

Theories of Comprehension and Comprehension Skill:  
Knowledge and Strategies versus Capacity and Suppression

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## Abstract

This chapter reviews the literature concerning differences between skilled and less skilled readers and theoretical accounts of comprehension skill. One of the most ubiquitous findings in the domain of reading comprehension is that skilled and less skilled comprehenders can be distinguished in terms of how often, when, and how they make inferences while reading. Theories differ, however, in explaining how or why skilled readers are better able to generate inferences. This paper reviews four principle accounts of comprehension skill and empirical evidence to support why skilled readers are able to make more inferences while reading. One class of theories propose that comprehension skill is driven by differences in working memory (WM) capacity, such that skilled readers are better able to make inferences while reading because they are able to hold in WM more information from the text or discourse. A second explanation proposes that skilled readers are better able to suppress contextually irrelevant information, and are thus able to process relevant information more effectively. A third account proposes that skilled readers possess and use more knowledge than less skilled readers. A related fourth account emphasizes the importance of reading strategies to promote knowledge use. We argue that the bulk of the evidence supports the latter two accounts and specifically, that reading skill is largely driven by world, domain, and reading strategy knowledge.

An important question in reading research regards what differentiates skilled and less skilled readers. Why does one person comprehend and learn from text with seeming ease, while another struggles to understand even the basic message from textually presented information? In what cognitive processes does the successful reader engage? Is the skilled reader born with certain internal mechanisms that allow comprehension success? Or, can cognitive processes be identified that can be taught to the less skilled reader? The practical importance of these questions is born out by the low levels of reading comprehension skills exhibited by students in our school systems. Studies by the National Assessment of Educational Progress (NAEP) show that many students struggle to understand even the basic message from text and consequently perform poorly in school and on standardized tests. Indeed, problems of reading ability permeate the school system and have a large impact on a variety of subject areas, particularly performance in difficult school subjects such as science (Bowen, 1999; Cottrell & McNamara, 2001; O'Reilly & McNamara, 2001; Snow, 2002).

The issue of reading skill differences is also of theoretical importance. Understanding these differences informs theories of reading by identifying the most critical processes in reading comprehension. This chapter describes the most prominent theories of comprehension skill and addresses the question of what mechanisms, processes, or characteristics best differentiate skilled and less skilled comprehenders.

### **Reading Comprehension Skill**

Many researchers have focused on the initial developmental stages of reading when the reader is essentially acquiring lexical and syntactic decoding skills. This research has shown for example that the more successful novice readers have had greater

exposure to print (Stanovich, West, Cunningham, Cipielewski & Siddequi, 1996) and have greater phonological awareness (Hulme & Snowling, 1992). Other areas of research have focused on the lower-level processes in reading, how words are decoded and how single sentences are comprehended. We know for example that more common words can be decoded from the form of the word, as a unit, whereas the letters of less common words contribute more to the decoding process (e.g., Healy, 1994). This and other research has established that word decoding is not a bottom-up process, from the letters to the word. Rather, decoding a word brings to bear many sources of available information in parallel, information from the word, the sentence, and the reader's knowledge (Reicher, 1969; Carr, 1986). The complexity of the word decoding process foreshadows the even more complex processes involved in comprehending sentences and entire texts, which is the focus of this chapter.

Comprehension refers to meaning making. Text comprehension is the construction of meaning of and from the words and phrases in written material. It is the building of the understanding of the relationships within the text, between the words, sentences, and paragraphs. It is the reader's construction of an understanding of the relationship between the information in the text and what the reader already knows. What the reader already knows, of course, plays an important role from the beginning. Word knowledge contributes to both decoding and comprehension processes (Perfetti, 1985, 1989). The use of this knowledge beyond the words in the text is often referred to as making inferences. Readers make backward inferences to information presented previously in the text and elaborative inferences to concepts outside of the text. Elaborative inferences can be predictive of what might come next in the text; they might

embellish certain ideas or concepts in the texts; or, they might enable the reader to better understand relationships between the current and prior text.

Making these inferences is difficult if not impossible if the reader is unable to decode or doesn't know the words in the text. As such, decoding and comprehension processes are tightly interwoven. Although, word decoding difficulties are correlated with and may ultimately result in reading comprehension deficits (e.g., Perfetti, 1985; Schankweiler et al., 1999), decoding and comprehension are separable processes. For example, a hyperlexic reader can decode but not comprehend, and a dyslexic reader can comprehend, but not decode. Indeed, poor comprehenders who do not have deficits at the level of word decoding or syntactic decomposition are not uncommon (Cain, 1996; Hoover & Gough, 1990; Stothard & Hulm, 1996; Cornoldi, DeBeni, & Pazzaglia, 1996). These readers read fluently and with apparent ease, and yet still perform poorly when answering questions, particularly questions that assess the reader's deep level understanding of the text.

How do these readers, who can decode words and syntax without difficulties but struggle to comprehend the deeper meaning of the text, differ from those who more successfully comprehend text? A large body of research has indicated that less skilled readers make fewer inferences that go beyond the explicit meaning of the text while reading. Skilled readers are more likely to generate inferences that repair conceptual gaps between clauses, sentences, and paragraphs, whereas less skilled readers tend to ignore gaps or fail to make the inferences necessary to fill in the gaps (e.g., Garnham, Oakhill, & Johnson-Laird, 1982; Long, Oppy, & Seely, 1994; Magliano & Millis, 2003; Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002; Oakhill, 1984; Oakhill

& Yuill, 1996; Oakhill, Yuill, & Donaldson, 1990; Yuill, Oakhill, & Parkin, 1989).

