Comprehension Skill: A Knowledge-Based Account

Danielle S. McNamara
Department of Psychology
Old Dominion University
Norfolk, VA, 23529
dsm200f@oduvm.cc.odu.edu

Abstract

Gernsbacher (e.g., 1990) has proposed that comprehension skill is a function of the ability to suppress inappropriate or irrelevant information. This hypothesis is based on the finding that the inappropriate meaning of an ambiguous word loses activation for skilled comprehenders after a delay, but remains activated and slows comprehension for less-skilled comprehenders. It is hypothesized here that comprehension skill is not due to the suppression of information, but rather is enhanced by the activation of more knowledge. Simulations based on the Construction-Integration model of comprehension (Kintsch, 1988) show that the activation of more knowledge leads to an initial activation of an inappropriate meaning of a concept which quickly decays. Without the activation of the knowledge, the inappropriate meaning remains activated. This account thus predicts and explains Gernsbacher's empirical data.

Introduction

One important question raised by cognitive scientists is why individuals differ in their ability to comprehend texts or discourse. Developing an understanding of why and how people differ in comprehension skill will help us to identify the cognitive processes involved in comprehension, and indicate interventions for less-skilled comprehenders. This article further explores findings regarding individual differences in the comprehension of ambiguous words. Specifically, Gernsbacher and her colleagues have shown that the inappropriate meaning of an ambiguous word loses activation for skilled comprehenders after a delay, but remains activated and slows comprehension for less-skilled comprehenders (e.g., Gernsbacher & Faust, 1991; Gernsbacher, Varner, & Faust, 1990). Gernsbacher contends that skilled and less-skilled comprehenders differ in the ability to suppress inappropriate or irrelevant information. I demonstrate here, through a computer simulation operating within the framework of the Construction-Integration (CI) model (Kintsch, 1988), that there exists an alternative explanation of Gernsbacher's findings. This explanation is based on the assumption that skilled comprehenders do not suppress knowledge, but on the contrary, make more inferences while reading or comprehending.

The Construction-Integration Model

The framework for this work is the CI model of comprehension (Kintsch, 1988). This model is an extension of earlier formulations of reading and discourse comprehension (van Dijk & Kintsch; 1983) that includes a more complete specification of the role of knowledge during comprehension. The CI model has been applied to numerous aspects of text comprehension (e.g., Kintsch & Welsch, 1991) and has generalized successfully to more complex domains such as problem solving and expert-novice differences in memory for technical prose and action planning for computing tasks (e.g., Doane, McNamara, Kintsch, Polson, & Clawson, 1992; Kintsch, Welsch, Schmalhofer, & Zimny, 1990).

According to the CI model, knowledge is represented as an associative network, the nodes of which are concepts and propositions. Comprehension arises from an interaction and fusion between the to-be-comprehended information and knowledge activated by the comprehender according to semantic or causal associations. Comprehension generally consists of three levels of understanding: the surface level, the textbase level, and the situation model. The surface level of understanding primarily consists of the arguments presented in the text. The textbase consists of the deeper meaning of the sentence depicted by its propositional representation. The situation model consists of the reader's prior knowledge integrated with the textbase. Together, these levels of understanding form the reader's mental representation of the text. The process of forming this mental representation is referred to as the construction phase.

The comprehender's mental representation is then integrated according to connectionist principles of constraint satisfaction. Concepts compatible with the overall context increase in activation and concepts that are inappropriate or irrelevant become deactivated. Although the deactivation of inappropriate concepts can occur as a result of direct suppression (e.g., Kintsch, 1988), it generally falls out naturally from the architecture because concepts not stimulated by other concepts in the network lose activation. In contrast, activation is essentially funneled to concepts linked to other concepts in the network. This latter aspect of the model is critical to the outcome of these simulations.

The Structure Building Model

Gernsbacher (e.g., 1990) proposes that comprehension consists of three primary processes: (a) laying a foundation for the text or discourse structure, (b) mapping information onto that foundation, and (c) shifting to new structures when new information cannot map onto the existing structure because it is incongruent or a new idea. Enhancement, which increases activation, and suppression, which decreases activation, are the two mechanisms that operate to determine the strength of memory nodes.

These basic characteristics of the structure building model are not highly distinguishable from certain assumptions of Kintsch's (1988) model of comprehension. Kintsch's model assumes that an initial mental representation is formed and new information is linked to it according to the degree of semantic or causal association (e.g., argument overlap). If there is no overlap, a separate representation is formed for the new information. However, the two models clearly part ways regarding their respective assumptions of the primary factors contributing to comprehension skill. According to Kintsch's model, many factors contribute to comprehension skill, but prior knowledge and the building of a coherent situation model are the central driving factors. In contrast, Gernsbacher's model assumes that comprehension skill is primarily guided by the ability to suppress irrelevant information. She assumes that there is a general comprehension skill for both linguistic and nonlinguistic information which is defined, not by the ability to enhance relevant information, but by the ability to suppress irrelevant information (e.g., Gernsbacher, 1990).

