

**MULTIMEDIA AND HYPERMEDIA SOLUTIONS FOR  
PROMOTING METACOGNITIVE ENGAGEMENT,  
COHERENCE, AND LEARNING**

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**ABSTRACT**

Users of educational hypertext are faced with the challenge of creating meaning both within and between texts. Cohesion is an important factor contributing to whether a reader is able to capture meaning and comprehend text. When readers are required to fill in conceptual gaps in text, comprehension can fail if they do not have sufficient knowledge. Cohesion helps low-knowledge readers to create a more coherent mental representation of the text. However, text that is too cohesive can inhibit active processing, and thus reduce coherence for more knowledgeable readers. Similar patterns have been found for hypertext, which requires readers to create coherence between multiple electronic texts. Domain novices are in greater need of explicit pointers to important links between documents and gain from having less control over system navigation. Domain experts are in less need of scaffolding within the system. We discuss the use of a multimedia reading strategy training program to help low-knowledge readers better understand less cohesive text. Finally, we discuss four principles to guide hypertext development geared toward improving coherence and metacognitive engagement.

**INTRODUCTION**

Understanding and learning from written material is one of the most important skills to possess in modern society. The ability to understand text affects one's success at deciphering materials ranging from the "three easy steps" for setting up

a computer to understanding the ever-dreaded physiology textbook and its companion Web site. Indeed, the ability to comprehend the challenging texts and hypertexts confronted in typical classrooms is one of the most important keys to success. However, many students are poor readers or have difficulty understanding expository texts (Bowen, 1999; Snow, 2002). Even relatively skilled readers can experience difficulty making sense of a large hypertext (Shapiro & Niederhauser, 2003). One important task facing readers of text or hypertext is creating coherence between ideas. That is, information contained in separate sentences, paragraphs, and documents must be connected within the reader's mental model of the text. The coherence of the reader's mental model, and by consequence the level of the reader's understanding, are essentially a function of these connections (e.g., Kintsch, 1998). The following sections describe what is currently understood about creating coherence within and between documents.

### CREATING COHESION AND COHERENCE WITHIN SINGLE DOCUMENTS

Cohesive elements in a text are grounded in explicit linguistic elements (i.e., words, features, cues, signals, constituents) and their combinations. The general approach to increasing text cohesion is to add surface level indicators of relations between ideas in the text. Such modifications range from adding low-level information—such as identifying anaphoric referents, synonymous terms, connective ties, or headers—to supplying background information left unstated in the text. Text comprehension can be facilitated and enhanced by rewriting poorly written texts to make them more cohesive and provide the reader in the text with all the information needed for ready comprehension (e.g., Beck, McKeown, Sinatra, & Loxterman, 1991; Beyer, 1990; Britton & Gulgoz, 1991; McKeown, Beck, Sinatra, & Loxterman, 1992). When consecutive sentences overlap conceptually, the reader can process them more quickly and is more likely to remember the content. Likewise, when relationships between ideas in the text are explicit by using connectives such as *because*, *consequently*, *therefore*, and *likewise*, the reader is more likely to understand and remember these relationships.

However, comprehension does not reside in the text; it emerges in the mind of the reader. While early research demonstrated the benefits of text cohesion, subsequent research demonstrated that these effects depended on the reader (e.g., McNamara, 2001; McNamara & Kintsch, 1996; McNamara, Kintsch, Songer, & Kintsch, 1996). The reader uses knowledge of words, syntax, context, and the topic to interpret and integrate the text. The connections within the reader's mental representation are constructed based on the elements available in the text combined with the reader's cognitive abilities and intentions. While text cohesion refers to connections between conceptual elements in a text, text coherence refers to the quality of the mental model formed by the reader, combining information from the text and prior knowledge (Graesser, McNamara, & Louwerse, 2003;

Louwerse, 2002; Louwerse & Graesser, 2004). The quality of the mental model is largely driven by the extent to which a reader understands the relations between ideas in a text and is able to construct a complete, well structured representation of the text. Coherence, therefore, results from an interaction between text cohesion and the reader.

McNamara et al. (1996) reasoned that a particular level of cohesion may lead to a coherent mental representation for one reader, but an incoherent representation for another. They reasoned further that the effect of cohesion for expository texts would most critically interact with the reader's domain knowledge. A plethora of research has demonstrated that readers' background knowledge facilitates and enhances comprehension and learning (e.g., Afflerbach, 1986; Chi, Feltovich, & Glaser, 1981; Chiesi, Spilich, & Voss, 1979; Lundeberg, 1987; Means & Voss, 1985; Shapiro, 2004). According to the Construction-Integration model of text comprehension (e.g., Kintsch, 1988, 1998), readers with more knowledge about the topic are able to form a more coherent situation (mental) model understanding of the text. The situation model understanding is the deeper understanding of the text that results from integrating the textbase with prior knowledge. A good textbase understanding relies on a cohesive and well-structured representation of the text. In contrast, a good situation model relies on different processes, primarily on the active use of long-term memory, or world knowledge, during reading.

McNamara et al. (1996) examined the effects of text cohesion and prior knowledge for middle-school students' comprehension of a science text about heart disease. They found that text cohesion benefited low-knowledge readers across all measures of comprehension. Low-knowledge readers cannot easily fill in gaps in low-cohesion text because they do not have the knowledge to generate the necessary inferences. Therefore, they need high-cohesion text to understand and remember the content. In contrast, high-knowledge readers benefited from low-cohesion text, but only according to the situation model measures of comprehension, including bridging-inference questions, problem solving questions, and a keyword sorting task. Requiring the reader to make bridging inferences while reading a low-cohesion text produced a deeper, situational understanding of the text—provided that the reader had sufficient background knowledge to do so. That is, the less cohesive text forced the reader to bridge gaps in the text by making knowledge-based inferences. Doing so requires accessing information from the reader's world knowledge which in turn results in the integration of text information with long-term memory. This gap-filling process can only be successful if the reader has the necessary background knowledge. Therefore, for a good situational understanding, a single text cannot be optimal for every reader: Low-knowledge readers benefit more from an easier, cohesive text, whereas high-knowledge readers should be allowed to make their own inferences with more challenging, less cohesive text (see also, McNamara & Kintsch, 1996). We will refer to the low-cohesion advantage for high-knowledge readers as the *reverse-cohesion effect*.

