped high-knowledge learners' performance on text-based questions when the text was augmented with diagrams, $F(1, 45) = 6.029$, $p = .018$, $d = .79$, but did not significantly improve performance when diagrams were not available, $F(1, 33) < 1$. Results suggest that although low-knowledge learners only benefit from cohesion in the absence of diagrams, high-knowledge learners only benefit from cohesion when diagrams are presented with the text. Furthermore, high-knowledge learners benefited from diagrams for the bridging questions, whereas low-knowledge learners did not benefit from diagrams for either question type.

Finally, the analysis including prior knowledge yielded a marginally significant four-way interaction between page configuration, diagram, cohesion, and prior knowledge, $F(1, 162) = 3.077$, $p = .081$. This interaction is depicted in Figure 5. Separate analyses for the text-left condition yielded a marginally significant two-way interaction between cohesion and question type, $F(1, 81) = 3.25$, $p = .075$, and a marginally significant interaction between prior knowledge and question type, $F(1, 81) = 3.81$, $p = .054$. A four-way interaction between question type, diagram, cohesion, and prior knowledge was also marginally significant, $F(1, 81) = 3.63$, $p = .060$. For the text-right condition, there was a significant three-way interaction between diagram, cohesion, and prior knowledge, $F(1, 80) = 5.12$, $p = .025$. These results suggest that the benefits of cohesion and diagrams depended on page configuration. This interaction is explored further in the forthcoming analyses for the high- and low-knowledge groups.

Reading Skill. A second mixed 2 x 2 x 2 x 2 repeated measures analysis of covariance was conducted, this time including the within-subjects factor of question type (text-based, bridging-inference), the between-subjects experimental factors of page configuration (text-left, text-right), diagram (present, not present) and text cohesion (high, low), and the quasi-experimental factor of reading skill (high, low). In addition, the continuous variable of prior domain knowledge was included as a covariate. The means and standard deviations as a function of text type, diagram, page configuration, reading skill, and question type are provided in Table 9.

As reported in the previous analyses, there was a main effect of question type, $F(1, 162) = 320.13$, $p < .001$, $d = 1.42$, as well as a significant main effect of diagram, $F(1, 162) = 5.80$, $p = .017$, $d = .35$, and a significant effect of cohesion, $F(1, 162) = 6.51$, $p = .012$, $d = .39$. The main effect of page configuration was not reliable, $F(1, 162) < 1$. A two-way interaction was found between question type and cohesion, $F(1, 162) = 8.79$, $p = .003$, as well as a significant interaction between question type and page configuration, $F(1, 161) = 4.17$, $p = .043$. Unlike the previous analysis, page configuration did not significantly interact with any of the other factors.

In addition to the replicated results, there was a main effect for reading skill, $F(1, 162) = 4.20$, $p = .042$, $d = .31$, indicating that skilled readers scored higher ($M = .32$, $SE = .015$) than less skilled readers ($M = .28$, $SE = .016$). New results then revealed a marginally significant three-way interaction between cohesion, diagram, and reading skill, $F(1, 162) = 4.67$, $p = .057$. This interaction is depicted in Figure 6. Further analyses showed that cohesion improved less-skilled readers' scores on the comprehension questions when diagrams were absent, $F(1, 39) = 8.63$, $p = .006$, $d = .88$ ($M_{\text{high cohesion}}$ =

.24, SE = .021; $M_{\text{low cohesion}}$ = .15, SE = .023), but did not improve scores significantly when diagrams were present, $F(1, 38) < 1$ ($M_{\text{high cohesion}}$ = .28, SE = .024; $M_{\text{low cohesion}}$ = .26, SE = .021). Additionally, diagrams benefited less-skilled readers when presented with a low-cohesion text, $F(1, 40) = 8.36$, $p = .006$, $d = .87$ (M_{diagram} = .25, SE = .020; $M_{\text{no diagram}}$ = .16, SE = .021), but not when presented with a high-cohesion text, $F(1, 37) < 1$ (M_{diagram} = .27, SE = .026; $M_{\text{no diagram}}$ = .25, SE = .023).

Analysis of the interaction for the skilled readers showed that the effect of cohesion when presented with diagrams was marginally significant $F(1, 40) = 3.12$, p = .085, d = .53 ($M_{\text{high cohesion}}$ = .40, SE = .030; $M_{\text{low cohesion}}$ = .30, SE = .032). There was no effect of cohesion when diagrams were absent, $F(1, 42) < 1$ ($M_{\text{high cohesion}}$ = .30, SE = .030; $M_{\text{low cohesion}}$ = .30, SE = .029). Results also showed a significant benefit of diagrams for skilled readers, when presented with a high-cohesion text, $F(1, 41) = 4.18$, $p = .047$, d = .61 (M_{diagram} = .40, SE = .030; $M_{\text{no diagram}}$ = .30, SE = .030), but that there was no effect of diagrams when they were presented with a low-cohesion text, $F(1, 41) < 1$ (M_{diagram} = .30, SE = .032; $M_{\text{no diagram}}$ = .29, SE = .029).

Finally, there was a significant interaction between diagram, reading skill, and question type, $F(1, 162) = 4.33$, $p = .039$. This interaction is depicted in Figure 7. Univariate analyses revealed the nature of the interaction. For less-skilled readers, diagrams were beneficial for text-based questions, $F(1, 78) = 9.51$, $p = .003$, $d = .45$ (M_{diagram} = .42, SE = .028; $M_{\text{no diagram}}$ = .35, SE = .028), but were not significantly beneficial on bridging questions, $F(1, 77) = 2.69$, $p = .105$ (M_{diagram} = .18, SE = .023; $M_{\text{no diagram}}$ = .14, SE = .023). Conversely, diagrams improved skilled readers' scores on bridging questions, $F(1, 83) = 5.98$, $p = .017$, $d = .48$ (M_{diagram} = .25, SE = .023; $M_{\text{no diagram}}$

= .16, *SE* = .022), but not on text-based questions, $F(1, 83) < 1$ (M_{diagram} = .45, *SE* = .028; $M_{\text{no diagram}}$ = .45, *SE* = .027).

To better understand the interactions of the two main analyses, separate tests were conducted for high-knowledge and low-knowledge learners as well as for the skilled and less-skilled readers.

Low-Knowledge Learners

A mixed 2 x 2 x 2 analysis of covariance was conducted for the low-knowledge group, with page configuration, text type, and diagram as between-subjects factors, question type as the within-subjects factor, and reading skill as a covariate (see Figure 8). For low-knowledge learners, there was a main effect of question type, $F(1, 82) = 162.84$, $p < .001$, d = 1.52, as well as a main effect of cohesion, $F(1, 82) = 7.60$, $p = .007$, $d = .54$. A significant main effect was also found for reading skill as a covariate, $F(1, 82) = 20.57$, $p < .001$. As in the main analysis, there was a two-way interaction between question type and cohesion, $F(1, 82) = 10.89$, $p = .001$.

The interaction between page configuration, cohesion, and diagram was not reliable for the low-knowledge group, $F(1, 82) = 1.73$, $p = .192$. However, there was a marginally significant interaction between cohesion and diagram for the text-right condition, $F(1, 39) = 3.10$, $p = .086$, but not for the text-left condition, $F(1, 42) < 1$, indicating that diagrams were beneficial on the comprehension questions when given with a low-cohesion text in a text-right configuration, $F(1, 20) = 4.99$, $p = .037$, $d = .95$ (M_{diagram} = .22, *SE* = .033; $M_{\text{no diagram}}$ = .11, *SE* = .032), but not when given with a high-cohesion text, $F(1, 18) < 1$ (M_{diagram} = .23, *SE* = .031; $M_{\text{no diagram}}$ = .22, *SE* = .043). However, there was also a three-way interaction between question type, cohesion, and diagram, $F(1, 82) = 7.20$, $p = .009$. Univariate analyses indicated that there was an interaction between cohesion and diagram on text-based questions, $F(1, 82) = 4.51$, $p = .037$, indicating that the effect of cohesion was significant when diagrams were absent, $F(1, 48) = 20.52$, $p < .001$, $d = 1.25$ ($M_{\text{high cohesion}} = .36$, $SE = .029$; $M_{\text{low cohesion}} = .18$, $SE = .031$), but was not significant when diagrams were available, $F(1, 33) < 1$ ($M_{\text{high cohesion}} = .30$, $SE = .037$; $M_{\text{low cohesion}} = .26$, $SE = .035$).

Separate analyses for the text-left and text-right conditions revealed that the interaction between question type, cohesion, and diagram was significant in the text-right condition, $F(1, 39) = 4.41$, $p = .042$, but was not reliable in the text-left condition, $F(1, 42) = 2.42$, $p = .127$. However, breaking down the interaction further revealed that cohesion improved performance on text-based questions when diagrams were absent in both the text-left condition, $F(1, 24) = 4.72$, $p = .040$, $d = .84$, as well as in the text-right condition, $F(1, 23) = 15.78$, $p = .001$, $d = 1.59$. Cohesion did not significantly improve performance when diagrams were available in either the text-left, $F(1, 17) < 1$, or text-right condition, $F(1, 15) < 1$.

Although there was not a main effect of diagram for low-knowledge learners, univariate analyses revealed that there was a marginally significant effect of diagrams on text-based questions when given with a low-cohesion text, $F(1, 42) = 3.51$, $p = .068$, $d = .58$, but not when given with a high-cohesion text, $F(1, 41) = 1.47$, $p = .233$. Separate analyses for each configuration condition showed that this improvement on text-based questions when diagrams were given with a low-cohesion text was significant for the text-right configuration, $F(1, 23) = 4.94$, $p = .038$, $d = .95$, but not for the text-left configuration, $F(1, 19) < 1$. For both configurations, there was a two-way interaction between question type and diagram for the high-cohesion text, $F(1, 41) = 4.41$, $p = .042$, indicating that diagrams hurt performance on text-based questions ($M_{\text{diagram}} = .30$, $SE = .042$; $M_{\text{no diagram}} = .36$, $SE = .033$) but helped performance on bridging questions ($M_{\text{diagram}} = .11$, $SE = .021$; $M_{\text{no diagram}} = .07$, $SE = .017$). However, although there was a benefit of diagrams on bridging questions for the text-right configuration across both cohesion conditions, $F(1, 39) = 4.67$, $p = .037$, $d = .66$, this benefit was not significant for the low-cohesion text, $F(1, 20) = 2.17$, $p = .156$, or for the high-cohesion text, $F(1, 18) = 2.67$, $p = .119$. There was no effect of diagrams on bridging questions in the text-left configuration, $F(1, 42) < 1$. In addition, although diagrams hurt performance on text-based questions when given with a high-cohesion text, this was not significant, $F(1, 41) = 1.47$, $p = .233$.

In sum, text cohesion helped low-knowledge learners' comprehension of the mitosis text when they were given a text-only format. This benefit emerged only on the text-based questions and did not depend on page configuration. Diagrams also helped low-knowledge learners perform better on text-based questions when they were presented with a low-cohesion text, provided that the diagrams were also presented in the text-right/diagram-left configuration. It was also shown that diagrams hurt performance on text-based questions but helped performance on bridging questions when presented with a high-cohesion text. The interaction between cohesion and diagrams was primarily evident in the text-right/diagram-left configuration, again suggesting the possibility that readers utilize diagrams more when they are on the left side of the page. Low-knowledge learners may have been induced to look for textual information in the diagrams to make up for a low-cohesion text, facilitating their textbase comprehension. In contrast, diagrams did not improve textbase comprehension when given with the high-cohesion text, presumably because the text was easier to understand. Although the low-knowledge learners were able to draw a minimal number of inferences from the diagram in the text-right configuration, at least enough to raise their performance above floor, adding cohesion did not improve their textbase comprehension.

High-Knowledge Learners

A mixed 2 x 2 x 2 analysis of covariance was conducted for the high-knowledge group, with page configuration, text type, and diagram as between-subjects factors, question type as the within-subjects factor, and reading skill as a covariate (see Figure 9). For high-knowledge learners, there was a main effect of question type, $F(1, 79) = 174.80$, $p < .001$, $d = 1.28$, again indicating that more text-based questions were answered correctly than bridging questions. The main effect of diagram was marginally significant, $F(1, 79) = 3.16$, $p = .080$, $d = .38$, and there was no main effect of either cohesion, $F(1, 79)$ 2.59, $p = .112$, or page configuration, $F(1, 79) < 1$. Reading skill showed a marginally significant effect as a covariate, $F(1, 79) = 3.10$, $p = .082$. There was a two-way interaction between question type and page configuration, $F(1, 79) = 5.19$, $p = .025$, indicating that the text-right configuration improved performance on text-based questions ($M_{\text{text-left}} = .53$, $SE = .034$; $M_{\text{text-right}} = .60$, $SE = .033$) but not on bridging-inference questions ($M_{\text{text-left}} = .29$, $SE = .035$; $M_{\text{text-right}} = .26$, $SE = .034$). No other significant effects or interactions were found. Univariate analyses revealed a marginally significant effect of cohesion for text-based questions, $F(1, 79) = 3.51$, $p = .065$, $d = .40$, but not for bridging questions, $F(1, 79) = 1.12$, $p = .293$. The effect of diagram was significant for bridging questions, $F(1, 79) = 4.81$, $p = .031$, $d = .47$, but was not significant for text-based questions, $F(1, 79) = 1.00$, $p = .320$.