Gernsbacher has supported this hypothesis by comparing the reaction times of skilled and less-skilled comprehenders to recognize the appropriateness of ambiguous words to a sentence context. For example, Gernsbacher et al. (1990) presented participants with sentences such as *He dug with a spade*, followed by an inappropriate target word, ACE. It was assumed that if the participant required more time to reject this word following the experimental sentence compared to a control sentence such as *He dug with a shovel*, then the inappropriate meaning's activation was slowing down the response. The difference between the experimental and control response times was used as a measure of the activation for the ambiguous word's inappropriate meaning. Gernsbacher et al. (1990) demonstrated that both skilled and less-skilled comprehenders showed equivalently high activations of the inappropriate meaning at an immediate test. However, after a 1 second delay, less-skilled comprehenders showed a high activation of the inappropriate meaning, whereas skilled comprehenders showed no activation. Gernsbacher and her colleagues concluded that skilled comprehenders more efficiently suppress inappropriate meanings of ambiguous words.

Knowledge and Comprehension Skill

The empirical evidence regarding comprehension skill and learning from text overwhelmingly weighs in favor of a theory postulating a critical role of prior knowledge and active inference processing during comprehension and learning. Although comprehension involves a complex interplay of linguistic and syntactic processes, generating inferences based on prior knowledge is a critical component of comprehension skill. Previous research indicated that prior knowledge was a driving factor in text comprehension (e.g., Bransford & Johnson, 1972; Chiesi, Spilich, & Voss, 1979). More recent research further shows that the active use of knowledge provides a critical distinction between good and poor comprehenders. For example, Oakhill and her colleagues have consistently found that less skilled comprehenders perform poorly on tasks requiring inferential ability (e.g., Oakhill, 1984; Oakhill & Yuill, 1996; Oakhill, Yuill, & Donaldson, 1990). Oakhill (1984) found that poor comprehenders (who do not have word decoding deficits) differed primarily in the ability to answer inference questions as compared to literal questions. Long and her colleagues have come to the same conclusions. They have demonstrated that skilled readers are more likely to make early global text inferences (Long & Golding, 1993), and are more likely to make on-line knowledge-based inferences (Long, Oppy, & Seely, 1994). These researchers have also provided compelling evidence ruling out basic linguistic processes as a source of less skilled comprehenders' deficiencies.

If less skilled comprehenders differ primarily in the their ability to generate inferences during reading, remediation focusing on this skill should result in greater improvement in contrast to other remedial techniques. Indeed, Yuill and Oakhill (1988) found that less skilled comprehenders benefited more from inference training than from word decoding training, and skilled comprehenders showed only minimal gains from inference training. This latter finding indicates that the skilled comprehenders already used active inferencing strategies prior to training (see also, Dewitz, Carr, & Patberg, 1987; Hansen & Pearson, 1983).

Indeed, many methods used to improve reading skill focus on inducing the reader to more actively process the text and to use prior knowledge to understand the text. For example, prompting subjects to explain the text while reading, or *self explanation*, is one methodology that has been found to enhance comprehension (e.g., Chi, de Leeuw, Chiu, & LaVancher, 1994). In addition, when readers are induced by the text structure to activate and use their prior knowledge while reading, they understand and remember the text better and at a deeper level (e.g., Mannes & Kintsch, 1987; McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara & Kintsch, 1996; O'Brien & Myers, 1985; Rauenbusch & Bereiter, 1991).

One the other hand, few instructional techniques focus on teaching the reader to *suppress* information. Intuitively, the reason for not attempting this approach seems evident. If I instruct you, "whatever you do, DO NOT think of a white elephant," your thoughts have little choice but to turn to a white elephant. If, on the other hand, I instruct you to concentrate on a black rather than the white elephant, you would find it an easier task to ignore the white elephant. This ease comes from focusing on and enhancing alternative information - in this case, my black elephant. We can, and do, learn to ignore irrelevant information. I propose, however, that this is not a process of suppression, but rather a process of focusing on the relevant information.

Simulations

Research on comprehension skill and learning from text does not suggest that comprehension or reading skill is function of the ability to suppression information. Rather, it implies that a skilled comprehender more actively integrates world knowledge and incoming information. The following simulations are based on the assumption that a critical factor leading to better comprehension skills is not the suppression of concepts, but the activation and integration of more concepts.