McNamara (2001) provided further evidence that the reverse-cohesion effect found for the high-knowledge readers was the result of active processing induced by the low-cohesion text. In this study, adult participants read both high and low versions of a text about cell mitosis. Comprehension was enhanced only for participants who read the low-cohesion version, followed by the high-cohesion version. This result showed that the low-cohesion text induced gap-filling inferences while the participant was reading the text, and it was this on-line active processing that enhanced comprehension. When the reader was exposed to the high-cohesion version first, and thus was not induced to generate the inferences, those benefits did not appear. These results further demonstrated that the amount of material read is not a factor that can explain the reverse cohesion effect. That is, the readers were all exposed to the same information, and thus the same amount of information—only the order of presentation differed.

Placing obstacles into the path of the reader prevents the reader from assuming a superficial mode of processing and forces a deeper level of processing. However, increasing the difficulty of comprehension will result in deeper and, hence, better processing only under certain restricted conditions. If the reader engages in extra processing that is irrelevant to comprehension, or in processing that would occur anyway during comprehension (e.g., McDaniel, Blischak, & Einstein, 1995), no advantages result. Furthermore, if the reader is unable to perform the required extra processing, then comprehension, memory, and learning may suffer a great deal. Often, the reason for such an inability is the reader's lack of adequate background knowledge, as was shown by McNamara et al. (1996). High-knowledge readers do not need highly cohesive text because they possess the knowledge to easily fill in the gaps in low-cohesion text. These readers benefit from low-cohesion text because generating inferences promotes integration of text material with prior knowledge.

Studies of individual differences in comprehension have shown that good and poor readers differ in terms of inference processes such as solving anaphoric references, selecting the meaning of homographs, processing garden-path sentences, making appropriate inferences on line, integrating text structures, and so on (e.g., Long & Golding, 1993; Long, Oppy, & Seely, 1994; Oakhill, 1983, 1984; Singer, Andrusiak, Reisdorf, & Black, 1992; Singer & Ritchot, 1996; Whitney, Ritchie, & Clark, 1991; Yuill & Oakhill, 1988). Skilled readers are more likely to generate inferences that repair conceptual gaps between clauses, sentences, and paragraphs (e.g., Long et al., 1994; Magliano & Millis, 2003; Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002; Oakhill, 1984; Oakhill & Yuill, 1996). In contrast, less-skilled readers tend to ignore gaps and fail to make the inferences necessary to fill in the gaps (e.g., Garnham, Oakhill, & Johnson-Laird, 1982; Oakhill, Yuill, & Donaldson, 1990; Yuill, Oakhill, & Parkin, 1989). In sum, one of the clearest distinctions between skilled and less-skilled comprehenders is their ability to make inferences while reading.

Accordingly, if a high-knowledge reader is naturally active and strategic, he or she may not need to be induced by gaps in the text to make inferences. A high-knowledge, strategic reader should be able to generate knowledge-based inferences while reading a high-cohesion text, despite the lack of inference-inducing gaps. Indeed, in a study of adult readers' comprehension of a science text about cell mitosis (used previously in McNamara, 2001), O'Reilly and McNamara (2005) found that only high-knowledge readers who were less strategic (measured in terms of reading skill and reading strategy knowledge) benefited from the low-cohesion version of the text. High-knowledge, strategic readers showed no effects of text cohesion. They also found that less skilled, low-knowledge readers understood little from this text, and did not benefit from cohesion. Thus, while cohesion is generally beneficial, less-skilled, low-knowledge participants may understand little from difficult science texts, regardless of cohesion. High-knowledge readers benefit from low-cohesion text because they do not actively process highly cohesive text. However, if they are skilled readers, and naturally read more actively, high-knowledge readers do not need low-cohesion text to promote active processing.

### **CREATING COHERENCE ACROSS DOCUMENTS**

As the previous discussion shows, the body of knowledge about how learners create meaning from isolated texts is fairly rich. Hypertext has emerged in modern society as another common source of information. How users create coherence between bits of information spread across separate but linked electronic documents, however, is less well studied.

To understand the process of creating meaning from hypertext, it is important to identify components of the task that differ from traditional text-based learning. The limited screen size, use of scrolling windows, reverse contrast, unusual color schemes, and drop down boxes all may alter the reading process somewhat (Waltz, 2001). For the purposes of the present discussion, the relevant differences stem from the nonlinear structure of linked documents. Nonlinear structure poses difficulty for learners because it often reduces global coherence. Further, learners are put in the position of creating coherence while simultaneously navigating through the system and staying oriented. This added requirement shifts the focus of attention away from reading and comprehension at times (Trumbull, Gay, & Mazur, 1992), thus requiring what Wenger and Payne (1996, p. 93) refer to as "a different balance of processing resources." In comparison to research on learning from traditional text, relatively little empirical work has been published about *hypertext aided learning* (HAL). Nonetheless, a number of published reports have informed our understanding of the processes relevant to creating coherence between ideas spread across linked documents (see Shapiro & Niederhauser, 2003, for a broad review of research on HAL).

The most salient factor that affects cohesion and coherence in hypertext is the structure of the system itself. Indeed, there is good evidence that system characteristics affect the nature of learners' understanding of the material in a hypertext (Britt, Rouet, & Perfetti, 1996; Chen & Rada, 1996; Egan et al., 1986; Instone, Teasley, & Leventhal, 1993; Lee & Lee, 1991; Melara, 1996; Shapiro, 1998a, 2000; Simpson & McNight, 1990). For example, Shapiro (2000) examined the effects of advanced organizers for hypertext systems as a function of prior knowledge. She first screened participants for their knowledge of ecosystems (e.g., symbiosis, predator-prey relationships, etc.) and animal family resemblances (e.g., adaptations of and similarities between members of a given family), and included participants with low knowledge of ecosystems and moderate to high knowledge of animal family relationships. These participants were presented with a hypertext system that provided information about a fictitious world of animals, including a hierarchical, interactive overview with embedded links to each animal. This overview was structured in one of two ways, by animal families (e.g., birds, reptiles) or by ecosystems (e.g., mountains, forests). Thus, the advanced organizer for animal families presented familiar information, whereas the advanced organizer for ecosystems presented less familiar information. Participants were assigned the goal of learning about either animal families or ecosystems, with the goal and overview factors fully crossed. Participants' subsequent performance on cued-association and keyword sorting tasks largely reflected the overview to which they were exposed. In contrast, the learners' goals had only a small effect on comprehension. These results demonstrate that the influence of an overview can be powerful enough not only to guide the structure of a novice's internal representations, but to overshadow the effect of the learning goal during that process.