Skilled readers also more successfully resolve anaphoric reference, select the meaning of homographs, process garden-path sentences, make appropriate inferences on line, integrate text structures, and so on (e.g., Long & Golding, 1993; Oakhill, 1983; Singer, Andrusiak, Reisdorf, & Black, 1992; Singer & Ritchot, 1996; Whitney, Ritchie & Clark, 1991; Yuill & Oakhill, 1988). Less skilled readers, in contrast, are less likely to generate topic related inferences on line or to integrate incoming information with preceding discourse (e.g., Long et al., 1994). Consequently, less skilled readers perform poorly on questions that address text-based or implicit inferences, even when the text is made available during questioning (Oakhill, 1984).

What aptitude or mechanism allows skilled readers to make the inferences necessary for successful comprehension? There are four principle accounts that we review in this chapter. The first is that skilled readers have greater working memory capacity and thus are able to hold and process more information from the text or discourse. The second is that skilled readers suppress or inhibit information that is not relevant to the context, whereas less skilled readers' resources are consumed by irrelevant information. The third is that skilled readers have more knowledge and are more likely to use that knowledge. The fourth is that skilled readers have more knowledge about reading strategies, which allows them to use their knowledge effectively.

### **Working Memory Capacity**

One observation has been that better readers show better performance than less skilled readers on tasks designed to assess working memory (WM) capacity. Measures of WM capacity are dual tasks, including a "processing" task and a "storage" task. The

storage task is generally a short-term memory task in which the participant is presented and then immediately recalls a list of words. The processing task is intended to occupy WM capacity, thus providing a measure of how much capacity remains to successfully encode the target words. For example, the reading span task requires reading sets of two to six sentences and subsequently recalling either the last word of each sentence (e.g., Daneman & Carpenter, 1980) or an unrelated word presented after a sentence or arithmetic problem (e.g., Turner & Engle, 1989). Working memory span is generally computed on the basis of one of two ways: (1) the set size (i.e., 2, 3, 4, 5, or 6) for which all of the words were recalled for all of the trials, or (2) the sum of words recalled from trials in which all of the words were recalled (i.e., regardless of the set size).

Correlational studies relating measures of WM capacity and measures of verbal ability (e.g., Nelson Denny Reading Comprehension test, SAT scores, pronoun resolution, ability to answer factual questions) have indicated that skilled readers recall more words in WM tasks than do less skilled readers. The strength of correlations between WM and verbal skills show a wide range, but generally hover in the range of .30 to .60 (Daneman & Merikle, 1996). In contrast, traditional measures of short-term memory (STM; e.g., digit span, word span) that require only storage, and require little processing, do not predict comprehension (Daneman & Carpenter, 1980, 1983; Dixon, LeFevre, & Twilley, 1988). Thus, better readers tend to have more capacity to both store and process information.

Likewise, high capacity readers make more inferences while reading (e.g., Daneman & Carpenter, 1980; Oakhill, Yuill, & Parkin 1986; Yuill & Oakhill, 1991). Daneman and Carpenter found that participants who performed better on the reading span

task also performed better on inferences questions for a target passage. Yuill and Oakhill (1991) demonstrated that skilled readers more successfully identified inconsistencies in a text when they were further apart in the text, implying that less skilled readers lacked sufficient WM capacity to simultaneously retain in memory (or retrieve) both portions of the text (see also, Oakhill et al., 1986). In sum, based on the research showing that better readers have greater WM capacity, and readers with greater WM capacity make more inferences, many researchers have concluded that greater WM capacity allows the reader to essentially hold more information in WM at any one time. These resources allow the reader to generate more inferences (e.g., Just & Carpenter, 1992).

There are several variations to theories of WM and the effects of an individual's capacity on higher level processing tasks such as reading (e.g., Daneman & Tardif, 1987; Engle, Cantor, & Carullo, 1992; Just & Carpenter, 1992). Most of these theories assume that there exists a stable construct, such as capacity, activation resources, or attention span, which causally constrains an individual's abilities. For example, when encountering a pronoun, a reader who performs well on WM tasks (and thus is presumed to have greater WM capacity) is more likely to recall the noun referent, and hence better comprehends the passage. According to capacity oriented theories, skilled readers make more text-based inferences because the two sources of information are both available in WM. Thus, an individual who has greater WM capacity is able to hold in consciousness more information relevant to completing complex tasks such as reading, and shows better performance as a result (e.g., Budd, Whitney, & Turley, 1995; Perfetti, 1989; Whitney et al., 1991).

Contrary to the WM capacity explanation, Ericsson and Kintsch (1995) proposed that skilled performance, such as reading skill or superior performance on a reading span task, is due to more efficient access to information in LTM through the use of *long-term working memory* (LTWM). LTWM entails the use of cues in WM to provide more efficient access to information or knowledge in LTM. For example, Chase and Ericsson (1982) demonstrated that a college student with a normal digit span of  $7 \pm 2$  digits increased his span to 80 digits by using mnemonics related to his favorite pastime of running. The large number of digits was recalled with cues that were hierarchically related to running times, races, race dates, and so on. The cues (not all 80 digits!) were held in WM, which helped the student to retrieve the digits from LTWM. Ericsson and Kintsch further proposed that LTWM allowed faster access to knowledge. McNamara and Kintsch (1996b) confirmed that typical WM retrievals from LTM require 1 to 2 s, whereas LTWM retrievals require approximately 400 ms. In their study, participants were interrupted while reading more or less familiar passages. Whereas the cost of the interruption was approximately 400 ms when reading more familiar information, the cost was 1 to 2 s for less familiar information. As predicted by Ericsson and Kintsch, this research indicates that more efficient LTM access results from using cues in WM to activate retrieval structures. These cues can be generated strategically using mnemonics, or emerge from more knowledge about the topic. In the latter case, LTWM bypasses WM processing limitations because experience within a particular domain leads to enriched knowledge structures and information retrieval strategies.