The CI Model (Mross & Roberts, 1992) was used as a framework for these simulations (see, e.g., Kintsch, 1988, or Kintsch & Welsch, 1991, for detailed explanations of the model). The goal here is not to provide exact estimates for the reaction time data originally reported (Gernsbacher et al.,1990; Gernsbacher & Faust, 1991), but rather, to provide a qualitative fit to the data as an alternative theoretical explanation. Note that exact estimates could be provided by this model by changing certain parameters such as initial node and link strength. This type of parameter estimation would, however, reduce the parsimony and generality of the model, which is in this case a clear advantage.

I have proposed here that knowledge activation underlies comprehension skill and the ability to ignore irrelevant information. It should be noted that an increase in the knowledge available or activated during the comprehension process may be a function of two factors: (a) the reader possesses more knowledge about the topic or domain, or (b) the reader engages in more active or strategic comprehension processes which result in a greater likelihood that related information is activated. Identifying the relative contributions of these two sources is an empirical question.

Ambiguous Words

Gernsbacher et al. (1990) presented skilled and less-skilled comprehenders with sentences such as *He dug with a spade*, followed by a target word, ACE. The participant was to decide if ACE was related to the preceding sentence. Gernsbacher et al. demonstrated that both skilled and less-skilled comprehenders showed high activations of the inappropriate meaning of the ambiguous word (e.g., spade) at an immediate test, but only less-skilled comprehenders showed high activation of the inappropriate meaning after a 1 second delay. Gernsbacher and her colleagues concluded that skilled comprehenders suppress the inappropriate meanings of ambiguous words.

To estimate the activation of the inappropriate meaning of spade, Gernsbacher et al. (1990) compared the reaction times to reject ACE following the experimental sentence to the same decision following a control sentence. For the present simulations this estimate of activation corresponds to a value of the decision regarding the word's relatedness which is output following the construction and integration of the sentence and decision task.

This simulation consists of two cycles, the first cycle represents the comprehension of the sentence, and the second cycle, the processing of the target word and the decision task. The comprehension of each sentence includes a surface structure, a textbase, and a situation model. For *He dug with a spade*, the surface structure consists of the arguments HE and SPADE, and the textbase consists of the propositional representation of the sentence, DIG(HE,SPADE,WITH). The situation model consists of knowledge related to the information presented in the sentence. Three networks were constructed to represent three levels of active sentence processing, low, medium, and high (see Figure 1). These networks differ only in the amount of prior knowledge available in the situation model--skilled comprehenders are assumed to have activated the greatest amount of prior knowledge during sentence comprehension. Although Gernsbacher et al. (1990) include only two levels of skill, high and low, my goal here is to show a linear relationship between knowledge activation and "comprehension skill". Therefore, three levels are simulated.

The initial activation values of the surface and textbase nodes were set at the default value of 1.0, and the initial activation values of situation model nodes were set at 0.0. Concepts in the situation model are given no initial activation because they are concepts that are not presented to the reader, but must be activated by the concepts presented in the text. All links were set at the default value of 1.0.

The mental representation of the sentence, consisting of the surface structure, textbase, and situation model, was integrated in parallel, yielding a final activation value for each of the concepts included in the representation. All three networks settled to a maximum criterion change of 0.001 after 10 iterations. The predicted activation of ISA(SPADE,GARDENTOOL) was 0.987, 1.00, and 0.974 for the skilled, medium-skilled, and less-skilled comprehenders, respectively. The high activation of the appropriate interpretation predicts that readers of all skill levels will correctly interpret the sentence. The predicted activation of the inappropriate interpretation, ISA(SPADE,CARD), was 0.198, 0.268, and 0.491 for the skilled, medium-skilled, and less-skilled comprehenders, respectively. A higher activation of the inappropriate interpretation indicates that this interpretation would be more likely to infer with and slow the subsequent decision task. Thus, the degree to which the inappropriate interpretation interfers with the subsequent task is predicted to be a function of skill level.

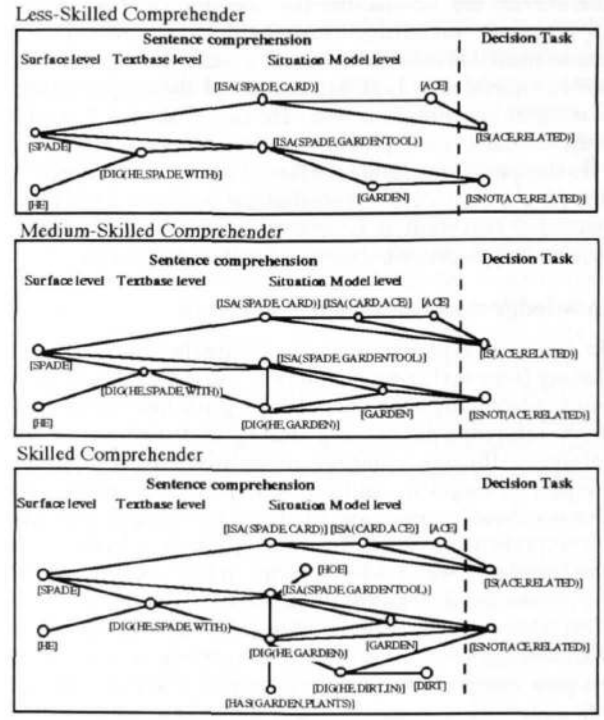

Figure 1. Comprehenders' representations of *He dug with a spade* and the decision task for whether ACE was related.