Shapiro (1988a) conducted a similar study, but included a posttest to probe participants' comprehension and learning of concepts related to animal families and ecosystems. As in Shapiro (2000), participants were assigned to one of two goal conditions and one of two interactive overview conditions. Participants all knew little about ecosystems, whereas they had moderate to strong knowledge of animal families. Regardless of overview condition, participants performed equivalently on items related to animal families. Thus, their prior knowledge contributed to a coherent representation of each animal family, even when those relationships were obscured by the system's overt structure. In contrast, performance on items related to ecosystems depended on the overview condition. Regardless of goal condition, those given the animal families overview performed poorly on the ecosystems posttest items. The ecosystem overview, however, enhanced learning about each ecosystem. Thus, learners with low prior knowledge of ecosystems constructed a more coherent understanding of each ecosystem only when the system's structure made that information explicit.

As one might predict from the empirical evidence about learning from traditional text, then, creating coherence across documents in a hypertext system

depends on an interaction between system structure and a learner's level of domain expertise. Given enough knowledge, learners require less help to create an integrated understanding of a system's content. Those with less knowledge, however, are aided by explicit pointers to the relationships between documents or ideas. A similar conclusion was drawn by Lee and Lee (1991). They presented learners who had varying degrees of chemistry knowledge with hypertexts that varied in control over their movement through the system. High-knowledge learners performed better when they had more control and were given less guidance about how to navigate through the hypertext. The opposite was true for low-knowledge learners, who performed better when the system had more control and provided more guidance.

Another factor that affects learners' ability to create coherence across documents is their ability to regulate their own learning. The importance of self-regulation has been demonstrated by a number of studies (Azevedo, Guthrie, Wang, & Mulhern, 2001; Boekaerts, Pintrich, & Zeidner, 2000; Kauffman, 2002; Paris & Paris, 2001; Shapiro, 1998b; Winne, 2001). Azevedo et al. (2001) varied self-regulated learning (SRL) strategy training across four conditions before presenting participants with a hypertext containing information about the human circulatory system. In one condition, each learner was paired with a human tutor who was trained in Winne's (1995, 2001) self-regulated learning (SRL) techniques. The tutor provided prompts to encourage strategies such as self-questioning, content evaluation, judgments of learning, planning, goal setting, and prior knowledge activation. In the second condition, participants were provided with the same strategy instruction as the tutors in the first condition. The third group was asked only to create a learning goal for themselves and to pursue it during study. The fourth group was merely given a series of factual questions to answer during study. Thus, conditions 3 and 4 served as controls, providing no prompts, tutors, or training. Azevedo et al. found large variability within the control groups' self-regulation. In contrast, those in the two SRL conditions demonstrated the most effective learning strategies. More importantly, the tutor and strategy instruction groups experienced a significant change in their mental models of the circulatory system while those in the control groups did not. In short, the SRL strategies employed during the study allowed learners to create more accurate and coherent representations of the material.

As defined by Kauffman (2002), SRL is comprised of three components—cognitive strategy use, metacognitive processing, and motivational beliefs. Each of these components has been studied to some degree within hypertext environments. With respect to the use of hypertext systems, metacognition refers to how principled or thoughtful learners are in their approach to navigating and understanding the system, and this component of SRL may be the most widely studied. In fact, metacognition has been related to a number of learning outcomes.

Shapiro (1998b) obtained an indirect measure of this phenomenon when she presented learners with one of two hypertexts about American history. Both

systems presented the same links and documents, and each document was several screens long. One system (the unstructured, clustered condition) presented all of the links at the end of each document while the other (the hierarchical, distributed condition) presented some at the beginning and some at the end of each document. All participants were given an essay posttest designed to assess conceptual understanding that was scored on four dimensions (integration, clarity, author knowledge, and overall quality).

Shapiro's (1998b) analysis of navigation patterns revealed that participants in the unstructured condition were more metacognitive about their movement through the system. The participants in the hierarchical condition used those links appearing at the end of each document most often. Because each document was several screens long, it would have required more work to go to the beginning of a document for the purpose of considering the links located there. Doing so would have demonstrated a more active, metacognitive strategy on the part of these learners. That is, taking the trouble to go back to the first screen of a document to consider link options would be a sign that the learner was considering all available options and being thoughtful about movement through the hypertext. The fact that learners in the hierarchical link condition rarely did so suggests that they seldom considered all of their navigation options and chose only from the more convenient choices (i.e., those immediately available to them at the end of the document). By settling for fewer choices, they were necessarily less thoughtful about where they should go next and why.

In contrast, participants in the unstructured, clustered condition who found all of the links at the end of each document used a greater variety of links. Since no links in this condition were more convenient to use than any other, this group was left only with document content as a criterion for link choice. With many more links and link types available at the end of their documents, this group was faced with a greater number of navigation choices. As such, their decision making process required a deeper level of thought than those in the hierarchical condition who seemed satisfied with a reduced number of links from which to choose. Within a hypertext environment, the more actively or deeply a learner thinks about link choice, the more metacognitive that learner is. Because of the nature of the unstructured condition, learners did not have their choices limited for them. As such, they were put in a position to be more metacognitive and this was reflected in their learning outcome.

As stated earlier, the evidence for the role of metacognition in hypertext navigation in Shapiro's (1998b) study is indirect. Others have reported more direct, and hence stronger, evidence. Specifically, other investigators have experimented with using prompts or questions designed to encourage metacognition, and hence encourage the creation of coherence, without training or tutors. Kauffman (2002) presented participants with a hypertext designed to teach about educational measurement. Half the participants were assigned to work with a system that presented metacognitive prompts each time a link was clicked. These

prompts presented questions to challenge the learner's understanding of the previous document or expectations for the document just chosen. The control group navigated freely, without any prompts or questions. While there was no difference between groups' performance on a declarative knowledge test, the metacognitive prompt group outperformed the control participants on a test of transfer to real-world problems that required integrating information from multiple documents. While it was the simple act of thinking through the answers to the questions posed in the prompts or thinking through them and writing out the answers, the addition of metacognitive prompts promoted better integration of information between documents.