Within separate analyses conducted with the text-left configuration, only a marginally significant interaction between question type and diagram was found, $F(1, 38) = 2.90$, $p = .097$, indicating that the benefit of diagrams depended on question type in the text-left condition. Although diagrams improved performance on bridging questions ($M_{diagram} = .33$, $SE = .043$; $M_{no\ diagram} = .24$, $SE = .051$), this effect was not significant, $F(1, 38) = 1.71$, $p = .199$. Additional analyses showed that the effect of diagram on bridging questions was not significant for the low-cohesion text, $F(1, 21) = 2.25$, $p = .148$, or the high-cohesion text, $F(1, 16) < 1$. Moreover, there was no effect of cohesion on either text-based, $F(1, 38) < 1$, or bridging questions, $F(1, 38) < 1$.

In the text-right condition, there was a marginally significant effect of cohesion $F(1, 40) = 3.35$, $p = .075$, $d = .55$, as well as a marginally significant effect of diagram, $F(1, 40) = 3.05$, $p = .088$, $d = .52$. No significant interactions were found, but univariate analyses yielded a marginally significant interaction between cohesion and diagrams on text-based questions, $F(1, 40) = 2.92$, $p = .095$, indicating that high-knowledge learners benefited from cohesion when diagrams were available, $F(1, 22) = 8.40$, $p = .008$, $d = 1.17$, but that they did not benefit from cohesion in the absence of diagrams, $F(1, 17) < 1$. In addition, cohesion also improved performance on bridging questions when diagrams were available, $F(1, 22) = 4.01$, $p = .058$, $d = .81$, but not when diagrams were absent, $F(1, 17) < 1$. Likewise, the effect of diagram was significant for the high-cohesion text, $F(1, 20) = 5.12$, $p = .035$, $d = .97$, indicating that high-knowledge participants benefited from diagrams with a high-cohesion text for both text-based, $F(1, 20) = 6.87$, $p = .016$, $d = .98$, and bridging questions, $F(1, 20) = 3.61$, $p = .072$, $d = .81$. The effect of diagram for the low-cohesion text was not significant, $F(1, 19) < 1$.

Overall, the high-knowledge learners performed equally across all conditions, and their comprehension did not improve as a function of any of the experimental manipulations, with one exception. The text-right configuration was generally beneficial for text-based questions, but this effect may be largely accounted for by the optimized performance on the high-cohesion text with diagrams. It appears that the combination of cohesion and diagrams helped high-knowledge learners form a superior textbase understanding in the text-right condition, which in turn also led to a better understanding of the relations among ideas in the text. In contrast, diagrams appeared to have no significant effect when combined with a low-cohesion text. Cohesion contributed to an improvement on both text-based and bridging questions when presented with diagrams in the text-right configuration. Apart from the exception of the text-right configuration, there appears to be a *non*-cohesion effect for high-knowledge learners. Taken together, results suggest that page configuration facilitated high-knowledge learners' ability to comprehend the mitosis lesson. This finding suggests that high-knowledge learners may have been induced into better mapping between text and diagram when presented with an ideal text, and this mapping led to a more stable mental model.

Less-Skilled Readers

A mixed 2 x 2 x 2 analysis of covariance was conducted for the less-skilled group, with page configuration, text type, and diagram as between-subjects factors, question type as the within-subjects factor, and prior knowledge as a covariate (see Figure 10). Overall, less-skilled participants correctly answered more text-based questions than bridging questions, $F(1, 78) = 209.86$, $p < .001$, $d = 1.67$. The main effect of cohesion was significant, $F(1, 78) = 6.77$, $p = .011$, $d = .56$, as was the main effect of diagram, F(1,

78) = 5.27, p = .024, d = .49. Prior domain knowledge was significant as a covariate in the full analysis, $F(1, 78) = 130.85$, $p < .001$. Cohesion was once more associated with text-based questions, as indicated by a significant two-way interaction with question type, $F(1, 78) = 4.29$, $p = .042$. The effect of page configuration was not significant, $F(1, 78) < 1$. However, a two-way interaction emerged between cohesion and page configuration, $F(1, 78) = 4.05$, $p = .048$, indicating that the benefit of cohesion was significant only for the text-right configuration, $F(1, 33) = 8.05$, $p = .008$, $d = .88$ ($M_{\text{high cohesion}} = .30$, SE = .024; $M_{\text{low cohesion}} = .19$, $SE = .025$) and was not reliable for the text-left configuration, $F(1, 44) < 1$ ($M_{\text{high cohesion}} = .23$, $SE = .022$; $M_{\text{low cohesion}} = .21$, $SE = .020$). In addition, univariate analyses indicated that the effect of cohesion in the text-right condition was significant for text-based questions, $F(1, 33) = 10.88$, $p = .005$, $d = 1.09$, but not for the bridging questions, $F(1, 33) = 2.04$, $p = .162$. Further analysis revealed that cohesion only had a significant effect in the absence of diagrams, $F(1, 17) = 13.31$, $p = .002$, $d = 1.67$, but was not significant when diagrams were present, $F(1, 15) < 1$. The interaction between cohesion and question type was not significant for the text-left configuration, $F(1, 44) < 1$, and univariate analysis confirmed that cohesion did not significantly improve performance on text-based questions, $F(1, 44) < 1$. Further analysis of each diagram condition showed similar results.

Although there was not a significant interaction between diagram and page configuration, separate analyses for the text-left and text-right conditions also revealed that the effect of diagram was significant for the text-right condition, $F(1, 33) = 4.49$, p = .042, $d = .64$, but was not reliable for the text-left condition, $F(1, 44) < 1$. The effect of diagram was also limited to text-based questions, $F(1, 33) = 5.79$, $p = .022$, $d = .79$, and did not significantly improve performance on bridging questions $F(1, 33) = 1.28$, $p = .267$. On the text-based questions, a two-way interaction between cohesion and diagram was not significant, $F(1, 33) = 2.80$, $p = .103$, although diagrams were more helpful when presented with a low-cohesion text, $F(1, 15) = 8.07$, $p = .012$, $d = 1.35$ ($M_{diagram} = .38$, $SE = .044$; $M_{no\ diagram} = .20$, $SE = .049$) than when they were presented with a high-cohesion text, $F(1, 17) < 1$ ($M_{diagram} = .44$, $SE = .051$; $M_{no\ diagram} = .42$, $SE = .040$).

Although the benefits of cohesion and diagrams for less-skilled learners depended on page configuration, their effects and interactions remain noteworthy. As shown in Figure 10, cohesion was beneficial overall, but its effect was much larger when diagrams were not available. Similarly, diagrams were much more effective when given with a low-cohesion text, and were particularly helpful on text-based questions. Considering that this large benefit on the text-based questions may have directly resulted from a text-right configuration, less-skilled readers may be focusing much more attention on the diagrams themselves when struggling with a low-cohesion text. Cohesion also compensated for the lack of diagrams, but the less-skilled readers' performance plateaued when diagrams were available. However, the finding that the benefit of cohesion in the absence of diagrams was only significant for the text-right configuration but not the text-left configuration is rather puzzling.

Skilled Readers

A mixed 2 x 2 x 2 analysis of covariance was conducted for the skilled readers, with page configuration, text type, and diagram as between-subjects factors, question type as the within-subjects factor, and prior knowledge as a covariate (see Figure 11). Other than the covariate effect of prior knowledge, $F(1, 83) = 47.34$, $p < .001$, the analysis did not yield any main effects. Question type was again significant, $F(1, 83) = 139.87$, $p < .001$, $d = 1.34$, but the main effect of cohesion was not significant, $F(1, 83) = 2.18$, $p = .144$, nor was the main effect of diagram, $F(1, 83) = 2.21$, $p = .141$. A significant interaction also emerged between question type and cohesion, $F(1, 83) = 5.72$, p = .019, indicating that cohesion improved performance on text-based questions, $F(1, 83) = 4.98$, $p = .028$, $d = .46$ ($M_{\text{high cohesion}} = .54$, $SE = .032$; $M_{\text{low cohesion}} = .44$, $SE = .033$) but not on bridging questions, $F(1, 83) < 1$ ($M_{\text{high cohesion}} = .24$, $SE = .026$; $M_{\text{low cohesion}} = .24$, $SE = .026$). Univariate analyses revealed that the benefit of cohesion on text-based questions was significant when diagrams were available, $F(1, 40) = 4.99$, $p = .031$, $d = .67$ ($M_{\text{high cohesion}} = .60$, $SE = .046$; $M_{\text{low cohesion}} = .45$, $SE = .050$), but was not reliable when diagrams were absent, $F(1, 42) < 1$ ($M_{\text{high cohesion}} = .49$, $SE = .045$; $M_{\text{low cohesion}} = .44$, $SE = .043$). In the full analysis, there was also a marginally significant interaction between diagram and question type, $F(1, 83) = 3.00$, $p = .087$, indicating that diagrams improved performance on bridging questions, $F(1, 83) = 5.98$, $p = .017$, $d = .52$ ($M_{\text{diagram}} = .29$, $SE = .026$; $M_{\text{no diagram}} = .20$, $SE = .026$) but not on text-based questions, $F(1, 83) < 1$ ($M_{\text{diagram}} = .50$, $SE = .031$; $M_{\text{no diagram}} = .48$, $SE = .031$).

Separate analyses for the text-left and text-right conditions revealed that the interaction between cohesion and question type was significant for the text-left condition, $F(1, 36) = 5.29$, $p = .027$, but was not reliable for the text-right condition, $F(1, 46) = 2.37$, $p = .130$. However, further analysis showed that the benefit of cohesion on text-based questions in the text-left condition was only significant when diagrams were present, $F(1, 17) = 5.94$, $p = .026$, $d = .62$, and was not significant when diagrams were absent, $F(1, 18) < 1$. Although the interaction between cohesion and question type was not significant for the text-right configuration, univariate analyses showed that the effect of cohesion on text-based questions was marginally significant in the text-right condition, $F(1, 46) = 3.49$, $p = .068$, $d = .53$. Further analysis showed that this effect was only marginally significant when diagrams were present, $F(1, 22) = 3.31$, $p = .083$, $d = .74$, but was not significant when diagrams were absent, $F(1, 23) < 1$. The fact that cohesion and question type did not have a significant interaction indicates that cohesion also improved performance on bridging questions when diagrams were present ($M_{\text{high cohesion}} = .38$, $SE = .058$; $M_{\text{low cohesion}} = .27$, $SE = .060$), but this effect was not significant, $F(1, 22) = 1.64$, $p = .214$.

Separate analyses for the text-left and text-right conditions demonstrated that the effect of diagram on bridging questions was marginally significant in the text-right condition, $F(1, 46) = 3.47$, $p = .069$, $d = .52$, but was not significant in the text-left condition, $F(1, 36) = 2.80$, $p = .103$. There was also a marginally significant interaction between cohesion and diagram on bridging questions in the text-right condition, $F(1, 46) = 2.90$, $p = .095$, indicating that skilled readers benefited from diagrams in a high-cohesion text, $F(1, 21) = 3.48$, $p = .076$, $d = .79$ ($M_{\text{diagram}} = .35$, $SE = .048$; $M_{\text{no diagram}} = .19$, $SE = .050$), but not in a low-cohesion text, $F(1, 24) < 1$ ($M_{\text{diagram}} = .22$, $SE = .043$; $M_{\text{no diagram}} = .20$, $SE = .038$).

These results indicate that the benefits of cohesion and diagrams are independent of page configuration for skilled readers (see Figure 11). Cohesion significantly improved performance on text-based questions regardless of whether the text was on the left or the right, but this improvement depended on the presence of diagrams. Diagrams improved scores on bridging questions in both configuration conditions, but the improvement was only significant in the text-right condition. However, this benefit was limited to the high-cohesion text in the text-right condition, and did not depend on cohesion in the text-left condition. It appears that skilled readers were able to take advantage of a high-cohesion text that was augmented with diagrams despite page configuration, particularly on text-based questions. This finding suggests that while high-knowledge learners are induced by a text-right configuration to establish a better textbase representation through greater informational overlap between text and diagram, skilled readers are able to do this regardless of how the text and diagrams are configured on the page.

Discussion

Most of the things we read consist of more than just textual information by itself. Diagrams, realistic pictures, animations, and other visual representations all contain information that plays a role in the knowledge we acquire when we read. Indeed, studies (e.g., Hegarty & Just, 1993; Schnotz, 2005) have shown that people frequently learn more when provided with a combination of text and diagrams than they do from either modality in isolation. We are particularly interested in comprehension that takes place from combining text and diagrams as regularly offered in textbooks. Research also shows that students have a hard time understanding expository text such as that found in science textbooks, and that increasing the cohesion improves comprehension (e.g., Britton & Gülgöz, 1991). However, research also shows that offering more cohesive texts or diagrams actually may not be helpful for all learners (e.g., McNamara, 2001; Tabachneck-Schiff et al., 1997). This dilemma arising from the relationship between multimodal texts and individual differences was the focus of this study. The goal of this study was to investigate the effects of cohesion and diagrams for learners of high and low knowledge and for skilled and less-skilled readers.