McNamara and Scott (2001) proposed that LTWM retrieval structures and strategies may be particularly important to WM task performance because of the need to switch attention repeatedly between processing and storage tasks. LTWM would allow

an individual to more efficiently re-access the words from LTM that were no longer available in STM. Hence, a person using strategies would appear to have greater WM capacity. They proposed, however, that the observed advantage was due to more efficient access to LTWM through the use of mnemonic strategies. Other researchers have similarly proposed that WM constraints are not caused by limits in the amount of WM activation, but instead by how efficiently that capacity or activation is used (e.g., Case, Kurland, & Goldberg, 1982; Cowan, 1988; Daneman & Carpenter, 1980; Engle & Marshall, 1983; Shiffrin & Schneider, 1977). McNamara and Scott demonstrated that participants who reported using more effective memory strategies such as imagery when completing STM tasks, also performed better on the WM span task. Moreover, participants who received training to use a chaining strategy (i.e., creating sentences to link the words) during STM tasks, showed substantial improvement on WM tasks. These results collectively show that participants can and do use strategies during WM tasks, and these strategies improve WM performance.

### **Suppression/Inhibition**

In contrast to the research that has implied that skilled readers can hold more information in WM, other research has indicated that skilled readers differ from less skilled readers because they maintain less information in WM (Conway & Engle 1994; Engle, 1996; Gernsbacher, 1990; Gernsbacher & Faust, 1991; Gernsbacher, Varner, & Faust, 1990; Rosen & Engle, 1997, 1998). Gernsbacher and colleagues proposed that skilled comprehenders more efficiently suppress, or inhibit the irrelevant information, whereas less skilled comprehenders lack such a suppression mechanism. In essence, more inferences can be made because fewer irrelevant processes are competing with the

pertinent inferences. This account is based on Gernsbacher's (1990) Structure Building Model. Briefly, comprehension consists of three processes: (a) laying a foundation for the text structure, (b) mapping information onto that foundation, and (c) shifting to new structures when information is new or incongruent and cannot map onto the existing structure. In addition, two mechanisms determine the strength of memory nodes.

*Enhancement* increases activation and *suppression* decreases activation. Comprehension depends on the efficient construction and maintenance of mental structures. If new information is related to the current structure, then it is enhanced and incorporated into the mental structure. However, if new information is not related to the current structure, the comprehender may shift to a new mental substructure, or alternatively, suppress the new irrelevant information. The latter results in fewer substructures and reduces memory load for the comprehender. Accordingly, some comprehenders are less skilled because they have an inefficient suppression mechanism; with less effective suppression of irrelevant information, too many substructures are created and maintained, such that comprehension suffers.

Gernsbacher and colleagues (e.g., Gernsbacher & Faust, 1991; Gernsbacher et al., 1990) found that interference from irrelevant information is maintained by less skilled readers after a delay, but is quickly suppressed by more skilled comprehenders. Specifically, Gernsbacher et al. (1990) asked participants to make meaning-fit judgments to sentences with and without ambiguous words. Participants decided whether target words such as ACE were related to either experimental sentences ending with homographs such as *He dug with a spade* or control sentences such as *He dug with a shovel*. Immediate response times showed an *ambiguity effects* such that the times to

reject the target word were slower for the homograph sentences than for the control sentences, indicating that the activation of the irrelevant meaning of the ambiguous word competed with the correct response. However, after a 1000 ms delay, the ambiguity effect disappeared for skilled comprehenders. That is, the response times to the target ACE when preceded by the sentence containing the ambiguous word *spade* were equivalent to response times to ACE when preceded by the sentence containing *shovel*. Gernsbacher and colleagues interpret this finding as showing that the readers suppressed the irrelevant meaning of *spade*. In contrast, the ambiguity effect remained for the less skilled comprehenders. After the 1000 ms delay, the less-skilled comprehenders showed slower responses for the sentences containing *spade* than *shovel*. This result indicated that the less skilled readers had failed to suppress the irrelevant meaning of the word *spade*, and thus lacked a suppression mechanism. Gernsbacher and Faust (1991) found similar results with homophones such as patients/patience and rose/rows. They further concluded that these results were not a function of greater enhancement because skilled and less skilled comprehenders showed equivalent facilitation for the appropriate meaning (GARDEN) in a biased context, *He dug with a spade*, as compared to an unbiased context, *He picked up the spade*. Thus, enhancement was equivalent regardless of comprehension ability.

Engle and colleagues (Conway & Engle 1994; Engle, 1996; Rosen & Engle, 1997, 1998) have further found that the ability to suppress thoughts and behaviors depends on WM capacity such that high memory span individuals are better able to suppress irrelevant information than low span individuals. Because span is correlated with reading comprehension ability, one conclusion drawn from this research is that

better readers suppress information better than less skilled readers. For example, Rosen and Engle (1997) asked high and low span participants to retrieve examples of various animals. Both groups retrieved an equivalent number of animals. However, high-span participants retrieved more unique animal names than low span participants. This result was interpreted as evidence that the low span participants were less able to suppress previously mentioned names. In addition, retrieval times between clusters of animals were longer for low span participants presumably due to intrusions of previously named items. In contrast, high span readers had little difficulty because they had suppressed the previously retrieved names.

Rosen and Engle (1998) found further evidence for the connection between span and suppression using an AB-AC-AB word-associate paradigm. For example, a participant might first learn the pair *table-car* and in the second list learn *table-boat*. When instructions emphasized speed, high span learners required fewer trials to reach criterion and made fewer AB intrusions when learning the second list (AC). Thus, high span learners were assumedly better able to suppress the inappropriate responses. In a second experiment, in which accuracy was stressed, high span readers took longer to retrieve the first list (AB) on list three than controls. This result suggested that the high span readers were more likely to suppress the AB list during second list AC learning. In contrast, low span participants were faster at retrieving the AB list, and thus were unlikely to have suppressed the list during AC learning.