In addition to metacognitive instruction and prompts, simple manipulations such as highlighting key links can also improve cohesion and thus enhance learners' ability to create coherence between linked documents. The importance of using particular links was demonstrated by Shapiro (1999), who exposed biology novices to one of four hypertexts that all presented the same documents about animal biology. One condition presented the information as a hierarchy. A second presented the same information as an arrangement of thematic clusters. This condition presented short phrases adjacent to each link button that provided some detail about the relationship between the current document and the one represented by the link. A third condition provided no global organizing theme, presenting the information in an unstructured collection of interconnected documents. The final condition was a control, presenting the information as a linear (electronic) book.

A simple analysis of participants' performance on a problem-solving posttest indicated comparable performance across conditions. More detailed analyses, however, revealed a relationship between problem-solving performance and link choice. Specifically, participants across conditions were more likely to answer a problem-solving question correctly if they had used the link that joined the documents relevant to the question. This result indicates that reducing learner control may actually improve novices' ability to create coherence between documents when there is an important inter-document relationship to be considered. Just as Shapiro (1998a) found that site maps can benefit novices by providing explicit pointers to relationships between documents, some directed navigation may also aid domain newcomers in the quest for coherence.

Schnackenberg and Sullivan (2000) have also reported evidence that steering learners toward important links or documents has a strong effect on learning outcomes. They presented learners with hypertexts designed to present part of a course. Half of the participants enjoyed a high degree of learner control while the other half were largely constrained in their navigation by the system. Those assigned to the learner control condition were divided into experimental groups based on the default options in the systems to which they were assigned. Half of the participants were exposed to default "continue" buttons on many pages that led to more practice exercises. The other half were exposed to default "continue" buttons that led to the next content topic. Both groups were also given the option of

choosing links to optional screens that led to more practice. The results indicated that participants in both learner control conditions were more likely to choose the default option than an optional link. As such, those in the “more practice” default version viewed about twice as many practice screens as those in the “skip practice” default condition. More importantly, the “more practice” default group outperformed their learner control counterparts on the final test.

In sum, acquiring a coherent, robust understanding of a hypertext’s content is not a simple matter for learners. As in linear text, creating coherence is especially difficult for individuals new to a domain and those who are unaccustomed to taking an active, thoughtful approach to learning. A poorly prepared, unmotivated learner will learn little from any medium. However, good hypertext design can improve learning outcomes for a wide variety of learners. The structure of a hypertext imparts information about the relationships between documents and ideas contained in the system. There is strong evidence that the amount of such information interacts with learner traits to affect learning outcomes. Similar to linear text, research on hypertext has highlighted the importance of matching learners’ levels of knowledge and metacognition with the level of structure provided by a hypertext system.

### **HOW CAN LEARNERS BE AIDED IN THEIR QUEST FOR COHERENCE?**

To this point, we have shown that creating coherence within and across documents is an important and oftentimes difficult task for learners. Our discussion has also highlighted several cognitive variables that are important to learners’ ability to create coherence. The remainder of this article is aimed at describing two approaches for helping users create coherence. The first describes an approach aimed at teaching learners overt strategies for improved reading skills. Toward this end, we discuss an automated multimedia system called Interactive Strategy Training for Active Reading and Thinking (iSTART), designed to provide users with training to use active reading strategies. We then describe design guidelines directed at helping learners form a better integrated understanding of a hypertext’s global content. Because the design features promoted in that section are embedded in the hypertext interface, they are invisible to users. That is, they guide learners into behaviors that promote learning without requiring additional training on the part of the hypertext user.

### **AN APPROACH FOR PROMOTING INTRA-TEXT COHERENCE: TRAINING USING iSTART**

How can we help readers more effectively process texts, regardless of the texts’ cohesion? We have seen that high-knowledge readers are less affected by text structure if they have sufficient reading skills. However, low-knowledge

and less-skilled readers have particular needs in terms of text cohesion. It is particularly important to be concerned with these readers given the prevalence of low-cohesion or poorly written instructional texts (e.g., Beck, McKeown, & Gromoll, 1989; Wilson & Anderson, 1986).

To address this need, we can turn again toward literature regarding skilled comprehenders. As mentioned earlier, skilled readers are more likely to make inferences and more actively process written material than less-skilled readers. In addition, comprehension monitoring and metacognitive reading strategies are increasingly recognized as critical to successful, skilled reading. Readers better understand and learn more from written material when they monitor their comprehension and use active reading strategies such as previewing, predicting, making inferences, drawing from background knowledge, and summarizing. Skilled readers are more likely to engage in comprehension monitoring and active reading strategies than are less-skilled readers (Brown, 1982; Long et al., 1994; Magliano & Millis, 2003; Oakhill, 1984; Oakhill & Yuill, 1996). Moreover, providing readers with instruction to use metacognitive reading strategies improves reading comprehension skills (Baker, 1996; Baumann, Siefert-Kessell, & Jones, 1992; Bereiter & Bird, 1985; Davey, 1983; Dewitz, Carr, & Patberg, 1987; Hansen & Pearson, 1983; Palincsar & Brown, 1984; Yuill & Oakhill, 1988).

Another successful reading and learning technique is *self-explanation* (Chi & Bassok, 1989). Self-explanation refers to the process of explaining text while reading. This process involves actively processing the text, understanding the relationships between separate ideas in the text, and relating the ideas to knowledge already possessed by the reader. In a laboratory setting, self-explanation involves reading and explaining aloud sentences or sections from a text. Readers who explain the text either spontaneously or when prompted to do so, understand more from the text and construct better mental models of the content (Chi & Bassok, 1989; Chi & VanLehn, 1991; Chi, de Leeuw, Chiu, & LaVancher, 1994; Magliano, Trabasso, & Graesser, 1999; Trabasso & Magliano, 1996; VanLehn, Jones, & Chi, 1992). Some readers, however, do not naturally self-explain text and, when prompted to do so, self-explain poorly.

McNamara (2004b; McNamara & Scott, 1999) examined whether self-explanation and reading strategies taught together might help readers to better understand text, particularly low-cohesion text. Self-Explanation Reading Training (SERT) is much like techniques based on thinking aloud (Baumann et al., 1992; Coté, Goldman & Saul, 1998; Davey, 1983). However, SERT places a greater emphasis on use of active reading strategies to explain the text than have previous think-aloud interventions. It was hypothesized that reading strategy instruction would help readers improve their self explanations. In turn, the external nature of self-explanation was intended to help readers be more aware of and learn to use reading strategies.