The results of the comprehensive factorial analyses indicate that although cohesion and diagrams are helpful for both high- and low-knowledge learners, these benefits share an inverse interaction with each other. The effect of diagrams is contingent both on the cohesion level of the accompanying text as well as the configuration of the diagram relative to the text. For low-knowledge learners, cohesion improved textbase understanding, but only when diagrams were not presented with the text. This effect was independent of page configuration. Results also showed that diagrams improve performance on text-based questions when given a low-cohesion text, and that performance on bridging questions improved for both cohesion conditions However, these improvements only manifested when the text was presented in a text-right configuration, with the diagrams positioned to the left of the text. It appears that the configuration plays an important role in determining whether low-knowledge learners paid attention to the diagrams, or whether they were able to suitably navigate between text and diagram. The text-right configuration perhaps induces low-knowledge learners to rely on the diagram to help build up a textbase representation in lieu of a confusing low-cohesion text, whereas they are not prompted to access the diagram as much while reading the text in a text-left configuration. It may be that readers concentrate entirely on the text when it is on the left side and fail to process the diagrams sufficiently, but they engage in a more integrative behavior between text and diagram when the diagram is on the left side. Although they were induced to view the diagrams more frequently, they relied on the diagram to draw some minimal level of inferences, but did not have the adequate cognitive resources to integrate the different representations. This may explain why textbase comprehension did not improve when they were given the high-cohesion text along with the diagrams. Unfortunately this interpretation is not directly testable in the present study, and remains a hypothesis for future research with process measures such as eye-tracking. Nevertheless, it is reasonable to suspect that diagrams made up for the confusing text, but that they did not help when presented with a better text because low-knowledge readers were reliant on the diagrams and did not engage in as much integration between text and diagram. For this reason, the availability of the diagrams yielded nominal improvement on bridging questions, but they did not take advantage of the high-cohesion text to help interpret the diagrams. Likewise, adding cohesion to a text improves low-knowledge learners' textbase representation when diagrams are not given, which improves the situation model for single sentences, but the learner generally lacks the adequate resources (i.e., knowledge) to generate the inferences necessary to connect separate ideas in the text.

In contrast, high-knowledge learners recall relational information from their internal mental model more frequently and accurately. Although results of the study indicate that diagrams largely did not improve comprehension, high-knowledge learners were able to optimize their performance when diagrams were provided with a high-cohesion text in a text-right configuration. Similarly, there was no effect of cohesion except when presented with diagrams in a text-right configuration. Recall that O'Reilly and McNamara (2007) found that the reverse-cohesion effect was limited to high-knowledge readers who lacked reading skill. However, the present study was unable to corroborate their results due to insufficient cell-sizes; there was simply no effect of cohesion, except when diagrams were given in the text-right configuration. Like their low-knowledge counterparts, high-knowledge learners are induced to access the diagram in a more efficient manner when the diagram is configured on the left side of the page. The more explicit connections and greater repetition of the vocabulary in the high-cohesion text (i.e., more tokens) may have led to an increase in informational overlap and mapping between text and diagram, which improved recall of the terms and facilitated understanding at the textbase level. Unlike the low-knowledge group however, the high-knowledge group also used the greater number of cohesive ties to improve their understanding of the relations among the objects depicted in the diagrams and described in the text. The more explicit connections in the text helped high-knowledge learners understand the spatial and structural associations between the entities in the diagram. In other words, they were induced by the configuration to access the diagrams more frequently, and the increased cohesion helped them to actually navigate and understand the diagrams. Conversely, their comprehension did not improve when given a low-cohesion text because the text did not adequately describe the relationships depicted in the diagram. As such, the configuration induced high-knowledge learners to use the explicit connections in the text to frequently inspect the diagrams, which improved textbase understanding as well as construction of a mental model.

Results comparing skilled and less-skilled readers are strikingly similar to those comparing high- and low-knowledge learners. Like low-knowledge learners, less-skilled readers benefit from cohesion on text-based questions in the absence of diagrams, and also benefit from diagrams when given a low-cohesion text. However, the effect of cohesion in the absence of diagrams was only significant in the text-right condition. This is a perplexing result given that diagrams were not available, because the natural assumption is that page configuration should be inconsequential when only text is presented (i.e., the other side of the page is merely empty space). One possible explanation is that reading time may have played a role because the low-cohesion text was read for a longer amount of time when given in the text-left configuration. Results also show that diagrams improve performance on text-based questions when given a low-cohesion text, provided that the text is presented in a text-right configuration. As with low-knowledge learners, configuration played an important role in determining whether less-skilled readers relied on diagrams to help compensate for the low-cohesion text. When presented with an easier, more cohesive text, less-skilled readers may rely on the text as the primary source of information. An alternative explanation is that their performance simply plateaus when given both diagrams and a high-cohesion text. Similar to the low-knowledge learner, the less-skilled reader will benefit from either cohesion or diagrams in isolation, but combining them does not afford further scaffolding. Unlike low-knowledge learners however, less-skilled readers do not generate a significant amount of inferences from the diagrams.

Like high-knowledge learners, skilled readers optimized their performance when presented with a high-cohesion text that was also augmented with diagrams. Unlike the high-knowledge learners however, this benefit did not depend on configuration. Results show that adding cohesion to the multimodal text increased performance on text-based questions, whereas adding diagrams to an already cohesive text increased performance on bridging questions. This finding signifies an important distinction between skilled readers and high-knowledge learners. Skilled readers are basically capable of integrating information between text and diagram autonomously, whereas high-knowledge learners need to be induced from the configuration to inspect the diagram while reading the text. Skilled readers took advantage of the explicit connections in the text to understand the spatial and relational properties shown in the diagrams, thus facilitating construction of a mental model. Moreover, the explicit connections along with the greater number of tokens may have increased the frequency of diagram inspection, facilitating understanding of the textbase and subsequent mental model.

This study makes a unique contribution to research on techniques for making integration between text and diagrams cognitively easier for readers. According to multimedia learning theories (Mayer, 2005; Sweller et al., 1998), instructional materials should be devised in order to promote integration of visual and verbal information into a coherent mental model. However, conventional materials such as science textbooks often do not offer clear links between text and diagram that would prompt the learner to engage in integrative reading. Research has shown that many learners concentrate primarily on the text and often fail to adequately engage with and process graphics (Tabachneck-Schijf et al., 1997). No matter how well-constructed the graphics may be, it is still up to the reader to ascertain the referential links between the text and the diagrams.

Two principles from multimedia learning frameworks are relevant to the results of this study. The first is the *spatial contiguity principle*, which states that “people learn more deeply from a multimedia message when corresponding words and pictures are presented near rather than far from each other on the page or screen” (Mayer, 2005, p. 184). In a separated format, readers may not shift their attention between the text and illustrations, but rather view them independently without integrating the information. In contrast, layouts in which the distance between text and graphics is physically shorter promote integration. Until now, studies on the contiguity of multimodal stimuli largely assessed performance as a function of *significant* changes in contiguity. For instance, presenting text and graphics at the same time and spatially close facilitates successful integration (e.g., Mayer & Anderson, 1992). Results of the present study reveal that spatial contiguity effects are not merely dependent on physical distance. Specifically, placing the text to the left of a diagram may compel readers to concentrate entirely on the text before scanning the diagram. In doing so, processing of the diagram is likely limited to a superficial understanding and is not properly integrated with information from the text. Thus, the text-left configuration may essentially constitute a separated format. Alternatively, placing the text to the right of the diagram appears to induce a greater amount of integration between text and picture. Although this configuration only significantly increases performance when the text is highly cohesive, the fact that most participants (with the exception of the skilled readers) only improve performance from a text-right configuration suggests that spatial contiguity may also depend on a *linear contiguity* of diagram and text. Similar results were found by Holsanova et al. (2008), in which a serial configuration enhanced text-picture integration compared to a radial configuration. However, that study did not compare a specific text-left/diagram-right configuration to diagram-left/text-right configuration. Thus, results of the present study lend credence to future exploration of a proposed *linear contiguity principle* as an extension of the spatial contiguity principle. It is also worth mentioning that effect of linear contiguity may be culturally constrained. Research has shown that people adopt verbal reading direction to follow pictorial sequences (Spinillo & Dyson, 2001), and results from the present study demonstrate that customary reading patterns (i.e., the western convention of reading left-to-right) may also apply to sequencing verbal with visual representations.

The second multimedia learning principle relevant to this study is the *signaling* principle. The signaling principle states that "people learn more deeply from a multimedia message when cues are added that highlight the organization of the essential material" (Mayer, 2005 p. 183). Such cues that can direct the learner's attention include headings, emphasis on key words (such as with bold or color-coded text), and lists. Halsonova and colleagues have suggested extending this principle to include cues resulting from the conceptual organization of content (Holsanova et al., 2008). However, the textual content in that study was modified so that it was grouped into macro-topics in a logical order of beginning with introductory information, then progressing to background information, advanced information, and practical information. In contrast, the modified text used in the present study modified cohesion both on a global and local level, but did not restructure the global organization of the content. Providing visible connections between entities described in the text likely produced a clearer understanding of the spatial features and structural relationships between those entities as depicted in the diagram (cf. Lockwood, Forbus, Halstead, & Usher, 2006). Adding cohesive devices such as connective words, descriptive elaborations, headings, and reference resolutions not only makes the text easier to understand, it is also liable to increase the conceptual overlap with the diagrams on a semantic level. Consequently, increasing the textual cohesion with more explicit descriptions of the spatial and relational properties depicted in the diagram yields greater coherence *between* text and diagram. The process of coherence formation requires that the learner identify and map the referential connections between information from both sources (e.g., Schnotz, 2005). This increase in inter-representational coherence may thus prompt learners to engage in more integrative behavior and cognitive processing. Eye movement studies (e.g., Hegarty & Just, 1993) have shown that learners shift their attention between conceptually related elements of text and diagrams over the course of many global and local inspections. Learners may crucially shift their attention to the diagrams more frequently and accurately if the text better communicates what is depicted in the diagram. Results of this study support previous research demonstrating that viewing of visual aids is often highly text-directed (e.g., Hegarty & Just, 1993). Moreover, it gives a strong indication that readers can be directed through difficult multimedia materials by textual features, and substantiates the addition of a *text cohesion principle* as an extension of the signaling principle, or as a new multimedia design principle unto itself. As the results demonstrate however, this effect is contingent upon the layout and may not apply if verbal and visual representations are not properly configured spatially.

Because the linear configuration provokes cognitive processing that is relevant to integrating information between text and diagram, it may be interpreted as a reduction of extraneous cognitive load and an increase in germane cognitive load. However, such an interpretation is overly simplistic because it does not consider the difference in reciprocal behavior that results from integrative processing as opposed to disconnected processing. If the linear configuration does in fact encourage readers to switch their attention between text and diagram, it unavoidably interrupts processing of the text, which necessarily imposes an extraneous cognitive load on readers as they attempt to regain their place in the text. This extraneous load may be reduced by a more cohesive text; that is, readers can find their place more easily because the text is easier to follow and understand. Such a conjecture may provide a potential explanation for why performance did not improve for the low-cohesion text, even though it was also supplemented with diagrams and presented in a linear configuration. However, this purported cache-22 underscores a current limitation of cognitive load research, namely, that there is no validated measure that distinguishes between the types of cognitive load (see Schnotz, 2007). Additionally, germane cognitive load is allegedly constrained by motivational aspects, that is, from the learner's willingness to devote additional cognitive resources. Although we did not obtain a self-report of mental effort or interest in the learning task, the fact that participants of all knowledge and skill groups benefited from linear configuration would seem to suggest that integrative processing was provoked involuntarily. In any case, an investigation of working memory load would not be concerned with the actual differences in cognitive processing and resultant mental models when learning from a separated format (i.e., reading a text, then examining a diagram) versus an integrated format (i.e., alternating exchanges between verbal and visual representations).

There are two limitations inherent in this study. First, the results are contextually constrained by the format in which the mitosis lesson was presented. Specifically, the lesson was given one section at a time, with one diagram per printed page. Although replication with multiple diagrams in a digital medium is warranted, there is some evidence that sequential formats with numerous diagrams and accompanying texts affects text-picture integration and learning (e.g., Holsanova et al., 2008). Second, the results and speculations need to be confirmed using eye-tracking data. More and more, eye tracking is applied in research on instructional design, as it can be used to detect shifts in attention, and thus can indicate what is being processed by the mind. For example, Hegarty and Just (1993) used eye tracking to demonstrate how learners read and re-read text, how they inspect diagrams, and when they switch from the text to the diagram (and vice versa). The role and frequency of integrative saccades (eye movements between text and diagram) would facilitate our understanding of inter-representational coherence and serve to substantiate the findings of the present study. Indeed, eye tracking can provide unique information on the distribution of visual attention in terms of what medium or representations are visually attended to, in what order, and for how long (e.g., Holsanova et al., 2008). Eye movement data may also be useful for studying individual differences in cognitive processing or for changes in cognitive processes at the individual level over time. Although the implications inferred from this study appear to reasonably explain the results, eye tracking methodology is needed in future studies in order to not only confirm these assumptions, but also to test alternative designs to facilitate integration of information from different sources and learners' resulting comprehension.

This thesis project offers two main contributions to the research fields of text comprehension and multimedia learning. First, the present study extends the traditionally unimodal investigations on text cohesion to the realm of learning with multimedia documents. Indeed, this study is perhaps one of the very first to investigate aspects of *text* in learning with graphics. As such, this study integrates in an original fashion with traditional multimedia learning research, and highlights the importance of textual features in learning with multimodal formats. Given that students are usually provided instruction with both text and graphics, particularly in science domains, the need for incorporating text comprehension with multimedia research cannot be understated. If researchers hope to fully recognize how people construct multiple *internal* representations from multiple *external* representations, and how educators can improve individualization of representational components to help their students, then the linguistic features of the language involved must be better accounted for as one of those representations. This may be true regardless of whether we are investigating reading a textbook or interacting with a fully computerized animation with accompanying text or spoken narration. Results of this study will hopefully spur further research along these lines in a number of diverse multimedia settings.