Long et al. (1994) found evidence that challenged the hypothesis that readers' ability to suppress or inhibit irrelevant information was a factor in explaining reading ability. Whereas Gernsbacher and Faust (1991) found that enhancement of the

appropriate response in the meaning-fit judgment task did not differ between good and poor comprehenders, Long et al. found that the results were different using a lexical decision task. They found that both high and low ability readers showed facilitation in a lexical decision task for appropriate as compared to inappropriate associates of homograph primes. For example, in Experiment 1, participants read a passage such as: *The townspeople were amazed to find that all the buildings had collapsed except the mint. Obviously, it had been built to withstand natural disasters.* Both high and low skilled readers responded faster to the context appropriate **associate** *money* than to the context inappropriate associate *candy*. Importantly, less skilled readers showed little facilitation for the context inappropriate prime. This finding provides evidence against the assertion that less skilled readers fail to suppress irrelevant information. Moreover, Long et al. also found that skilled readers were more likely to show facilitation for **topic** primes than less skilled readers. For example, skilled readers more quickly responded to the topic prime *earthquake* for the above passage than the prime *breath*. In contrast, there was little influence for topic appropriateness for less skilled readers. The authors interpreted this as evidence that only skilled readers generate knowledge-based inferences to elaborate their representation of the text.

McNamara (1997) similarly proposed that the suppression results reported by Gernsbacher and colleagues (e.g., Gernsbacher et al., 1990) could be explained in terms of greater elaboration of sentences. Within the framework of the Construction-Integration model of comprehension (Kintsch, 1988), she demonstrated that these results could be explained more parsimoniously in terms of enhancement of relevant information via elaborative inferences, rather than inhibition of irrelevant information. Although

Kintsch (e.g., 1998) uses inhibitory links to in the Construction-Integration model to simulate suppression, McNamara proposed that suppression could be modeled with fewer parameters using only enhancement as the critical process (see also, McDaniel, Schmalhofer, & Keefe, 2001; Schmalhofer, McDaniel, & Keefe, 2002). According to the model, incoming information and associated knowledge are represented as an associative network of nodes (concepts, ideas, or propositions) and links (relations or actions). Concepts that are compatible with the overall context generally have more links whereas irrelevant concepts tend to have fewer links. Because the model relies on connectionist principles of constraint satisfaction, concepts with more links increase in activation, whereas concepts with fewer links gradually lose activation.

McNamara (1997) proposed that if more knowledge associated with the context provided in the sentence were activated during comprehension, then more links to the relevant meaning of the ambiguous word would be created and the irrelevant meaning would quickly lose activation. In support of that hypothesis, she demonstrated within a computational simulation that the number of activated associations to the relevant meaning predicted the rate of activation loss for the irrelevant meaning. In this knowledge-based model, skilled comprehenders were assumed to more actively process the information provided in the sentence, which in turn activated more relevant knowledge. These links essentially fed activation to the relevant meaning of the ambiguous word and led to a rapid deactivation of the irrelevant meaning. To simulate less skilled comprehenders, less associated knowledge was activated. The relevant meaning was rapidly activated to threshold leading to an accurate understanding of the

sentence, but the irrelevant meaning retained enough below-threshold activation to interfere with processing when it was presented in the decision task.

This interpretation seemingly contradicts Gernsbacher and Faust's (1991) conclusion that their results were not a function of greater enhancement given equivalent facilitation for appropriate meanings of sentences. However, McNamara (1997) showed that the differences between skilled and less skilled comprehenders in her simulation emerged primarily from interference from the irrelevant meaning (for less skilled comprehenders), and not because of differences in facilitation. That is, the increase in associations to the appropriate meaning (for skilled comprehenders) had minimal effects on the time for the correct response to reach threshold. However, the increased associations in the skilled comprehender simulation essentially took over the network such that the irrelevant meanings essentially died out. In contrast, in the less skilled comprehender simulation, the lack of competition for resources between relevant links and irrelevant links resulted in residual activation for the irrelevant meaning of the ambiguous word. Accordingly, less skilled comprehenders do not use resources effectively, whereas skilled comprehenders' maximal use of resources drives out irrelevant information.

In support of McNamara's (1997) predictions, McNamara and McDaniel (2004) found with the meaning-fit judgment task used by Gernsbacher and colleagues (e.g., Gernsbacher & Faust, 1991; Gernsbacher et al., 1990) that greater domain or general knowledge produced effects similar suppression effects to those obtained for skilled comprehenders in the Gernsbacher studies. Specifically, in Experiments 1 and 2, participants with more knowledge of baseball showed an ambiguity effect with baseball

sentences at the immediate test and the absence of an effect after a delay. In contrast, participants with less knowledge of baseball maintained a reliable ambiguity effects after a delay. Likewise, in Experiment 3, participants with greater general knowledge showed a reduction of the ambiguity effect after a delay whereas the interference persisted for those with less general knowledge. These results further indicate that individual differences in ambiguity resolution can depend on dynamics associated with knowledge activation during comprehension.

The results of Rosen and Engle (1997) can be explained in similar manner. As mentioned earlier, Rosen and Engle demonstrated that low-span individuals repeated more animals and paused longer between clusters of animals. That is, participants who made fewer elaborative inferences (perhaps in the form of images) of the animals previously listed would be more likely to forget that they had already named that animal. If an animal is named and the individual does not process features of the animal (either automatically with prior knowledge or actively using mnemonic strategies), then there will be fewer links to the animal name and it will likely be forgotten. Using the same line of reasoning, if less elaborative processing occurs, there will be fewer links within a cluster of animals. This lack of cohesion may result in greater lapses between clusters. That is, there would be less available information (perhaps in LTWM), to distinguish between clusters and specific examples within clusters. Rosen and Engle's (1998) results using the AB-AC-AB word-associate paradigm can be explained similarly. That is, if more elaborative inferences (i.e., using knowledge or mnemonics) are generated when learning an item or pair, it will be learned more quickly and better retained (e.g., Ericsson & Kintsch, 1996; McNamara & Scott, 2001). Thus, the assumption that 'high-span'

individuals develop more elaborative inferences when learning the second AC pair, rather than inhibiting the AB pair, provides an alternative interpretation of the Rosen and Engle results.