SERT is an experimenter- or teacher-delivered intervention that can be administered to a small group of students in about 2 hours. It begins with a brief instruction

including definitions and examples of self-explanation and reading strategies. Self-explanation is described as reading text aloud and explaining what the text means, and several examples are provided. Six reading strategies are then introduced to the students as a means for improving self-explanation: a) comprehension monitoring, being aware of understanding; b) paraphrasing, or restating the text in different words; c) elaboration, using prior knowledge or experiences to understand the text (i.e., domain-specific knowledge based inferences); d) logic or common sense, using logic to understand the text (i.e., domain-general knowledge based inferences); e) predictions, predicting what the text will say next; and f) bridging, understanding the relation between separate sentences of the text. For each strategy, a description of the strategy and examples of self-explanations using the strategies are provided. Comprehension monitoring is presented as a strategy that should be used all of the time. Paraphrasing is presented as a basis or jumpstart for self-explanation, but not as means for self-explaining text. The remaining strategies are various forms of inferences (i.e., domain specific, domain-general, predictive, and bridging) that were predicted to most likely enhance comprehension and explanation.

After the introduction, students read a science text and watch a video of a student in the process of self-explaining the text. The video is paused at certain points and the students are asked to identify the strategies used by the student in the video for the sentence. They then discuss these strategies as a group. It is important that all of the students are asked to write down what strategies were used. In this way, they are all more likely to discuss their answers and construct a better understanding of the strategies and self-explanation. The students then work with partners to practice the strategies, taking turns in reading orally and sharing thoughts. Instructors are present to assist and monitor the students.

McNamara (2004b) first examined the effects of SERT with 42 adult readers, half of whom received training. In contrast to the training approach described above, however, each participant received individual training, practicing with four texts and watching four videos of a student self-explaining those texts. After training, all of the participants self-explained the low-cohesion cell mitosis text (used in McNamara, 2001). Little benefits were expected for high-knowledge readers. These readers will automatically use their knowledge to bridge conceptual gaps in text, with enough motivation to understand the text.

There were two possible predictions regarding the low-knowledge readers. On the one hand, cohesion gaps may be only surmountable with sufficient prior knowledge. On the other hand, reading strategy training may help the low-knowledge reader to use logic and common sense rather than domain-relevant prior knowledge to fill in conceptual gaps. It was hypothesized that improved reading strategy knowledge would compensate for a reader's knowledge gaps. While prior knowledge may be the most direct and natural way to resolve cohesion gaps, the reader may be able to "work harder" to understand the text by generating more logic-based and text-based inferences. If that is the case, however, benefits

of strategy training should only appear on the more text-based measures of comprehension, as opposed to the more knowledge-demanding, situation model comprehension questions. That is, the development of a coherent situation model, or deep understanding, of a text is highly dependent on having sufficient prior knowledge.

McNamara (2004b) found that only prior domain knowledge contributed to performance on the bridging inference questions. In contrast, text-based questions revealed an effect of training for the low-knowledge readers. SERT was most effective for students who had less prior knowledge about the text domain. This training provided students with strategies that they could use while reading, which effectively compensated for their lack of domain knowledge. In addition, protocol analyses indicated that these readers instead relied on their common sense and logic to understand the text.

Three subsequent experiments conducted by McNamara and colleagues have shown that SERT training not only improves text comprehension, but also improves undergraduate students' exam performance in science courses (McNamara, April 2004; 2004a; McNamara, Best, & Castellano, 2004). Across five classrooms including almost 1000 students, consistent benefits have been found for SERT. Reliable advantages on exam scores for students who received SERT training in comparison to control students have ranged between 5% and 14%. In addition, prior knowledge of scientific facts generally showed the strongest correlations with exam performance, whereas prior reading skill showed the lowest correlations (which were generally non-significant). Most importantly, training generally had the greatest benefits for those students with less prior knowledge about science (McNamara, April 2004, 2004a; McNamara et al., 2004; O'Reilly, Best, & McNamara, 2004).

For example, McNamara (2004a) described a study that examined students' learning in an ecology course including 92 students, 33 of whom had participated in SERT. Training was administered between Exams 1 and 2, resulting in a substantial improvement on Exam 2 for those who received training in comparison to control students. In addition, there was a decline in performance across exams for all students except students with less knowledge about science who received SERT training. Indeed, these low-knowledge students showed comparable performance on the final exam to high-knowledge students in the control condition who did not participate in SERT.

Within all of these experiments, low-knowledge students who did not receive training often left the science course without a passing grade. Hence, for some students, SERT made the difference between passing and not passing the course. Nevertheless, many of the high-knowledge students, who had more knowledge about the targeted course, reported that they had used the strategies for more challenging courses in which they were enrolled and that these strategies were effective. Therefore, this type of training has the potential to be beneficial to many students, regardless of their prior knowledge.

SERT has been implemented in a multimedia tutor designed to automate the training program. iSTART (McNamara, Levinstein, & Boonthum, 2004) begins with an introduction to self-explanation and reading strategies delivered by three automated agents, a teacher-agent and two student-agents. The human student watches while the teacher-agent interacts with the student-agents to teach them the reading strategies. For example, the teacher-agent poses questions to the student-agents, and vice versa. They also interact to provide and discuss examples of the strategies. The goal is to simulate the learning experience such that the student-user learns the strategies vicariously (e.g., Craig, Gholson, Ventura, Graesser, & the Tutoring Research Group, 2000; McKendree, Stenning, Mayes, Lee, & Cox, 1998; Shebilske, Jordan, Goettl, & Paulus, 1998).

As in SERT, the reading strategies include comprehension monitoring, paraphrasing, prediction, elaboration, and bridging. One difference in comparison to SERT is that the Logic and Common Sense strategy was explained in the context of elaboration as using general knowledge rather than domain knowledge. This alteration was made because it was very difficult for students to discriminate between domain knowledge-based elaboration and general knowledge elaboration. For each strategy, the strategy is defined, and then examples are provided.