The second contribution regards the role of prior knowledge and reading skill in learning with multimedia documents. As the results show, although diagrams are beneficial to learners of high and low proficiencies, the specific behavior they engage in may be contingent on their own cognitive capacities. Particularly, results reveal that an aptitude in reading skill is critical for overcoming effects of linear contiguity, whereas greater prior knowledge does not make learners autonomously engage in integration processes. This finding highlights the importance of promoting reading strategy instruction in schools, so that students may sufficiently process the visual aids commonly offered in textbooks and hypermedia.

The presented study underlines the fact that text and visual aids are indeed processed differently by students of different ability levels. Future research with eye-tracking is needed to corroborate the data and suppositions and to replicate these findings with computer-based instructional materials. Pending further investigation, the results provide a contribution to the refinement of multimedia design principles. Furthermore, this study uncovers the importance of inter-representational coherence and how cohesion is a vital component for helping learners comprehend the semantic connections between text and visual aids. Future research should systematically examine the process of learning with multiple representations and the design and use of supportive information. Potential investigations should specifically focus more extensively on attention allocation as indicated by eye movements and integrative saccades. Theoretically, it is necessary to specify the nature of interactions between external representations and internal mental models, and to work towards a comprehensive model of text-picture integration. Practically, such research can provide recommendations on how to design more effective textbooks and computer-based learning environments, and how to effectively support students in learning with distinctive multiple representations.

References

Ainsworth, S., & VanLabeke, N. (2004). Multiple forms of dynamic representation. *Learning and Instruction*, *14*, 241-255.

Albrecht, J. E., & O'Brien, E. J. (1993). Updating a mental model: Maintaining both local and global coherence. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *19*, 1061-1070.

Alexander, P. A., & Murphy, P. K. (1998). Profiling the differences in students' knowledge, interest, and strategic processing. *Journal of Educational Psychology*, *90*, 435-447.

Azevedo, R. (2008). The role of self-regulation in learning about science with hypermedia. In D. Robinson & G. Schraw (Eds.), *Recent Innovations in Educational Technology that Facilitate Student Learning* (pp. 127-156). Charlotte, NC: Information Age Publishing.

Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon Press.

Beck, I. L., McKeown, M. G., Sinatra, G. M., & Loxterman, J. A. (1991). Revising social studies text from a text-processing perspective: Evidence of improved comprehensibility. *Reading Research Quarterly*, *26*, 251-276.

Best, R. M., Floyd, R. G., & McNamara, D. S. (2008). Differential competencies contributing to children's comprehension of narrative and expository texts. *Reading Psychology*, *29*, 173-164.

Britton, B. K., & Gülgöz, S. (1991). Using Kintsch's model to improve instructional texts: Effects of repairing inference calls on recall and cognitive structures. *Journal of Educational Psychology*, *83*, 329-345.

Brown, J., Fishco, V., & Hanna, G. (1993). *Manual for scoring and interpretations: Forms G & H.* Chicago, IL: Riverside Press.

Butcher, K. R. (2006). Learning from text with diagrams: Promoting mental model development and inference generation. *Journal of Educational Psychology*, *98*, 182-197.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor analytic studies.* New York, NY: Cambridge University Press.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*, 293-332.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review*, *3*, 149-210.

Clark, R. C., & Mayer, R. E. (2003). *E-learning and the science of instruction*. San Francisco: Pfeiffer.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*, 211-245.

Floyd, R. G., Bergeron, R., & Alfonso, V. C. (2006). Cattell-Horn-Carroll cognitive ability profiles of poor comprehenders. *Reading and Writing*, *19*, 427-456.

Forget, M. A. (1999). *Comparative effects of three methods of staff development in content area reading instruction on urban high school teachers*. Unpublished doctoral dissertation. Old Dominion University.

Gernsbacher, M. A., Varner, K. R., & Faust, M. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 430-445.

Goldman, S. R., & Rakestraw, J. A. (2000). Structural aspects of constructing meaning from text. In M. L. Kamil, P. B. Mosenthal, & P. D. Pearson (Eds.), *Handbook of reading research* (Vol. 3, pp. 311-335). Mahwah, NJ: Lawrence Erlbaum.

Goldman, S. R., & Saul, E. U. (1990). Flexibility in text processing: A strategy competition model. *Learning and Individual Differences*, *2*, 181-219.

Graesser, A. C., Millis, K. K., & Zwaan, R. A. (1997). Discourse comprehension. In J. T. Spence, J. M. Darley, & D. J. Foss (Eds.), *Annual Review of Psychology*. Palo Alto, CA: Annual Reviews Inc.

Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review*, *101*, 371-395.

Hannon, B., & Daneman, M. (2001). A new tool for measuring and understanding individual differences in the component processes of reading comprehension. *Journal of Educational Psychology*, *93*, 103-128.

Hegarty, M., Carpenter, P. A., & Just, M. A. (1991). Diagrams in the comprehension of scientific text. In R. Barr, M. L., Kamil, P. B Mosenthal & P. D. Pearson (Eds.), *Handbook of reading research* (Vol. 2, pp. 641-668). New York, NY: Longman.

Hegarty, M., & Just, M. A. (1989). Understanding machines from text and diagrams. In H. Mandl & J. Levin (Eds.), *Knowledge acquisition from text and picture* (pp. 171-194). Amsterdam: North-Holland.

Hegarty, M., & Just, M. A. (1993). Constructing mental models of machines from text and diagrams. *Journal of Memory and Language*, *32*, 717-742.

Hegarty, M., Kriz, S., & Cate, C. (2003). The roles of mental animations and external animations in understanding mechanical systems. *Cognition and Instruction*, *21*, 325-360.

Höffler, T., & Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. *Learning and Instruction*, *14*, 343-351.

Holsanova, J., Holberg, N., & Holmquist, K. (2008). Reading information graphics: The role of spatial contiguity and dual attention guidance. *Applied Cognitive Psychology*, *22*, 1-12.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA: Harvard University Press.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*, 163-182.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York, NY: Cambridge University Press.

Koedinger, K. R., & Anderson, J. R. (1990). Abstract planning and perceptual chunks: Elements of expertise in geometry. *Cognitive Science*, *14*, 511-550.

Kosslyn, S. M. (1988). Aspects of a cognitive neuroscience of mental imagery. *Science*, *240*, 1621-1626.

Kosslyn, S. M. (1994). *Image and brain: The resolution of the imagery debate*. Cambridge, MA: MIT Press.

Kozma, R. B. (1991). Learning with media. *Review of Educational Research*, *61*, 179-211.

Kulhavy, R. W., Stock, W. A., & Kealy, W. A. (1993). How geographic maps increase recall of instructional text. *Educational Technology Research and Development*, *41*, 47-62.

Landauer, T. K., McNamara, D. S., Dennis, S., & Kintsch, W. (Eds.) (2007). *Handbook of Latent Semantic Analysis*, Mahwah, NJ: Lawrence Erlbaum.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, *11*, 65-99.

Levin, J. R., Anglin, G. J., & Carney, R. N. (1987). On empirically validating functions of pictures in prose. In D. M. Willows & H. A. Houghton (Eds.), *The psychology of illustrations: Basic research* (Vol. 1, pp. 51-85). New York, NY: Springer-Verlag.

Lockwood, K., Forbus, K., Halstead, D., & Usher, J. (2006). Automatic categorization of spatial prepositions. *Proceedings of the 28th Annual Conference of the Cognitive Science Society.* Vancouver, Canada.

Long, D. L., Oppy, B. J., & Seely, M. R. (1994). Individual differences in the time course of inferential processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 1456-1470.

Magliano, J., Radvansky, G. A., & Copeland, D. E. (2007). Beyond language comprehension: Situation models as a form of autobiographical memory. In F. Schmalhofer & C. Perfetti (Eds.), *Higher level language processes in the brain: Inference and comprehension processes* (pp. 379-391). Mahwah, NJ: Lawrence Erlbaum.

Mayer, R. E. (1992). The instructive animation: Helping students build connections between words and pictures in multimedia learning. *Journal of Educational Psychology*, *84*, 444-452.

Mayer, R. E. (2001). *Multi-media learning.* Cambridge, UK: Cambridge University Press.

Mayer, R. E. (2002). *The promise of educational psychology: Vol. 2, Teaching for meaningful learning*. Upper Saddle River, NJ: Prentice Hall.

Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 31-48). New York, NY: Cambridge University Press.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology*, *82*, 715-726.

Mayer, R. E., & Sims, V. K. (1994). For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Journal of Educational Psychology*, *86*, 389-401.

McNamara, D. S. (2001). Reading both high-coherence and low-coherence texts: Effects of text sequence and prior knowledge. *Canadian Journal of Experimental Psychology*, *55*, 51-62.

McNamara, D. S. (2004). SERT: Self-explanation reading training. *Discourse Processes*, *38*, 1-30.

McNamara, D. S., Kintsch, E., Songer, N. B., & Kintsch, W. (1996). Are good texts always better? Interactions of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction*, *14*, 1-43.

McNamara, D. S., & Magliano, J. (2009). Toward a comprehensive model of comprehension. In B. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 51), 297-384. New York, NY: Elsevier Science.

Miyake, A., & Shah, P. (1999). Toward unified theories of working memory: Emerging general consensus, unresolved theoretical issues, and future research directions. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 442-481). New York: Cambridge University Press.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*, 358-368.

Oakhill, J., & Yuill, N. (1996). Higher order factors in comprehension disability: Processes and remediation. In C. Cornaldi & J. Oakhill (Eds.), *Reading comprehension difficulties: Processes and Intervention* (pp. 69-92). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

O'Reilly, R. C., & Rudy, J. W. (2001). Conjunctive representations in learning and memory: Principles of cortical and hippocampal function. *Psychological Review*, *108*, 311-345.

O'Reilly, T., & McNamara, D. S. (2007). Reversing the reverse cohesion effect: Good texts can be better for strategic, high-knowledge readers. *Discourse Processes*, *43*, 121-152.

Ozuru, Y., Dempsey, K., & McNamara, D. S. (2009). Prior knowledge, reading skill, and text cohesion in the comprehension of science texts. *Learning and Instruction*, *19*, 228-242.

Parkhurts, P. E., & Dwyer, F. M. (1983). An experimental assessment of students' IQ and their ability to benefit from visualized instruction. *Journal of Instructional Psychology*, *10*, 9-20.

Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford University Press.

Paivio, A., Clark, J. M., & Khan, M. (1988). Effects of concreteness and semantic relatedness on composite imagery ratings and cued recall. *Memory and Cognition*, *16*, 422-430.

Reynolds, R. E. (1992). Learning important information from text: The role of selective attention. *Review of Educational Psychology*, *4*, 345-391.

Rieber, L. P. (1990). Using computer animated graphics with science instruction with children. *Journal of Educational Psychology*, *83*, 135-140.

Rieber, L. P. (1991). Animation, incidental learning and motivation. *Journal of Educational Psychology*, *83*, 318-328.

Rouet, J., Lowe, R., & Schnotz, W. (2008). *Understanding multimedia documents*. New York: Springer.

Rumelhart, D., & McClelland, J. (Eds.) (1986). *Parallel distributed processing: Explorations in the microstructure of cognition*. Cambridge, MA: MIT Press.

Schmitt, M. (1990). A questionnaire to measure children's awareness of strategic reading processes. *The Reading Teacher*, *49*, 454-461.

Schnotz, W. (2002). Towards an integrated view of learning from text and visual displays. *Educational Psychology Review*, *14*, 101-120.

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 49-69). New York: Cambridge University Press.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction*, *13*, 141-156.

Spinillo, C. G., & Dyson, M. C. (2001). An exploratory study of reading procedural pictorial sequences. *Information Design Journal*, *10*, 154-168.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257-285.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*, 251-296.

Tabachneck-Schiff, H. J. M., Leonardo, A. M., & Simon, H. A. (1997). CaMeRa: A computational model of multiple representations. *Cognitive Science*, *21*, 305-350.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies*, *57*, 247-262.

Ullman, S. (1984). Visual routines. In S. Pinker (Ed.), *Visual Cognition* (pp. 97-159). Cambridge, MA: MIT Press.

van den Broek, P., Rapp, D. N., & Kendeou, P. (2005). Integrating memory-based and constructionist approaches in accounts of reading comprehension. *Discourse Processes*, *39*, 299-316.

Van Dijk, T., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.

Vekiri, I. (2002). What is the value of graphical displays in learning? *Educational Psychology Review*, *14*, 261-312.

Verhoeven, L., & Perfetti, C. A. (2008). Advances in text comprehension: Model, process, and development. *Applied Cognitive Psychology*, *22*, 293-301.

Voss, J. F., & Silfies, L. N. (1996). The interaction of knowledge and comprehension skill with text structure. *Cognition and Instruction*, *14*, 45-68.

Walker, C. H. (1987). Relative importance of domain knowledge and overall aptitude on acquisition of domain related information. *Cognition and Instruction*, *4*, 25-42.

Westelinck, K., Valcke, M., Craene, B., & Kirschner, P. (2004). Multimedia learning in social sciences: limitations of external graphical representations. *Computers in Human Behavior*, *21*, 555-573.

Winn, B., (1987). Charts, graphs, and diagrams in educational materials. In D. M. Willows & H. A. Houghton (Eds.), *The psychology of illustration* (pp. 152-198). New York, NY: Springer.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, *123*, 162-185.

Appendix A

Original low-cohesion mitosis text

Cell Division

In eukaryotic cells there are two distinct but overlapping stages of cell division. In the first stage, mitosis, one complete set of chromosomes goes to each daughter cell. Mitosis guarantees that all of the genetic information in the nuclear DNA of the parent cell will go to each daughter cell.