### **Knowledge**

There is ample evidence that readers who have more knowledge about the topic of a text better understand the written material (e.g., Alexander, & Kulikowich, 1991; Alexander, Kulikowich, & Schulze, 1994, Chiesi, Spilich, & Voss, 1979; Haenggi & Perfetti, 1994; Bransford & Johnson, 1972). Bransford and Johnson (1972) demonstrated that titles that help the reader activate the appropriate knowledge for ambiguous texts. For example, one of the texts presented to participants regarded how to wash clothes. Without the title of the text it was virtually impossible to understand what the text was about. Participants who were presented with the title before reading the text recalled approximately twice as much as those presented with the title after reading the text or not at all. Thus, comprehension depends on the reader activating appropriate, related knowledge while reading.

It is also important that the knowledge that a reader uses is stable and interconnected. Simply teaching the reader a set of facts that are needed to generate the inferences may actually inhibit comprehension rather than improve it (McNamara & Kintsch, 1996a). If the knowledge is not interconnected, then a *fan effect* may occur (Anderson, 1974). That is, when more facts about a certain concept are available, resources are spread across those facts, thus reducing the amount of activation for each one and slowing processing. However, when the facts are interrelated, a fan effect does not occur (Reder & Anderson, 1980; Reder & Ross, 1983). In that case, according to

connectionist or network theories, the interrelated and connected concepts feed activation back to one another.

In essence, when knowledge is more coherent or connected, it is more stable and easily retrievable. Consequently, readers who have greater domain knowledge show better comprehension than those who lack sufficient knowledge. For example, Chiesi et al. (1979) found that less skilled readers (i.e., children) who knew more about baseball showed better recall of a text regarding a baseball game than skilled readers (i.e., adults) who lacked such knowledge. Thus, knowledge can overcome, and perhaps be more important for comprehension, than reading skill per se.

Shapiro (2004) also concluded that knowledge was more important to reading comprehension than reading skill. In her first experiment, 24 students read two fictional history texts from Voss and Silfies (1996). In Experiment 2, 21 students read two texts about memory. Domain knowledge was assessed via tests on history and memory respectively, and reading skill was assessed with the Nelson Denny Reading Comprehension test. She found in both experiments that prior domain knowledge showed higher correlations than reading skill with comprehension, and was the only significant predictor in regression analyses.

In contrast to the results reported by Shapiro (2004), Cottrell and McNamara (2002) found with 144 undergraduates that both knowledge and reading skill contributed significantly to comprehension, with a greater contribution from reading skill than knowledge. Like Shapiro, they also examined comprehension of a text about memory, and measured reading skill using the Nelson Denny. However, prior knowledge was assessed using a general test about psychology, rather than a test focused solely on

memory (as in Shapiro's second experiment). A knowledge test using questions more specific to the domain of the target text may have yielded results more similar to those found by Shapiro. In principle, a knowledge test with questions that are most closely aligned with the topic of the text will yield a more accurate estimate of knowledge. Such a measure was not used in the Cottrell and McNamara study because their goals went beyond that of predicting just text comprehension. They also looked at the relationships of students' aptitudes with their performance in the Introductory Psychology course in which the students participating were enrolled. In contrast to the results for the passage comprehension test, reading skill did not correlate with exam performance. Rather, prior knowledge was the best predictor of exam performance. However, prior knowledge was only a benefit for students who used reading strategies. Less strategic students with prior knowledge about psychology were apparently less likely to make use of their knowledge, and as a result performed as poorly as those lacking such knowledge.

The majority of the studies showing that knowledge can be more important than reading skill for successful comprehension have been conducted with adults. Other studies with children have found that knowledge and reading skill are both necessary to successful comprehension. For example, Adams, Bell, and Perfetti (1995) examined the relative contributions of reading skill (as determined by the California Achievement Test) and domain knowledge with 32 male children in grades 4 through 7. They found that children with less skill or knowledge showed equivalent comprehension, whereas only children with both high knowledge and greater reading skill showed superior comprehension of a text regarding football. Nonetheless, the less skilled, high-knowledge readers showed a comprehension advantage when reading the domain-

specific text about football in comparison to their comprehension of a domain-general text about fires. Thus, while the less-skilled, high knowledge readers' comprehension of the football text was comparable to the comprehension of the low-knowledge participants, it was greater than their own comprehension of a domain general text.

Although the number of participants in the Adams et al. (1995) is notably low, O'Reilly and McNamara (2002) found similar results in a study that included 1651 high-school students. This study showed that only skilled readers with high domain knowledge showed greater comprehension of a text about meteorology than less skilled, low-knowledge readers. However, these results only occurred for the multiple-choice comprehension questions. In the case of the open-ended questions (comparable to what Adam et al. used), both knowledge and reading skill contributed equally to performance. As a result, students with either aptitude performed better on the questions than the students with deficits in both areas, and the students with both aptitudes showed the best comprehension. In sum, the results were mixed as a function of question type.

Although the studies are somewhat contradictory, it is clear that when young students have both domain knowledge and reading skill at their disposal, they are more likely to comprehend what they read. Collectively, these results suggest that knowledge is critically important to comprehension, but the reader benefits from and may need sufficient reading skill, or knowledge of reading strategies to use their prior domain knowledge. That is, the reader must be an active reader who knows, implicitly or explicitly, to apply and integrate prior knowledge with new information to better understand the text at hand.

According to the Construction-Integration model of text comprehension (Kintsch, 1988; 1998), text-based and knowledge-based inferences result in more links between concepts, and thus a more cohesive mental structure. Thus, activation of prior knowledge helps the reader form a more coherent mental representation of the text. Readers with more knowledge of the text domain (e.g., science or history) show better comprehension when they use their prior knowledge to comprehend and learn, particularly on measures that assess deeper levels of understanding (e.g., bridging-inference and problem solving questions, rating and sorting tasks). Hence, according to the Construction-Integration model, inducing the reader to generate inferences (successfully) can improve learning.