At the end of each strategy section, the student takes a quiz to assess their understanding of the strategy. Each quiz includes four multiple-choice questions that cover the basic definitions of the strategies and assess the student's ability to choose explanations that exemplify the strategy. After the introduction, the student moves on to the demonstration module in which two new agents, Merlin and Genie, demonstrate the strategies while self-explaining a text. The student identifies what strategies are being used in the examples.

In the last training module, the student practices self-explaining science texts and receives feedback from Merlin. To provide feedback to the student during the practice module, the iSTART system must assess the self-explanations on a number of dimensions (McNamara et al., 2004; McNamara, Boonthum, Levinstein, & Millis, in press; Millis, Magliano, Wiemer-Hastings, Todaro, & McNamara, in press). It first assesses whether the self-explanation is too short or simply a close repetition of the sentence. This is important because the purpose of the system is to push the student to go beyond the sentence by using prior knowledge or prior text to explain the sentence. But the self-explanation must also be relevant. Thus, the system also assesses whether the self-explanation is relevant to the topic of the sentence text by comparing it to a set of associated words. Finally, it assesses the quality of the self-explanation in terms of the number of words and the number of associations (as opposed to words directly from the sentence). Based on these assessments, Merlin provides the student with requests (e.g., to add more information) or feedback (e.g., Ok, Very Good, Excellent). Merlin also asks the student which strategies he or she used in the self-explanation and for critical sentences

asks the student to use other strategies if the student has used only paraphrasing or comprehension monitoring.

Our laboratory results from three experiments conducted thus far indicate that iSTART is highly effective in improving students' ability to understand difficult texts (McNamara & The CSEP Lab, 2004; O'Reilly, Sinclair, & McNamara, 2004a, 2004b). Our first goal was to verify that iSTART was as effective as SERT in helping students to improve their reading strategies. To answer this question, a study with 300 college students compared iSTART, SERT (the live version), and a control condition (who read the same texts but were not given strategy instruction). The results showed reliable advantages for both iSTART and SERT in comparison to the control condition on comprehension of a science text one week after training (O'Reilly et al., 2004b). Thus, this study confirmed that iSTART was as effective as SERT in helping readers to develop a more coherent mental representation of text.

A second study was conducted with 38 middle-school students (O'Reilly et al., 2004a; McNamara & The CSEP Lab, 2004). In this study, half of the students were provided with iSTART training and half were not before they were asked to read and self-explain a text about heart disease. The locus of comprehension gains from iSTART training depended on both the students' prior knowledge of reading strategies and the level of comprehension assessed (see e.g., Kintsch, 1998; McNamara et al., 1996). Specifically, iSTART as compared to the control condition resulted in better performance on text-based questions for children with less prior knowledge of reading strategies. Thus, less-strategic children gained primarily in terms of understanding the text at the textbase level of comprehension. In contrast, students showed improvement from iSTART on bridging inference questions if they had greater prior knowledge of reading strategies prior to training.

A similar pattern of results was found in a third study that included 44 college students (Magliano et al., 2005; McNamara & The CSEP Lab, 2004). These students read and self-explained two texts before and two texts after iSTART training. As found with the middle-school students, better readers gained in terms of deeper levels of comprehension. That is, they performed better on bridging-inference questions after training than before. In contrast, less-skilled readers gained in terms of their surface level understanding of the text, showing significant improvement on text-based questions.

In sum, our results thus far indicate that iSTART training helps students make progress in their area of proximal development (e.g., Vygotsky, 1978). Readers must first learn to create a coherent representation of the text-based information; that is, the information presented in the individual sentences. Then, readers can learn how to understand the text at a deeper level, by processing the relationships between the ideas conveyed across sentences. iSTART allows this progression of improvement by providing training at both levels of processing.

The current version of iSTART does not adapt training according to the learner's prior skill or knowledge—only to the performance as the learner proceeds through the multimedia system. Future versions of iSTART will use the information gleaned from the research conducted thus far with iSTART to guide training more adaptively. For example, the research thus far indicates that less-skilled readers need more practice and more positive reinforcement for reading strategies such as paraphrasing before moving on to more complex strategies such as elaboration and making bridging inferences. The research with SERT and iSTART has laid a foundation such that reading strategy training can be adapted to fit the needs of individual readers.

The critical difference between iSTART and the hypertext systems discussed earlier is that iSTART is designed to teach readers to use more effective strategies when reading and learning from linear text. The hypertext systems that we have discussed are systems in which readers are expected to learn the content in the text. One might predict that iSTART could be used to improve comprehension of text embedded in a hypertext as well as it improves comprehension of linear text. Indeed, the results by Azevedo et al. (2001) indicate that a tutorial method such as the one implemented in iSTART may very well improve comprehension for hypertext. However, in absence of reading strategy interventions such as those provided by SERT and iSTART, research indicates that hypertext systems can be designed such that they promote more engagement during reading. Moreover, a successful intervention may need to go beyond the strategies covered in iSTART. The following section discusses the principles that can be used to help learners develop more coherent understandings of the text by adapting the structure of hypertext systems.

### **AN APPROACH FOR ENCOURAGING INTER-TEXT COHERENCE: USING HYPERTEXT DESIGN PRINCIPLES**

How can we help learners more effectively understand the content of a hypertext? Helping learners create a coherent understanding of information spread across a number of linked documents presents different challenges from those faced in single, linear texts. Specifically, learners are faced with the challenge of making connections between ideas in an order of their choosing. Since the author of a learner-controlled system does not know the order in which a learner will access each document, the content of any given document may not necessarily mention its relationship to other documents. As such, understanding relationships between documents in a very large hypertext can be particularly difficult. Additionally, not all hypertext environments lend themselves to explicit strategy training. This is especially true in informal educational settings such as museums or informational Web sites. An alternative, then, is to use design principles that are largely invisible to the user. Indeed, it is possible to design hypertext environments that implicitly encourage learners to generate a coherent understanding of a

hypertext's global content rather than merely helping users travel between pages. In other words, we are concerned with learner-centered design (e.g., Soloway, Guzdial, & Hay, 1984) rather than user-centered design (e.g., Norman & Draper, 1986). That is, these guidelines are designed to improve learning. They are not human factors principles designed to improve usability.