In the second stage of cell division the cytoplasm and its contents divide. This process is cytokinesis. Cytokinesis is not as precise a process as mitosis. The amount of cytoplasm in a daughter cell will be about half of that in the parent cell. Each daughter cell will have about half of the organelles from the cytoplasm of the parent cell. But there is no precise mechanism working during cytokinesis to guarantee that each daughter cell will receive exactly half of the parent cell's cytoplasm and its organelles.

There are four distinct phases of mitosis: prophase, metaphase, anaphase, and telophase. These phases are well-known because it is possible to observe them with the light microscope.

The first phase of mitosis is called prophase. During this phase the invisible threadlike chromatin of the nucleus condense into doubled chromosomes, each unit of which is called a chromatid. In the human cell there are 92 chromatids, which result from replication of the 46 chromosomes during the S phase of the interphase. The chromatids are attached at one place, like Siamese twins. The place where they are attached is called the centromere.

In animal cells, two small structures called centrioles move to opposite ends of the cell. Around each centriole, filaments develop and radiate in all directions. These filaments resemble a flower and are called asters. During later prophase, many of the filaments between the centrioles lengthen and connect with each other. This network of filaments is called the spindle. Late in prophase some filaments of the spindle become attached to the kinetochores, which link the chromatids. In human cells, prophase lasts from 30 to 60 seconds.

In the second phase of mitosis, called metaphase, the chromatids become aligned at the midregion, or equator, of the cell. At this time the centrioles, if present, are at opposite ends of the cell. These regions are called the poles. Also during metaphase, the formation of the spindle is completed. Metaphase in human cells requires from two to six minutes.

At the beginning of anaphase, the third phase of mitosis, the kinetochores all divide at one time. This causes the chromatids to separate into daughter chromosomes. They then move equally to each pole.

The fourth stage of mitosis, called telophase, begins when all the chromosomes reach the two poles. During telophase the spindle begins to disappear. Later, the nuclear membrane reappears and encloses the two groups of chromosomes. While this is happening, the chromosomes begin to disappear as the chromatin material spreads throughout the nucleus.

Cytokinesis, the division of the cytoplasm, also begins during telophase. In animal cells the cytoplasm begins to pinch inward. In plant cells a partition, called the cell plate, begins to grow and divide the cytoplasm. Telophase in humans is quite variable, requiring from 30 to 60 minutes.

The preliminary steps of cytokinesis occur during the G phases of the cell cycle. In the G phases, various membrane structures, such as the endoplasmic reticulum and Golgi bodies, are produced out of components in the cytoplasm. Therefore, before cytokinesis, there is growth in the size of the cytoplasm and in the number of its organelles.

During the G phases there is reproduction of the mitochondria and chloroplasts. These organelles contain their own DNA, called organelle DNA, and their reproduction includes its replication.

Cytokinesis usually begins during telophase and continues after the nuclei of the daughter cells are completely formed. However, cytokinesis does not always occur when mitosis occurs. In some cells, such as those found in certain molds, mitosis occurs repeatedly without cytokinesis taking place. This results in cells with several nuclei.

Appendix B

High-cohesion mitosis text

Cell Division

Cell division occurs to reproduce and replace cells. The division of cells with a membrane-bound nucleus and organelles (eukaryotic cells) involves two distinct but overlapping stages, mitosis and cytokinesis. Mitosis occurs to replicate the cell's genetic material in the nucleus, whereas cytokinesis occurs to divide the gel-like liquid surrounding the cell's nucleus, called cytoplasm. Mitosis includes four phases which will be described here. Cytokinesis begins during the last of the four phases.

Mitosis

In the first stage of cell division, mitosis, one complete set of chromosomes goes to each new cell, which are called daughter cells. Mitosis guarantees that all of the genetic information from chromosomes in the nuclear DNA of the parent cell will go to each new daughter cell.

There are four distinct phases of mitosis called prophase, metaphase, anaphase, and telophase. These four phases are well known because it is possible to observe them with the simple light microscope.

1. Prophase

The first phase of mitosis is called prophase. Pro- means “before”, hence this phase takes place before the other three phases. During prophase, invisible, threadlike DNA fibers of the nucleus, which are called chromatin, condense and double into two chromosomes, each unit of which is called a chromatid. Each pair of chromatids is attached at one place, like Siamese twins, to form a single chromosome. The place where these chromatids are attached is called the centromere. In the human cell there are 92 chromatids, which result from the replication of 46 chromosomes.

Soon after the chromatin material has condensed into doubled chromosomes, centrioles begin to migrate away from each other. Centrioles are two small structures located outside the cell's nucleus that help to produce a spindle which later divides the chromosomes between the two daughter cells. In cells with centrioles (which include all animal cells), the two centrioles move to opposite ends of the cell. Threadlike filaments, called asters, then develop around each centriole and radiate in all directions, resembling a flower. During later prophase, many of the filaments between the two centrioles lengthen and connect with each other. This network of filaments is called the spindle. Late in prophase some filaments of the spindle become attached to the kinetochores, which are protein structures located within the centromere of the chromatids. In human cells, prophase lasts from 30 to 60 seconds.

2. Metaphase

The second phase of mitosis is called metaphase because meta- means “mid”. During metaphase the chromatids become aligned at the midregion, or equator, of the cell. At this time the centrioles, if present, are at opposite ends of the cell, which are called the poles. Also during metaphase, the formation of the spindle between the two centrioles is completed. Metaphase in human cells requires from two to six minutes.

3. Anaphase

At the beginning of the third phase of mitosis called anaphase (ana- means "away"), the kinetochores all divide at one time. This division causes the chromatids to separate into daughter chromosomes. The daughter chromosomes then move equally to each cell pole, which is why this is called the "away" phase.

4. Telophase

The fourth stage of mitosis is called telophase, because telo- means "end", and it begins when all the daughter chromosomes reach the two cell poles. During telophase the spindle that was completed in metaphase begins to disappear. Later, the nuclear membrane reappears and encloses the two groups of chromosomes at the two poles. While this is happening, the chromosomes begin to disappear and turn back into threadlike chromatin material, or DNA, which spreads throughout the nucleus. Cytokinesis, the division of the cytoplasm, also begins during telophase. Telophase in humans is quite variable, requiring from 30 to 60 minutes.

Cytokinesis

Cytokinesis, the second stage of cell division, begins to occur before mitosis is complete (usually during telophase) and continues after the nuclei of the daughter cells are completely formed. The preliminary steps of cytokinesis occur during the growth interphases (called the G phases) of the cell cycle. In the G phases, various membrane structures and organelles, such as the endoplasmic reticulum and Golgi bodies, are produced out of components in the cytoplasm. Therefore, before cytokinesis begins, there is growth in the size of the cytoplasm and in the number of its organelles. During the G phases there is also reproduction of the mitochondria and chloroplasts. These organelles contain their own DNA, called organelle DNA, and the organelles' reproduction includes the replication of the organelle DNA.

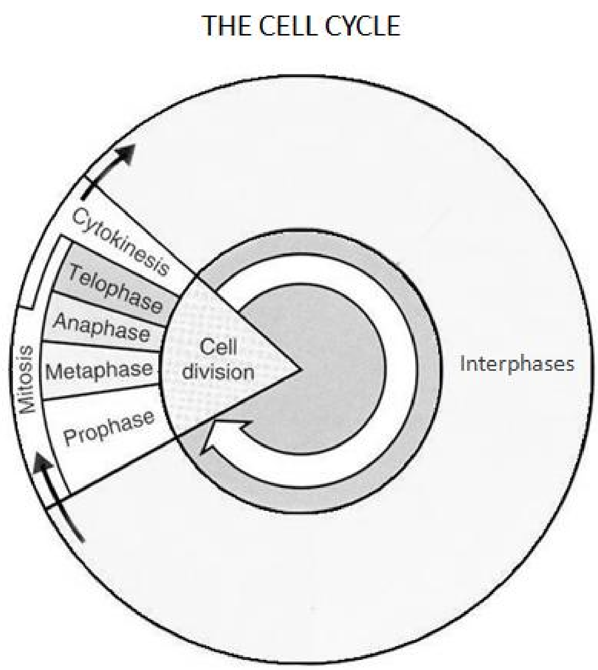
During cytokinesis, the cytoplasm and its contents divide. In animal cells, the cytoplasm divides by pinching inward, whereas in plant cells, a partition, called the cell plate, begins to grow and divide the cytoplasm. Cytokinesis is not as precise a process as mitosis because the amount of cytoplasm in a daughter cell will be about half, but not exactly half, the amount of cytoplasm in the parent cell. In addition, each daughter cell will have about half of the organelles from the cytoplasm of the parent cell. In contrast to mitosis, there is no precise mechanism working during cytokinesis to guarantee that each daughter cell receives exactly half of the parent cell's cytoplasm and its organelles.

Cytokinesis does not always occur when mitosis occurs because in some cells (such as those found in certain molds) mitosis occurs repeatedly without cytokinesis taking place. In this case, each repeated replication of genetic material with no division of cytoplasm (or final separation into new daughter cells) results in cells with two nuclei.

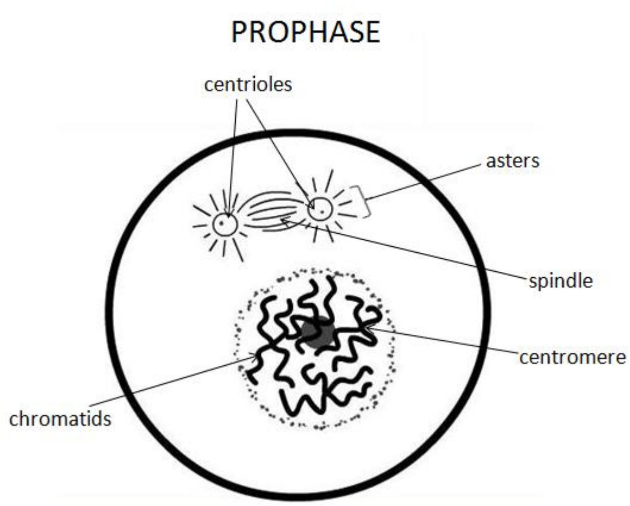
Appendix C

Diagrams corresponding to phases of cell mitosis (*displayed alongside text)*

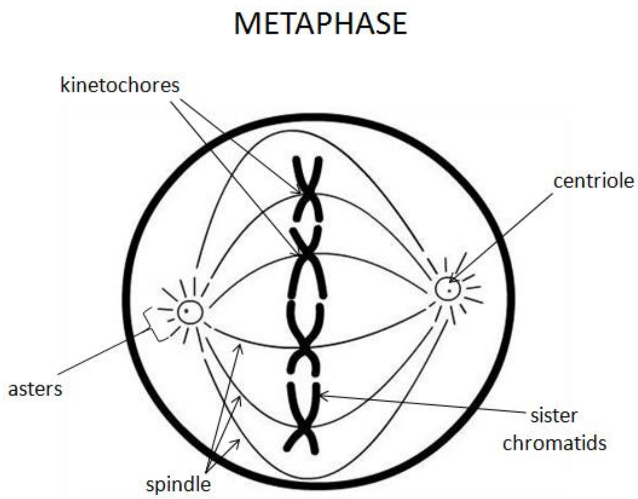
Introduction



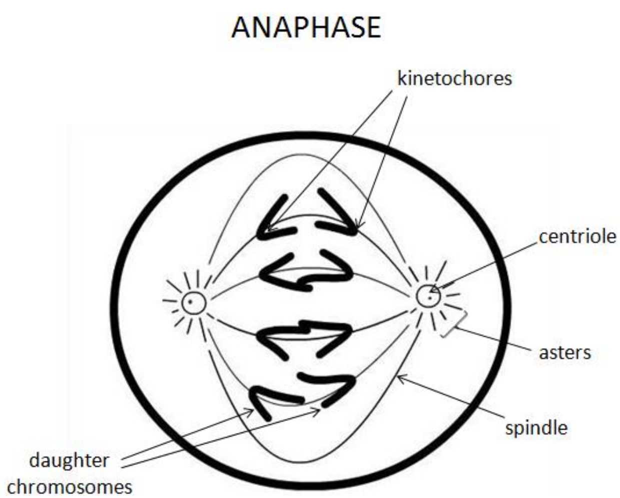
Prophase



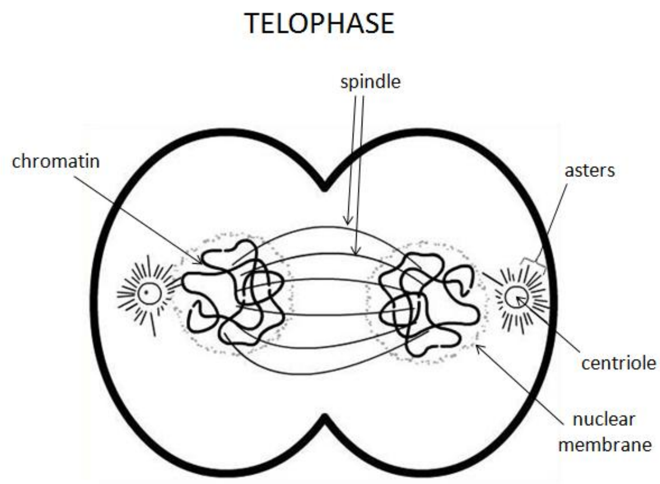
Metaphase



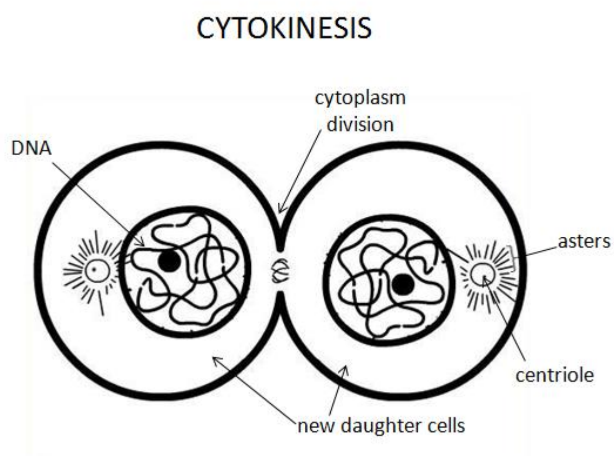
Anaphase



Telophase



Cytokinesis



APPENDIX D

Table 1

Traditional and Coh-Metrix cohesion measures for the high- and low-cohesion texts

Cohesion measure	High-cohesion text	Low-cohesion text
Number of words	901	650
Reading ease	48.163	52.935
Reading grade level	10.468	9.171
Causal cohesion	0.326	0.182
LSA global cohesion	0.595	0.623
Type-token ratio	0.595	0.623
Connectives	63.687	52.795

Note. LSA = Latent Semantic Analysis.