One way to increase inference making is to increase the demands of the text. Indeed, research has confirmed that comprehension can be enhanced when readers are induced by the text to generate inferences and these inferences are successful (e.g., Einstein, McDaniel, Owen, & Cote, 1990; Mannes & Kintsch, 1987; McDaniel, Einstein, Dunay, & Cobb, 1986; O'Brien & Myers, 1985; Rauenbusch & Bereiter, 1991). For example, Mannes and Kintsch (1987) found that giving college students an advanced organizer in the form of an outline for a text that didn't match the organization of the text resulted in deeper comprehension of the text than if the outline matched the organization of the text. They concluded that the readers in the mismatched condition were induced to make more inferences while reading to resolve the differences between the outline and the text, and these inferences influenced the readers' deep-level comprehension.

Rauenbusch and Bereiter (1991) demonstrated that deleting letters in the text improved comprehension for young readers. Einstein and McDaniel and their colleagues (Einstein et al., 1990; McDaniel et al., 1986) further demonstrated that the benefits of

deleting letters only improves memory at the word level, and thus in their study comprehension was only enhanced for folk tales, and not for non-folk tales. In contrast they found that scrambling the order of the sentences of a text improved comprehension at the sentence level, and thus improved comprehension of non-folk tales, but not folk tales. Thus, comprehension can be improved by manipulating the text structure, and the most effective manipulations to improve comprehension processes are those that require the reader to make inferences that link the sentences in the text.

Along these lines, McNamara and colleagues (McNamara, 2001; McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara & Kintsch, 1996a; O'Reilly & McNamara, 2004) have found that texts with cohesion gaps help high-knowledge readers use their knowledge. A cohesion gap occurs when the text forces the reader to generate an inference in order to understand the text. The inference can be relatively automatic or require more effort, depending on the text and the reader. For example, consider the following two sentences: The man jumped out of the taxi. He hoped he would make it on time. A facile inference is that 'He' refers to the man from the first sentence. More elaborative inferences based on prior knowledge may include that the man is in a hurry and that he perhaps has a flight to catch. A more cohesive series of sentences might include the intermediary: The man was in a hurry to catch a flight. A less cohesion text forces the reader to make inferences to fill in the gaps. When the reader has sufficient background knowledge, as most readers would have for this example, then the necessary inferences are relatively automatic and can go unnoticed. In contrast, when the information is less familiar, the inferences can be more challenging. McNamara's research on text cohesion has shown that the benefits of increasing text cohesion (e.g.,

Beck, McKeown, Sinatra, & Loxterman, 1991; Britton & Gulgoz, 1991) are greatest for low-knowledge readers (e.g., McNamara, 2001; McNamara et al., 1996; McNamara & Kintsch, 1996). As such, the comprehension differences between high-knowledge and low-knowledge readers are most exaggerated for low-cohesion texts with more conceptual gaps. Whereas high-knowledge readers are able to generate the inferences necessary to fill in conceptual gaps, low-knowledge readers are unable to fill in the gaps because they don't have the necessary knowledge to do so. Thus, a low-knowledge reader has great difficulty comprehending a low-cohesion text.

When the reader has sufficient prior knowledge, the challenge resulting from low cohesion text can force the reader to access and use prior knowledge or information from previous text. The integration of the textual information with prior knowledge helps not only to better understand the information, but helps to tie the new information with the reader's knowledge base. As a result, a high-knowledge reader can show better comprehension of a low-cohesion text than a high-cohesion text. Whereas the low-cohesion text induces inferences that tie the text with prior knowledge, high-cohesion text can induce a more passive reading whereby the text remains essentially separate from related knowledge.

If the advantage of low-cohesion text for high knowledge readers is due to passive or superficial comprehension processes as proposed by McNamara and colleagues (e.g., McNamara et al., 1996), then more active reading process should override this effect. Indeed, O'Reilly and McNamara (2004) found that only less skilled, high-knowledge readers need the booster that is provided from low-cohesion text. Skilled, more strategic, high-knowledge readers show equivalent comprehension of high-cohesion and low-

cohesion texts. Essentially, the low-cohesion text induces more effortful reading, which the skilled readers engage in more naturally.

One critical difference between skilled and less skilled readers is their ability to make inferences that complete cohesion gaps, particularly those involving pronominal reference. Skilled readers are more likely to resolve anaphors, especially when referent is distant (Oakhill & Yuill 1986; Yuill & Oakhill, 1988). Comprehension of anaphors is more critical in text than discourse comprehension because there is little shared context in the former. In contrast, there is a wealth of contextual information available to the speakers in face to face conversations. Anaphor resolution difficulties are particularly problematic for younger and less skilled readers. This difficulty persists even when there is a gender cue and when the clause containing the referent is available to the reader (Oakhill & Yuill, 1986). Because all of the necessary information is readily available, this result is not easily explained with capacity accounts. In addition, skilled and less skilled readers seem to have a different method of resolving anaphoric relations. Less skilled readers seem to search the preceding sentence for an appropriate syntactic form, and thus rely on low level features of the text. In contrast, skilled readers tend to resolve anaphors by relying on their model of the story and existing knowledge (Yuill & Oakhill, 1988). Thus, more successful readers use their prior knowledge and their mental representation of the situation together to resolve anaphors.

It appears based on the effects of cohesion for low-knowledge readers (e.g., McNamara et al., 1996) that readers with knowledge deficits have a hopeless case if the text they are faced with has many conceptual gaps. This is a concern because most texts veer toward low-cohesion rather than high-cohesion. That is, most texts, particularly

textbooks that are geared for learning new information or classroom instruction have a large number of conceptual gaps (Beck, McKeown, & Gromoll, 1989; VanLehn, 1996, 1998; Wilson & Anderson, 1986). Nonetheless, the research by McNamara and colleagues (McNamara, 2004; McNamara & Scott, 1999) has indicated that training readers to use reading strategies which help the reader to make more inferences helps low-knowledge readers to better understand low-cohesion text, in many cases as well as the high-knowledge readers. The following section reviews the research showing the importance of strategies to skilled reading and the success of interventions that promote deeper reading strategies.