As the research discussed earlier demonstrates, the nature of the environment that best lends itself to the creation of coherent mental representations is dependent upon characteristics of individual learners. With that in mind, we offer here a number of hypertext design guidelines aimed at helping learners recognize the relationships between ideas scattered across a hypertext. These design guidelines are based upon the empirical work on HAL discussed earlier. As such, they reflect the need to accommodate individuals' knowledge and learning style.

### **Guideline 1: Provide Ill-Defined Global Structure for Advanced Learners in a Domain**

This guidance is based on evidence showing that less guidance and structure provided by a hypertext can promote the use of prior knowledge and meta-cognitive strategies. A study discussed earlier by Lee and Lee (1991), for example, showed that high-knowledge learners performed better when given more control and less guidance in a hypertext. The sizable literature on Cognitive Flexibility Theory also speaks to the advantage of ill-structured hypertext for advanced learners in a domain, particularly within ill-structured domains. The basic argument is that advanced, flexible knowledge is promoted by presenting learners with opportunities to explore a complex domain from multiple perspectives. This approach is discussed at some length by Spiro, Feltovich, Jacobson, and Coulson (1991).

A great deal of evidence has accumulated that robust learning occurs when newly encountered information is integrated in memory with prior knowledge, as predicted by the construction-integration model (Kintsch, 1988). By doing so, learners come to a fuller understanding of novel information, one that can lead to the generation of inferences or new knowledge. When knowledgeable learners are "spoon fed" information, they are dissuaded from invoking prior knowledge to make sense of what they have read. Salmerón, Cañas, Kintsch, and Fajardo (2005) found evidence for this assertion by presenting learners with either high or low cohesion pathways through a hypertext designed to teach about air pollution. In Experiment 2, the low-knowledge learners performed best on both cued association and inference tests after following a high-cohesion path through the hypertext. High-knowledge learners performed best on these measures after following a low-cohesion path.

Because knowledgeable learners are less likely to invoke their existing knowledge when presented with clear pointers to the relationships between documents, the information is less likely to be integrated with information in long-term

memory. As such, their best learning outcomes may not be achieved. For this reason, well-defined structures such as hierarchies, which make the relationships between linked ideas apparent, are not recommended for advanced learners in a domain.

Clark and Mayer (2003) have also recognized the need to induce advanced learners to use prior knowledge when engaged in HAL. In a discussion of learner control issues, they suggest that more knowledgeable learners be given a greater degree of control over their navigation behavior. The reasoning underlying this suggestion is the same as that explained here. That is, learners with sufficient prior knowledge benefit from encouragement to use what they know in order to stay oriented in a hypertext. They also benefit from encouragement to make principled choices about what to read and when to read it.

This principle can also be used to guide revisions of iSTART. These revisions concern the cohesion of the texts that the learner reads while learning the strategies and the flexibility of the iSTART system for the learner. Regarding text cohesion, one current goal is to provide more challenging, less cohesive texts to readers with more knowledge about a certain domain and more cohesive texts to learners with less knowledge. Along these same lines, more cohesive texts need to be presented to learners at the start of training, and the text needs to increase in difficulty as training proceeds. Regarding flexibility, one goal is to provide learners with more flexibility and choices in the system when appropriate. For example, some learners will be given the option for more examples or for more opportunities for practice. Learners may also be given choices in the texts that they read, such that they are potentially more interested and engaged in the text topic.

## **Guideline 2: Provide Well-Defined, Goal Appropriate Global Structure for Domain Novices**

While advanced learners can benefit from their accumulated domain knowledge, beginning learners have little to draw from. For this reason, novices require more “hand holding” in their quest to create coherence between documents. Their lack of prior knowledge also makes them more prone to disorientation and the feeling of being “lost” in the system (Nielsen, 1989, 1990). By providing a well-defined structure, such as a hierarchy, learners are given implicit information about how ideas between documents are related. The benefit of this design practice was demonstrated by Shapiro (1998a, 2000), who was able to improve novice participants’ ability to understand interspecies relationships simply by structuring their interactive overview map to clarify those relationships. In contrast, when exposed to systems that presented organizers that were inconsistent with their learning goals, novice participants had great difficulty and often failed to meet their learning goals. These findings indicate that, in addition to revealing the relationships between documents, a hypertext’s structure should be consistent

with learners' goals. A number of other studies also point to the benefit of providing a well defined hypertext structure for low-knowledge learners (Foltz, 1996; Lee & Lee, 1991; Steinberg, 1989). For example, Foltz found that cohesion manipulations to a hypertext system based on the Kintsch Construction-Integration model improved comprehension for low-knowledge learners (see also, McNamara et al., 1996).

An organizing structure need not be hierarchical to improve learning among novices. Notations attached to a link about the relationship it represents can be very effective (Shapiro, 1998b), as can overview maps illustrating the relationships between documents (Shapiro, 1998a, 2000). This point is good news for students of ill-structured domains (e.g., literary theory), which do not always lend themselves to strictly hierarchical representations. Even disciplines that are typically thought of as well-structured, such as mathematics or chemistry, are only well-structured at their fundamental levels. Most disciplines become less hierarchical as one moves into more advanced topics in the field. Nonetheless, we suggest that some degree of structure or explanation about topic relationships be offered by a hypertext, even when the topic itself is ill-structured.

Some guidance about the nature of that structure is offered by the research on text cohesion (e.g., Britton & Gulgoz, 1991; McNamara, 2001). As applied to hypertext, this research indicates that the novice readers will benefit most when linked documents are maximally cohesive with one another. Hence, documents should be linked that have the most overlap; and, hypertext authors should maximize the potential for coherence between linked documents by explicitly expressing the relationships between the documents.

### **Guideline 3: Create an Environment that Encourages a Metacognitive Approach to the System Content**

As discussed in the introduction, it is well understood that good metacognitive skills lead to enhanced learning outcomes. The iSTART program described above has been successful in teaching learners to create a coherent understanding of information contained in a text. Likewise, the metacognitive training program tested by Azevedo et al. (2001) has proven successful at helping learners create a more coherent understanding of information housed in separate hypertext documents. It is not always feasible, however, to engage hypertext learners in a training program, particularly in informal learning environments. For this reason, it can be helpful to incorporate design principles into a hypertext that encourages better metacognition. That is, learners should be encouraged to think about their navigation choices and the relationships between documents.