Table 2

Text-based and bridging-inference comprehension questions for mitosis text

Also used in O'Reilly & McNamara (2007)	
2.	What is the name of the place where the chromatids are attached? (bridging-inference)
4.	What is the name of the network of filaments between the centrioles that lengthen and connect with each other during prophase? (bridging)
5.	During which phase do the chromatids become aligned at the midregion, or equator, of the cell? (text-based)
6.	Describe two things that happen in the late phrophase stage of mitosis (bridging-inference)
8.	Why does the size of the cytoplasm increase before cytokinesis? (bridging-inference)
9.	Where are the chromosomes located in the cell when telophase begins? (text-based)
10.	How does cytokinesis differ for plant and animal cells? (bridging-inference)
11.	How much of the parent cell's cytoplasm and its organelles does each daughter cell receive? (text-based)
12.	Describe what happens in a cell when it is in the telophase stage of mitosis. (bridging-inference)
13.	What structures are produced out of components in the cytoplasm during the G (growth) phases?

Table 2 (continued)

New comprehension questions not used in O'Reilly & McNamara (2007)	
1.	List the stages of mitosis in chronological order (text-based)
3.	During prophase, threadlike filaments develop around each centriole and radiate in all directions, resembling a flower. What are these filaments called? (text-based)
7.	How long does metaphase last in human cells? (text-based)
14.	The passage states that cytokinesis does not always take place. Give one example of when this might occur and describe what happens as a result. (bridging-inference)
Dropped questions from O'Reilly & McNamara (2007)	
	In which stage of mitosis do chromosomes form? (text-based)
	What happens as a result of division of the kinetochores? (bridging-inference)

Note. Items are numbered according to their order of presentation in the current study.

Table 3

Domain-specific cell prior knowledge questions

Also used in O'Reilly & McNamara (2007)	
1.	What are the three parts of the cell theory?
2.	How are prokaryotic and eukaryotic cells similar? How are they different?
6.	What is the function of mitochondria?
7.	What is the function of chloroplasts in plant cells?
New prior knowledge questions not used in O'Reilly & McNamara (2007)	
3.	How do cancer cells differ from noncancerous cells?
4.	What are cell organelles?
5.	How does the nucleus control the cell's activities?
8.	What is the function of vacuoles in cells?
Dropped questions from O'Reilly & McNamara (2007)	
	Name two structures found in most cells.
	What is the name of the stage in the cell cycle after a cell has divided and before the next division occurs?
	Where are the centrioles located?
	What is the endoplasmic reticulum?

Note. Items are numbered according to their order of presentation in the current study.

Table 4

Proportion correct, standard deviations, and minimum and maximum scores for individual difference and dependent measures

	Current study				O'Reilly & McNamara (2007)			
	M	*SD*	*Min*	*Max*	*M*	*SD*	*Min*	*Max*
MSI	.55	.21	0.00	1.00	.48	.14	0.20	0.92
Nelson-Denny	.54	.20	0.13	0.97	.57	.12	0.32	0.89
Humanities knowledge	.52	.18	0.16	0.95	.56	.18	0.21	1.00
Biology knowledge	.40	.14	0.10	1.00	.45	.13	0.10	0.86
Cell knowledge	.21	.19	0.00	0.76	.26	.21	0.00	0.83
Mitosis text-based	.42	.24	0.00	0.93	.54	.28	0.00	1.00
Mitosis bridging	.18	.20	0.00	0.76	.29	.22	0.00	0.90

Note. MSI = Metacomprehension Strategy Index

Table 5

Correlations among the individual difference and dependent measures

	MSI	ND	Hum PK	Bio PK	Cell PK	BC	TB	Brid
ND	.28**	–						
Humanities knowledge	.35**	.53**	–					
Biology knowledge	.29**	.45**	.64**	–				
Cell knowledge	.21**	.32**	.50**	.55**	–			
Biology cell combined	.28**	.44**	.65**	.88**	.88**	–		
Mitosis text-based	.22**	.41**	.42**	.54**	.58**	.64**	–	
Mitosis bridging	.29**	.40**	.49**	.55**	.66**	.69**	.71**	–
Mitosis total	.27**	.44**	.48**	.60**	.67**	.72**	.94**	.91**

Note. MSI = Metacomprehension Strategy Index; ND = Nelson-Denny; Hum PK = humanities prior knowledge; Bio PK = biology prior knowledge; Cell PK = cell prior knowledge; BC = biology cell combined; TB = text-based; Brid = bridging.

**$p < .001$.

Table 6

Time on task (in seconds per word) as a function of text type, diagram, and page configuration

		Low Cohesion			High Cohesion		
		M	*SD*	*n*	*M*	*SD*	*n*
Textleft	Diagram present	.66	.22	23	.54	.16	22
	Diagram absent	.72	.31	23	.54	.19	23
Textright	Diagram present	.62	.26	22	.60	.23	21
	Diagram absent	.52	.20	23	.54	.28	23

Table 7

Proportion correct on the mitosis passage as a function of text type, diagram, page configuration, and question type

			Low Cohesion			High Cohesion	
		M	*SD*	*n*	*M*	*SD*	*n*
Text left	Diagram present						
	Textbased	.38	.23	23	.43	.26	22
	Bridging	.22	.23	23	.20	.22	22
	Diagram absent						
	Textbased	.33	.22	23	.40	.20	22
	Bridging	.13	.15	23	.15	.19	22
Text right	Diagram present						
	Textbased	.41	.23	22	.61	.27	21
	Bridging	.18	.17	22	.33	.27	21
	Diagram absent						
	Textbased	.36	.29	23	.46	.21	23
	Bridging	.14	.15	23	.13	.19	23

Table 8

Proportion correct on the mitosis passage as a function of question type, text type, diagram, page configuration, and prior knowledge

		Text left						Text right					
		Low Cohesion			High Cohesion			Low Cohesion			High Cohesion		
		M	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
High knowledge	Diagram present												
	Textbased	.49	.22	14	.57	.24	11	.52	.24	11	.75	.17	14
	Bridging	.34	.22	14	.30	.25	11	.24	.19	11	.43	.28	14
	Diagram absent												
	Textbased	.50	.21	10	.54	.16	8	.55	.28	11	.57	.17	9
	Bridging	.21	.20	10	.29	.23	8	.19	.18	11	.21	.28	9
Low knowledge	Diagram present												
	Textbased	.21	.10	9	.30	.20	11	.29	.15	11	.32	.18	7
	Bridging	.04	.07	9	.10	.13	11	.13	.12	11	.12	.09	7
	Diagram absent												
	Textbased	.20	.12	13	.32	.18	14	.18	.16	12	.39	.22	14
	Bridging	.07	.07	13	.07	.11	14	.08	.07	12	.07	.06	14

Table 9

Proportion correct on the mitosis passage as a function of question type, text type, diagram, page configuration, and reading skill

		Text left						Text right					
		Low Cohesion			High Cohesion			Low Cohesion			High Cohesion		
		M	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
High Reading skill	Diagram present												
	Textbased	.43	.24	9	.55	.26	11	.44	.26	12	.67	.26	13
	Bridging	.31	.23	9	.29	.26	11	.24	.18	12	.40	.29	13
	Diagram absent												
	Textbased	.40	.22	10	.48	.14	11	.45	.30	15	.53	.23	11
	Bridging	.18	.20	10	.21	.22	11	.18	.16	15	.13	.18	11
Low Reading skill	Diagram present												
	Textbased	.35	.22	14	.32	.21	11	.36	.18	10	.50	.25	8
	Bridging	.17	.22	14	.12	.13	11	.11	.12	10	.20	.19	8
	Diagram absent												
	Textbased	.28	.21	13	.32	.22	11	.19	.18	8	.40	.19	12
	Bridging	10	.10	13	.10	.14	11	.05	.06	8	.13	.20	12

APPENDIX E

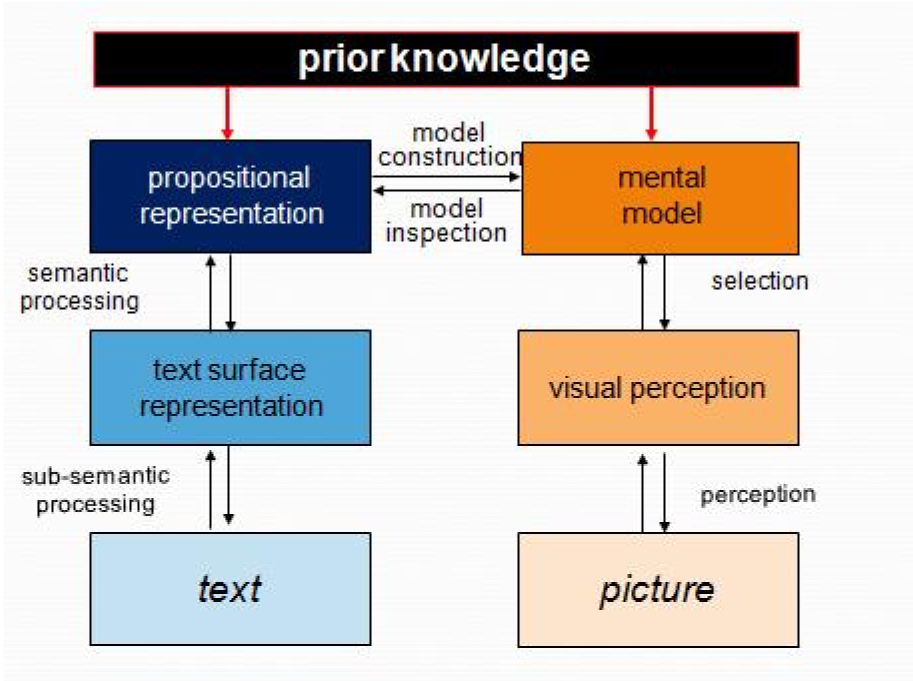


Figure 1

Schnotz's integrative model of text and picture comprehension (adapted from Schnotz, 2002)

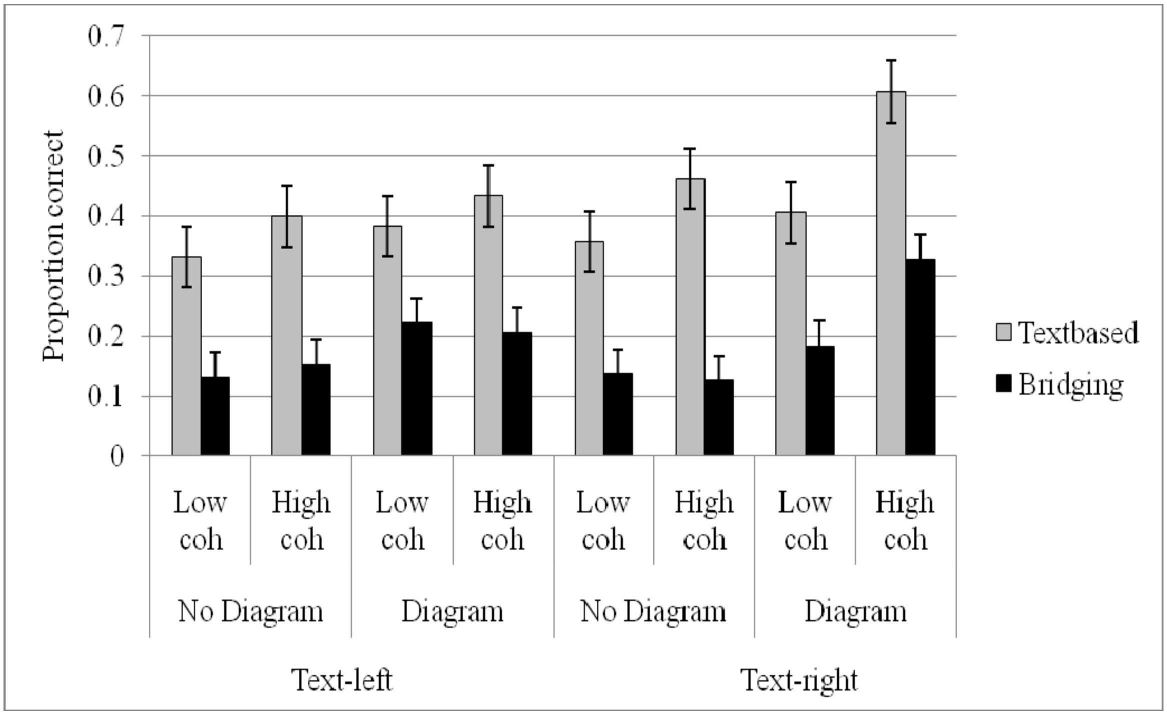


Figure 2

Mean proportion of correct text-based and bridging-inference questions (*+SE) on the mitosis lesson as a function of page configuration, diagram, text cohesion* (*coh), and question type.*