### **Reading Strategies**

Research has indicated that possessing knowledge is not sufficient. The research on text cohesion has indicated that knowledgeable readers lacking reading skills may need conceptual gaps in the texts for them to use their knowledge. Other research has indicated that readers may not generate deep-level inferences unless they have an appropriate comprehension goal (McKoon & Ratcliff, 1992; Noordman, Vonk, & Kempf, 1992). Readers' knowledge may remain inert either because they don't realize that the knowledge is applicable or because they have difficulty applying knowledge to novel situations (Bransford, 1979; Bransford, Vye, Adams, & Perfetto, 1989).

There are two lines of research that have indicated that importance of reading strategies to better knowledge use as well as overcoming knowledge deficits. First, skilled readers have more metacognitive knowledge (Baker, 1982; Wong, 1985) and more likely to use reading strategies (e.g., Baker, 1994; Garner, 1987; Long & Golding, 1993; Long et al., 1994; Oakhill, 1982, 1983). In contrast, less skilled readers either lack

knowledge about strategies or mainly engage in bottom-up strategies. Second, providing instruction to generate inferences and use active reading strategies can improve comprehension for less-skilled readers and low knowledge readers. Interventions that target more active or strategic use of knowledge improve reading skill and comprehension (e.g., Bereiter & Bird; 1985; Chi, de Leeuw, Chiu, & LaVancher, 1994; Dewitz, Carr, & Patberg, 1987; Hansen & Pearson; 1983; Kucan & Beck, 1997; McNamara, 2004; McNamara & Scott, 1999; Palincsar & Brown, 1984; Paris, Cross, & Lipson, 1984; Paris, & Jacobs, 1984, Yuill & Oakhill, 1988). Such studies demonstrate that simply knowing how and when to make inferences dramatically improves reading comprehension.

There are two principle approaches to addressing these deficiencies in less skilled readers. The first approach is to train the reader to ask more and better quality questions. Rosenshine, Meister, and Chapman (1996) conducted a meta-analysis of 26 empirical studies comparing conditions that instructed or modeled question asking skills to learning conditions without question asking training. They reported median effect sizes of 0.36 for standardized tests, 0.87 for experimenter-generated multiple-choice tests, and 0.85 for summaries of texts. For example, Beck and her colleagues have developed a successful approach called *questioning the author* (e.g., Beck, McKeown, Hamilton, & Kucan, 1997) which teaches students to change their view of authors by considering them simply as people who have expressed their ideas, rather than infallible authorities. The goal of this method is to transform reading from a passive process of information reception to an active process of meaning construction. More recently, Graesser and his colleagues have used animated conversational agents (i.e., talking heads) to model the asking of deep-

reasoning questions while college students learned about topics in computer literacy. In a transfer task of comprehending other topics on computer literacy, Craig, Gholson, Ventura, Graesser, and the Tutoring Research Group (2001) found that memory for the material nearly doubled following an increase in deep questions asked by the students.

A second approach to strategy training is to provide instruction regarding general reading strategies that promote better metacomprehension and deeper processing.

Palincsar and Brown's (1984) reciprocal teaching methodology includes instruction in the use of four strategies: clarifying misunderstandings, identifying the main idea of a section of text, summarizing the content, and predicting future content. Multiple sessions are provided to the students in which the tutor or teacher models the strategies, invites the learner to demonstrate these strategies, and gives feedback on the learner's activities. In turn, the students practice the skills with each other and model the skills for their fellow students. A comprehension test at the end of instruction showed significant gains for the group provided with the strategy instruction compared to a control group. Bereiter and Bird (1985) demonstrated the effectiveness of providing instruction for four repair strategies: restatement, re-reading, demanding relationship, and problem formulation. Their study also showed that providing both explanation of the strategies and modeling was more effective than only modeling the strategies. The "modeling-plus-explanation" condition included demonstrations of the strategies combined with explanations of situations in which the four strategies could be used. This condition scored significantly higher on the comprehension post-test than the control group receiving only modeling. Thus, the students' benefited from comprehension-monitoring activities consisting of recognizing comprehension problems and selecting repair strategies.

McNamara (2004) examined the benefits of a reading strategy intervention, called Self-Explanation Reading Training (SERT) with 42 college students. During SERT, the students were provided with training to self-explain text and to use metacognitive reading strategies that improve self-explanation. Self-explanation involves reading a section of text aloud, usually a sentence, and explaining what the sentence means. Research by Chi and her colleagues has shown that students who self-explain text are more successful at solving problems, more likely to generate inferences, construct more coherent mental models, and develop a deeper understanding of the concepts covered in the text. (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi et al., 1994). However, many students are not able to self-explain successfully. Thus SERT provides students with training to use reading strategies that help the reader to make inferences while reading and self explaining difficult text.

Specifically, SERT (McNamara, 2004) coaches students in five reading strategies: comprehension monitoring, paraphrasing, making bridging inferences, predictions, and elaborations. *Comprehension monitoring*, enables the reader to recognize a failure of understanding and it is this recognition that triggers the use of additional active reading strategies. The first such strategy, *paraphrasing*, essentially helps students remember the surface structure of the text by transforming it into more familiar ideas. However, SERT encourages students to go beyond this basic sentence-focused processing by invoking knowledge-building strategies that link the content of the sentences to other information, either from the text or from the students' prior knowledge. Making *bridging inferences* improves comprehension by linking the current sentence to the material previously covered in the text and form a more coherent mental representation of the text content.