This recommendation may be seen as a caveat to Guideline 2, as it suggests that providing too much structure or information can mitigate learning, even for novice learners. That is, too much "hand holding" can breed passivity on the part of the student. Indeed, there is the rare domain novice who will do better with

an ill-structured system because he or she has strong metacognitive skills. These are typically older learners who have achieved a level of expertise in other areas. Alexander (1997) refers to these readers as competent or proficient learners. Other than level of knowledge in a domain, an important distinction between proficient and beginning learners is the strategies employed by proficient learners (Alexander & Jetton, 2000). While the advanced strategies used by proficient learners are most effectively used in their domain of expertise, they generally tend to be very strategic metacognitive readers. For these students, the degree of guidance may be reduced in order to encourage a metacognitive approach to the material. How to find the right balance between the need to support domain novices as they begin exploring a discipline and the need to encourage a thoughtful approach to the material is a matter that requires further study. However, a number of strategies are available to shift the balance between support of a learner's knowledge level and metacognitive behavior.

One strategy shown to be successful by Kauffman (2002) is the use of metacognitive prompts. By providing pop-up windows that ask users to consider how well they have understood what they just read, what they expect to see on a document just chosen, or how they view the relationships between documents, learners may be encouraged to think more deeply about the material and their navigation choices. This is a good design choice for novices because prompts can be incorporated into a system without reducing the support structures that benefit those who are new to a field. Such prompts can also be incorporated as a game, allowing the user to accumulate points. Users may also be treated to a cartoon character that provides feedback about their responses. Cartoons may work best, of course, for younger users. Also, they should be kept to a minimum, as providing too much extraneous graphics and sound can mitigate learning (Mayer, 2001).

Shapiro (1998b) has also demonstrated that link placement choices can alter how thoughtfully users approach the material presented by a hypertext. By providing some links in a more convenient location than others, users are encouraged to make the expedient choice. While that fact can be used to a learner's advantage by encouraging the use of particularly important links (see Guideline 4), this practice also discourages thoughtful navigation. Default navigation choices, then, can be a problem because the act of deciding where to go next is an exercise that promotes coherence. For this reason it is suggested that, unless a given link is particularly important, learners should be encouraged to think about their choices by making each link equally accessible and appealing.

#### **Guideline 4: Highlight Links that Denote Very Important Inter-Document Relationships**

As discussed earlier, Shapiro (1999) asked participant to solve novel problems after reading a hypertext. To solve these problems, learners were required to understand the relationship between ideas on separate but linked documents.

Shapiro was able to show that when learners used the links between these documents, rather than accessing them via other avenues, they were more likely to correctly solve those problems. Thus, when it is particularly important for learners to understand the relationship between ideas on separate documents (i.e., create coherence between them), some method should be used to alert learners to the importance of moving directly between highly related documents and understanding the relationships between their respective contents. This can be achieved by highlighting the link or putting it in a conspicuous place on the screen. In addition, Clark and Mayer have suggested that “important instructional events” be made the default navigation option (2003, p. 236). As discussed under Guideline 2, this type of guidance is particularly important for domain novices, as they are less likely to recognize the relationships between documents on their own. In contrast, highlighting important relationships is less crucial for more knowledgeable learners who are more likely to recognize the importance of the link without aid, or may already understand the relationship. Even experts in a field, however, can fail to recognize important relationships; so highlighting important links can still be useful to seasoned veterans of a discipline. Of course, this practice should be used sparingly, as an abundance of such default links will dilute their effectiveness and reduce learners’ need to be metacognitive, as discussed under Guideline 3.

In summary, creating a coherent understanding of a hypertext’s global content is not a simple task. A well-designed hypertext will encourage advanced learners to invoke their knowledge during study. For knowledgeable or very metacognitive learners, this can be done by making the relationships between ideas contained in the hypertext less obvious. A well-designed hypertext for novices will help them overcome the gaps in their knowledge by pointing to relationships between ideas more explicitly. In an ideal world, all learners would have enough metacognitive skill to create coherence between documents, but that simply is not reality for the vast majority of learners. Even those who have prior knowledge to draw from during HAL often lack the metacognitive skills to integrate new information with existing memory. While metacognitive training may be helpful in overcoming this difficulty, such training is not always feasible. For these reasons, we have offered a series of hypertext design principles that are aimed at helping learners with varying knowledge and metacognitive levels generate a coherent understanding of the information spread across a hypertext.

## CONCLUSIONS

The research described in this article points away from facilitating the reading or learning process, and toward increasing the reader’s engagement and effort while reading to learn. The complexities of learning from linear text and hypertext are similar to those associated with general knowledge and skill acquisition. For example, there is a large body of research showing that facilitating the learning

process can speed acquisition, but results in superficial learning and poor retention (Battig, 1979; Healy et al., 1993; Healy & Sinclair, 1996). Long-term retention and intra-task transfer is enhanced with training methods that slow acquisition by making the learning process optimally difficult and thereby increasing the learner's active engagement. The process is no different when learning from text or hypertext. Whereas high-cohesion presentations can appear to facilitate learning, they can inhibit the active processing necessary to enhance comprehension, for some learners.

However, other learners need greater text or inter-text cohesion because they do not possess enough background knowledge to generate the necessary inferences. The dilemma then seems to be finding the best of all worlds. This leads us to the effects of the strategies described in this article. Providing readers with training to use more active reading techniques, such as self-explanation, in combination with instruction regarding reading strategies, in the SERT system has provided remarkable results, particularly for low-knowledge readers. When low-knowledge students were provided with SERT they have been able to understand texts and pass science course exams at the level of the high-knowledge students. Systems such as iSTART take us closer to the goal of being able to provide larger numbers of readers with training, combined with the ability to match training to the reader's particular needs. With respect to hypertext, a number of design strategies have been demonstrated as useful in furthering users' learning goals. Building in pop-up windows or obscuring the global structure of a hypertext can induce learners to become more metacognitive in their approach. Additionally, varying the level of support in the form of overview maps and other cues to the inter-document relationships denoted by links can be highly effective for learners with varied domain knowledge.

In conclusion, the best of all worlds seems to arise from two complementary approaches. The first is to provide relatively cohesive texts and hypertexts, matching as best we can the reader to the material. The second is to provide students with reading strategy training or hypertext design features that focus on reading actively, attempting self-explanation, and making text and knowledge based inferences to support those explanations. These two approaches combined should lead to optimal comprehension and learning, and thus coherence.

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