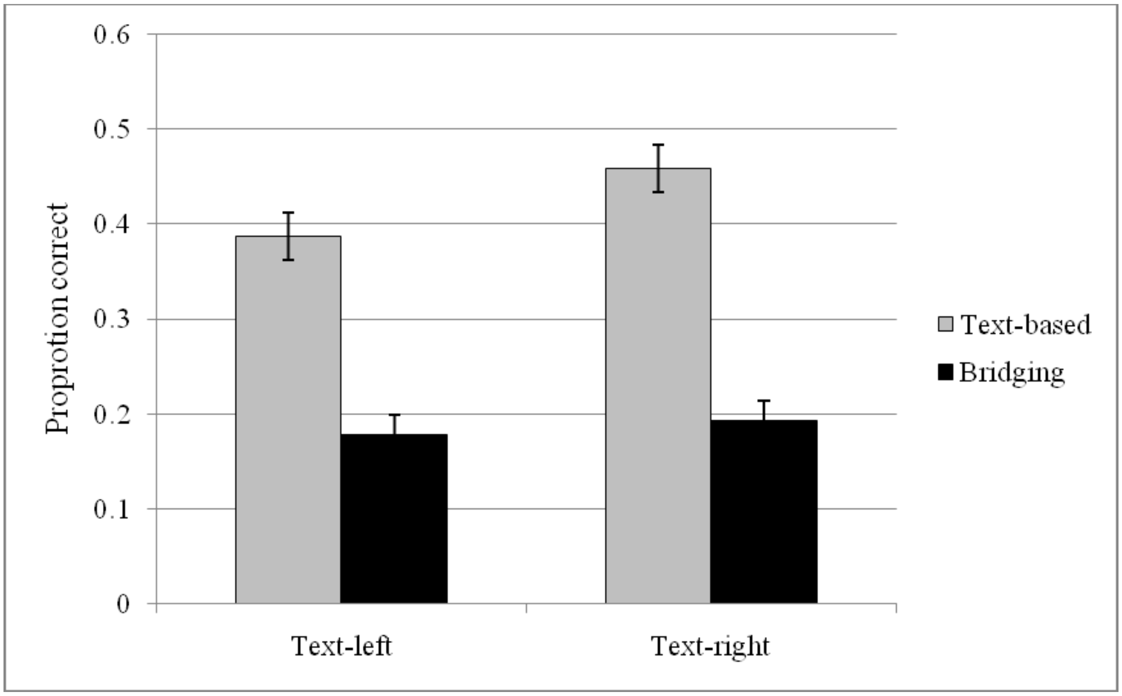


Figure 3

Mean proportion of correct comprehension questions (+SE) on the mitosis lesson as a function of page configuration and question type.

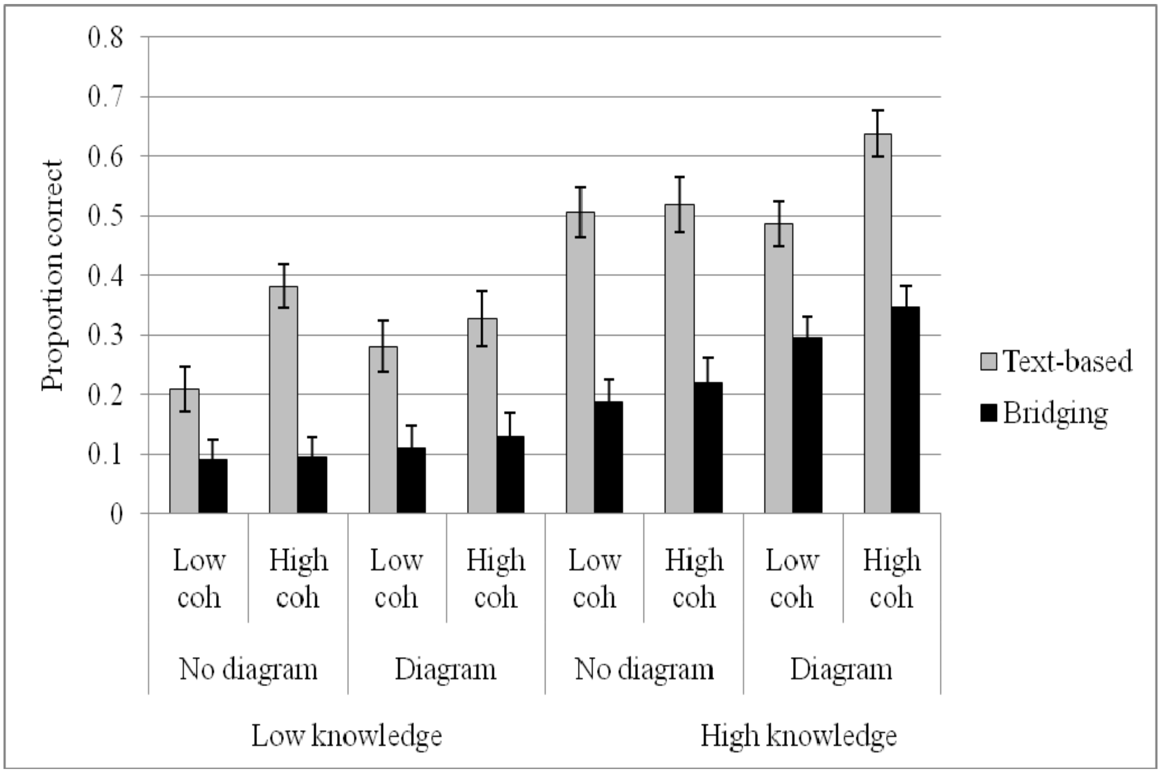


Figure 4

Mean proportion of correct comprehension questions (+SE) on the mitosis lesson as a function of question type, text cohesion (coh), diagram, and knowledge. The left side of graph represents data for the low-knowledge learners, and the right side of the graph represents data for the high-knowledge learners. Reading skill is included as a covariate.

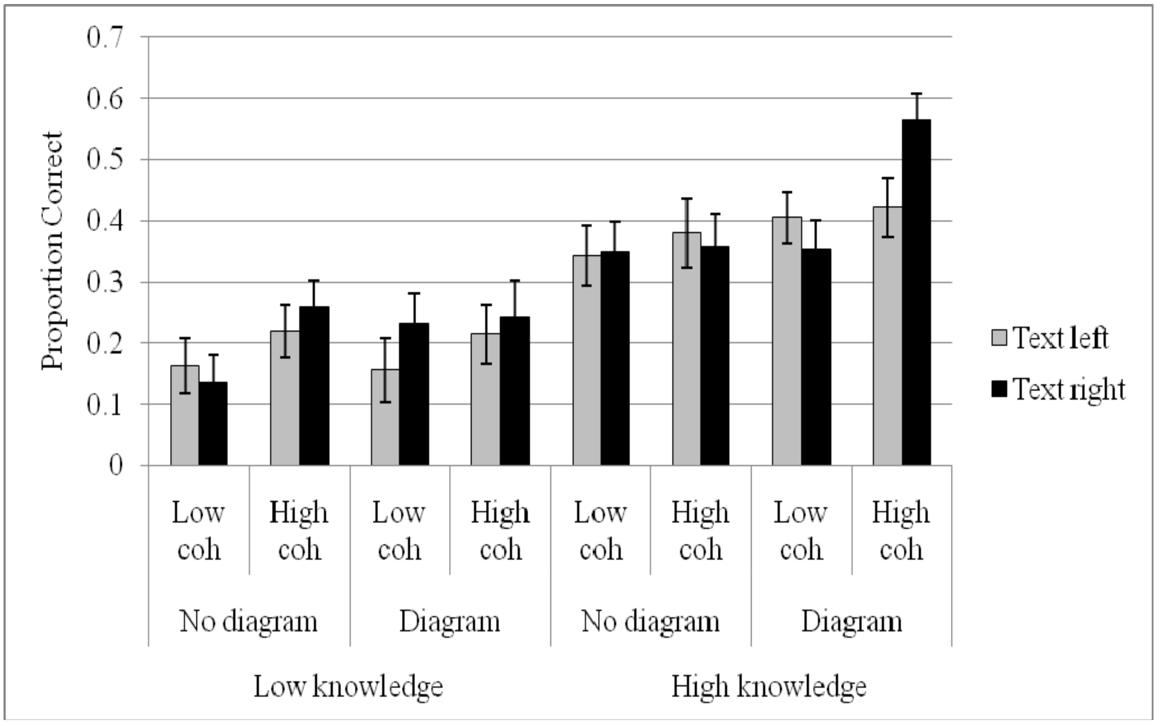


Figure 5

Mean proportion of correct comprehension questions (+SE) on the mitosis lesson as a function of page configuration, cohesion, diagram, and prior knowledge. The left side of the graph represents data for the low-knowledge learners, and the right side of the graph represents data for the high-knowledge learners. Reading skill is included as a covariate.

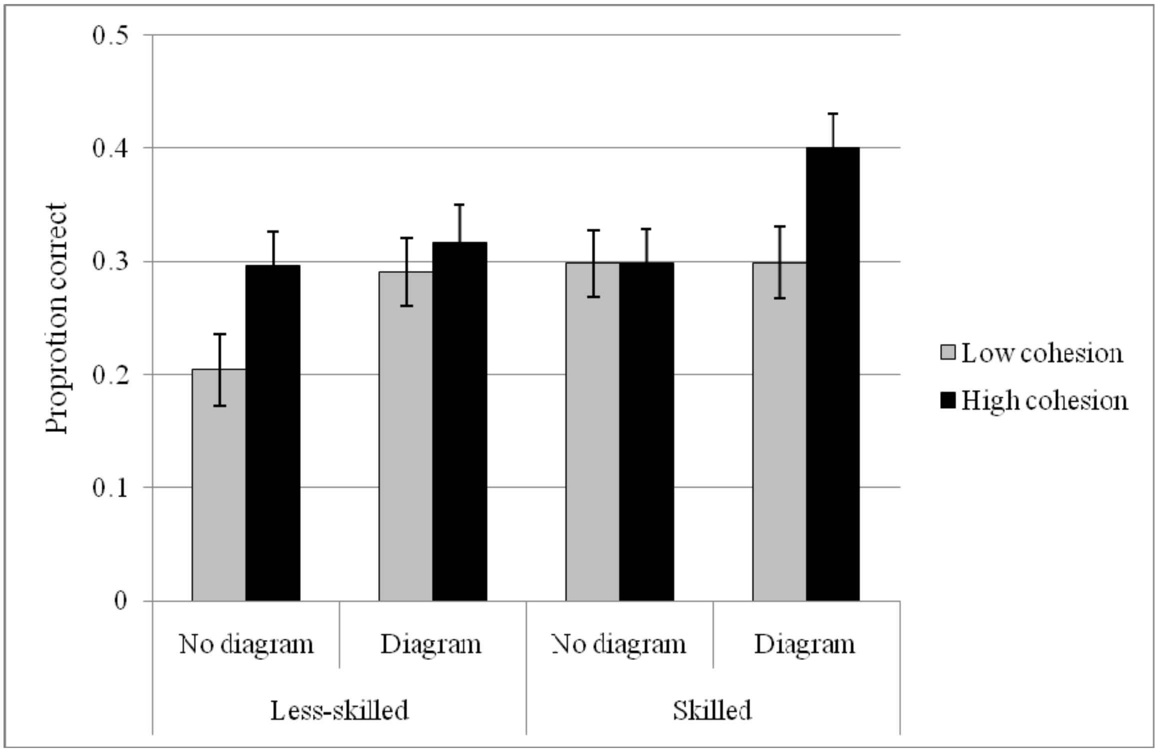


Figure 6

Mean proportion of correct comprehension questions (+SE) on the mitosis lesson as a function of cohesion, diagram, and reading skill. The left side of the graph represents data for the less-skilled readers, and the right side of the graph represents data for the skilled readers. Prior knowledge is included as a covariate.