Students may also use *prediction* to anticipate the content subsequent text, either by guessing what is coming next or by reminding themselves to watch out for some particular item that will aid comprehension. Finally, readers are encouraged to associate the current sentence with their own related prior knowledge using a strategy called *elaboration*. Importantly, readers are encouraged to draw upon logic and common sense, or domain-general knowledge, particularly when they do not have sufficient knowledge about the topic of the text.

In McNamara's (2004) study, half of the participants ( $n = 42$ ) received SERT, which included the reading strategy instruction and self-explanation practice with four science texts. In contrast, the control participants read aloud the four science texts. After training, both SERT and control participants self-explained a difficult text about cell mitosis (the low-cohesion version from McNamara, 2001). The results showed that SERT improved comprehension and self-explanation quality, but only for participants with low domain knowledge. In contrast, high-knowledge readers are able to access the necessary information (from LTWM) and are able to fill in the gaps in the low-cohesion text without self-explanation. Protocol analyses further indicated that SERT helped the low-knowledge participants to use logic, or domain-general knowledge, rather than domain-specific knowledge to make sense of the text.

Further research has confirmed the benefits of SERT for low-knowledge and less-skilled readers (McNamara, 2004a; O'Reilly, Best, & McNamara, 2004). To provide SERT to a wider audience, SERT has been implemented in an automated tutor called the Interactive Strategy Trainer for Active Reading and Thinking (iSTART; McNamara, Levinstein, & Boonthum, 2004). iSTART delivers SERT using animated characters who

discuss, teach, and model the reading strategies in the first two modules of the program. During the final module the student practices using the strategies by typing self-explanations to science texts. One of animated agents gives the student feedback generated by language algorithms (McNamara, Boonthum, Levinstein, & Millis, in press). The feedback encourages the student to generate self-explanations that go beyond the explicit meaning of each sentence by making links to previous sentences and to prior knowledge.

Our laboratory results from three experiments conducted thus far indicate that iSTART is highly effective in improving students' ability to understand difficult texts (O'Reilly, Sinclair, & McNamara, 2004a; O'Reilly, Sinclair, & McNamara, 2004b). One of our studies has confirmed that iSTART is as effective as SERT in helping students to improve their reading strategies (O'Reilly et al., 2004b). This study included 300 college students randomly assigned to iSTART, SERT (the live version), or a control condition (who read the same texts but were not given strategy instruction). As expected, iSTART produced improvements in students' self-explanation quality equivalent to SERT. The results also showed reliable advantages for both iSTART and SERT in comparison to the control condition on comprehension of a science text one week after training.

A second study was conducted with 42 middle-school students (O'Reilly et al., 2004a). 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., in press). 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, 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.

## **Summary**

Several explanations of the differences between less skilled and skilled readers have been proposed. The earliest and perhaps most popular explanation of comprehension skill has been that better readers have greater WM capacity than less

skilled readers (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992). An alternative explanation of WM effects has been that high-capacity readers are more efficient, either due to greater knowledge or to strategy use (Ericsson & Kintsch, 1996; McNamara & Scott, 2001). A second explanation of skilled reading proposes that poor readers have difficulty suppressing “noisy” information, such as contextually irrelevant meanings of homographs. One such theory proposes that less skilled readers lack a suppression mechanism and thus perform frequent structure “shifts” whereas good readers continue mapping information into an ongoing structure (e.g., Gernsbacher, 1990). As such, the successful comprehender is better able to suppress or inhibit irrelevant information, leaving more resources for relevant information (e.g., Rosen & Engle, 1998). An alternative explanation of inhibition is that it results from greater knowledge activation or elaboration, which essentially drives out irrelevant information (McNamara, 1997; McNamara & McDaniel, 2004). Along these lines, a third class of explanations emphasizes that skilled comprehenders more actively and efficiently use their knowledge. Accordingly, reading comprehension is largely due to knowledge differences about the text topic (e.g., Kintsch, 1988; McNamara & McDaniel, 2004). A fourth, related account proposes that the activation of knowledge also relies on the use of metacognitive reading strategies. Evidence in favor of the latter two knowledge-based accounts comes from three sources. First, the amount of available prior knowledge and the degree to which the reader uses their knowledge are associated with better comprehension. Second, reading strategies that promote readers’ use of knowledge result in better comprehension. Third, interventions and manipulations to increase readers’ use of knowledge improve comprehension.

According to WM and suppression accounts of reading skill, making more inferences should overload a limited WM capacity even more, or lead a less skilled reader to create even more substructures (which could not be suppressed). Thus, according to either the capacity or suppression account, teaching a reader to more actively process written material and generate more inferences should inhibit comprehension for the less skilled reader. On the contrary, we reviewed a large body of research showing that when readers learn strategies to more effectively use their knowledge while reading, reading comprehension improves. Hence, WM capacity and suppression accounts of skill differences cannot easily explain these results. Results showing that the advantage of skilled reader's performance on inference questions persist even when the text is made available to the readers (Oakhill, 1983, 1984) shed further doubt on capacity accounts. The reader's memory resources should be at least partially relieved if the text is made available when the reader answers the inference questions. In contrast, the bulk of the evidence indicates that the ability to generate inferences requires the knowledge that relating different parts of the text is necessary for successful comprehension.

### **Conclusion**

One can easily imagine that WM capacity, suppression, knowledge and metacognitive processes work together in a complex, interdependent fashion. However, the literature indicates that the most useful accounts of skilled comprehension are those which focus on metacognitive strategies and the more active use of knowledge. These accounts have a large body of empirical support and are more useful in the sense that they provide a direction of remediation for students and educators. Knowing that a less

skilled readers' WM capacity may be low, or that they may lack the ability to suppress irrelevant information hardly provides hope for their bridging the comprehension gap. In contrast, research focused on metacognitive reading strategies has led to a host of reading skill remediation techniques. Moreover, these techniques have successfully improved both text comprehension and academic performance.

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