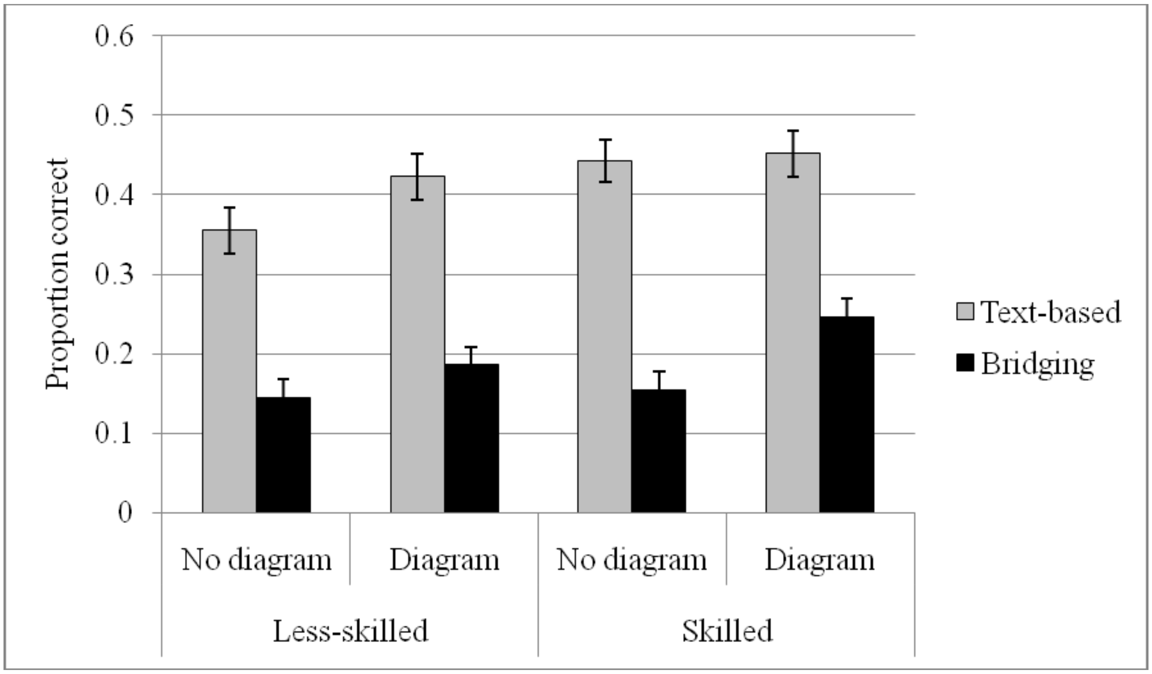


Figure 7

Mean proportion of correct comprehension questions (+SE) on the mitosis lesson as a function of question type, diagram, and reading skill. The left side of the graph represents data for the less-skilled readers, and the right side of the graph represents data for the skilled readers. Prior knowledge is included as a covariate.

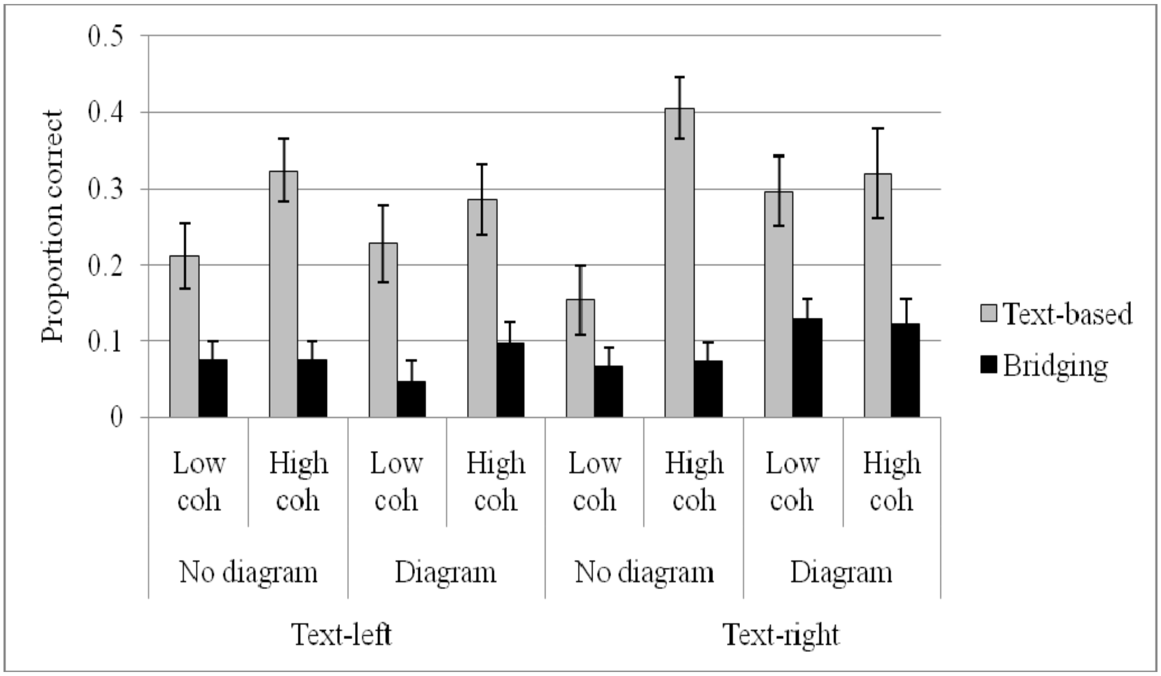


Figure 8

Mean proportion of correct comprehension questions (+SE) as a function of question type, cohesion, diagrams, and page configuration for low-knowledge learners. Reading skill is included as a covariate.

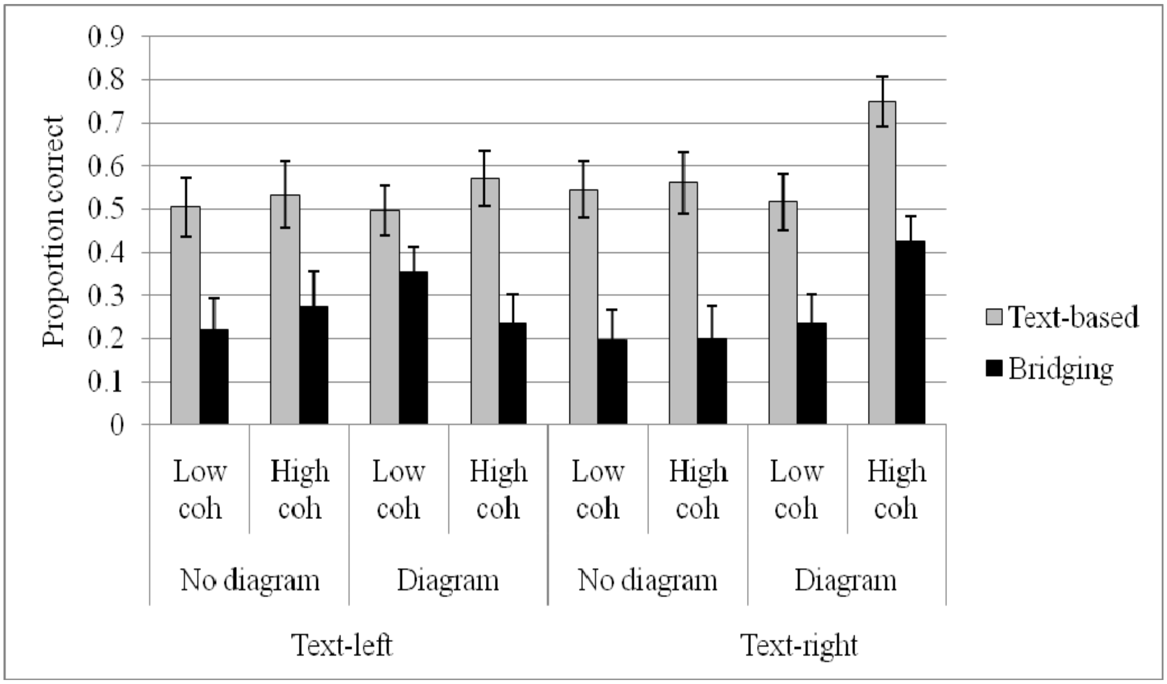


Figure 9

Mean proportion of correct comprehension questions (+SE) as a function of question type, cohesion, diagrams, and page configuration for high-knowledge learners. Reading skill is included as a covariate.

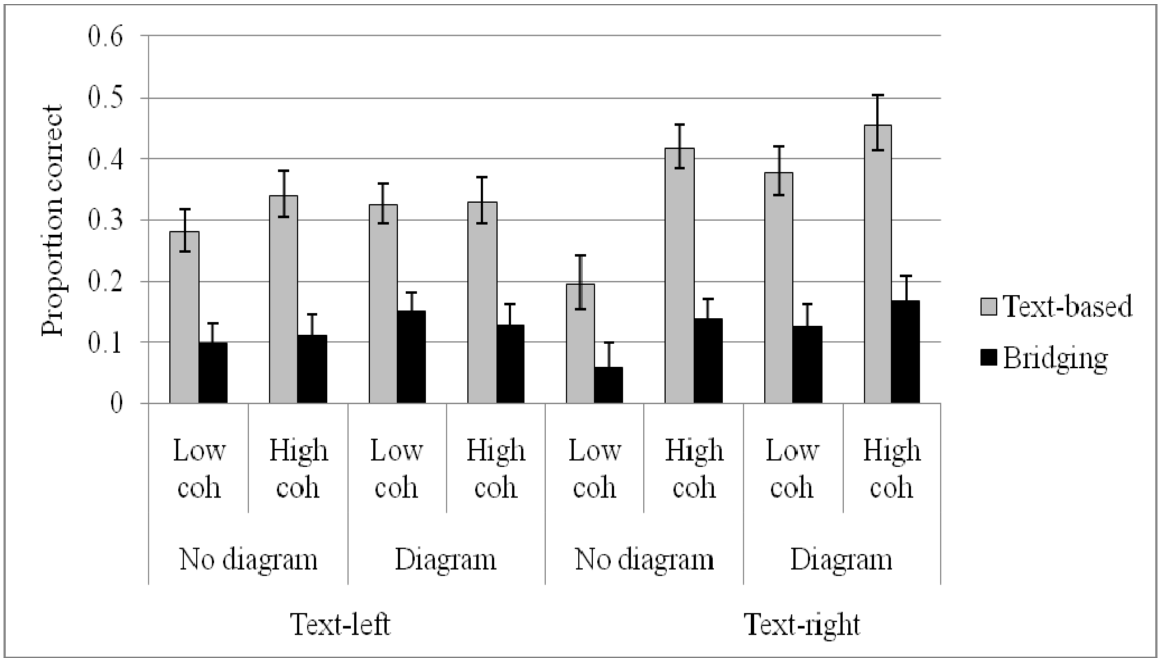


Figure 10

Mean proportion of correct comprehension questions (+SE) as a function of question type, cohesion, diagrams, and page configuration for less-skilled readers. Prior knowledge is included as a covariate.

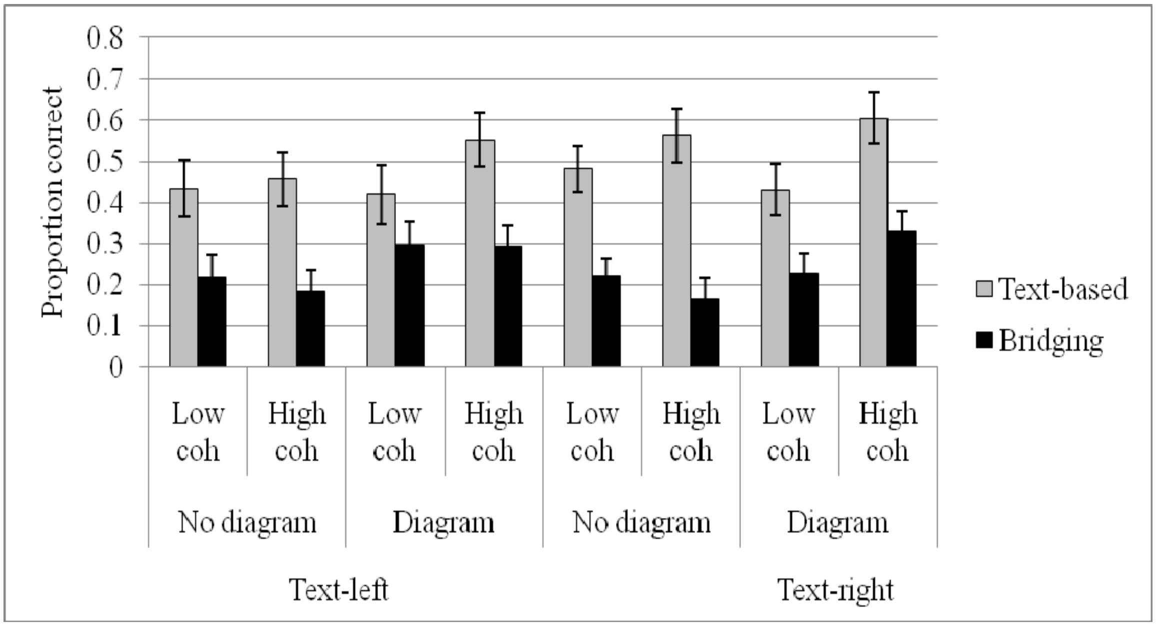


Figure 11

Mean proportion of correct comprehension questions (+SE) as a function of question type, cohesion, diagrams, and page configuration for skilled readers. Prior knowledge is included as a covariate.

APPENDIX F

Consent Form

Investigators: Dr. Danielle McNamara
Adam M. Renner, B.A.
Department of Psychology
The University of Memphis

Title: Picture and Text Comprehension

I, ___________________________________, hereby agree to participate as a volunteer in the above named research project.

The purpose of this study is to investigate comprehension. You will complete a series of tasks assessing comprehension and memory. The information gathered in this project will help psychologists to understand comprehension processes.

I understand that the information collected in this study will be kept confidential within the limits of the law.

I understand that at any time I am free to refuse to participate or answer any question without prejudice to me, that I am free to withdraw from the experiment at anytime, and that The University of Memphis does not have any funds budgeted to compensate for injury damages, or other expenses.

I understand that this study will last approximately 120 minutes and that, for participation, I will receive 2.0 hours of research credit in the class of my choosing.

I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

Student's signature ____

Date:_________________________

If you have any questions regarding research participants' rights please contact the Chair of the Committee for the Protection of Human Research Participants at 678-2533.