The second cycle of the simulation was the processing of the target word and the decision task. Included in the network are the textbase (i.e., DIG(HE,SPADE,WITH), the situation model, the target word (i.e., ACE), and the two decisions (i.e., related, not related). The activation levels for the textbase and situation model were those values output from the sentence comprehension cycle; the initial activation of the target word presented to the participant was re-set at 1.0 (i.e., because it is presented to the reader); and the initial activations of the two possible decisions were set at 0.0. All links between concepts are set at the default value of 1.0. The crucial outcome of this simulation concerns the relative activation values for the two decisions. The time course of these activation levels, as indicated by the outcome after each iteration of the simulation, is plotted in Figure 2 for the decision that ACE is not related, and in Figure 3 for the decision that ACE is related .

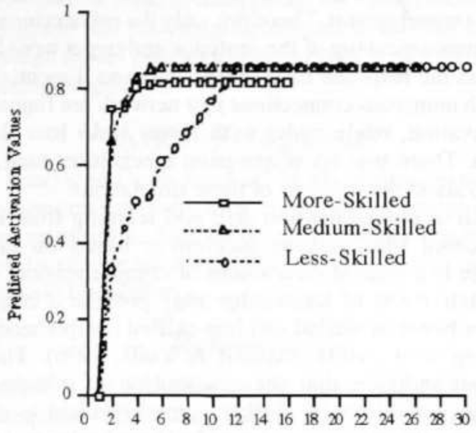

Figure 2. Predicted activation levels of the correct decision that ACE was not related to *He dug with a spade*.

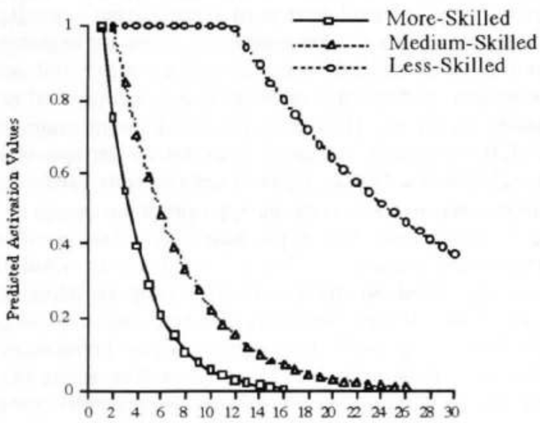

Figure 3. Predicted activation levels of the incorrect decision that ACE was related to *He dug with a spade*.

The network settled after 16, 26, and 70 iterations for the skilled, medium-skilled, and less-skilled comprehenders, respectively. There was relatively equivalent activation of the decision that ACE was not related for the three groups. The activation of the incorrect decision that ACE was related (which would cause interference and slow response time) was high early in the process for the skilled comprehenders, but dropped quickly. In contrast, for the medium-skilled comprehenders, the activation level of the incorrect decision was high early in the process but decreased more slowly. For the less-skilled comprehenders, the incorrect decision that ACE was related was 1.00 across 11 iterations and dropped slowly to 0.041 only after 70 iterations.

This simulation thus correctly predicts that skilled comprehenders will have slow responses for an immediate test, but show no interference from the inappropriate meaning of an ambiguous word after a delay, and that medium-skilled, and even more so, less-skilled comprehenders will have slower responses for both the immediate and delayed tests.

Homophones

Gernsbacher and Faust (1991, Experiment 1) demonstrated with homophones the same type of effects found with ambiguous words. They presented sentences such as *He had lots of patients*, followed by a target word, CALM. They demonstrated that both skilled and less-skilled comprehenders showed high activations of the inappropriate meaning of the homophone at the immediate test, whereas after 1 second, less-skilled comprehenders showed a high activation of the inappropriate meaning compared to the skilled comprehenders who showed little to no activation.

In this simulation, only two levels of skill level will be compared, relatively more- and less-skilled comprehenders. The networks constructed to represent the processing of the task by skilled and less-skilled comprehenders are shown in Figure 4. These networks differs from the previous ones (Figure 1) in that direct links from the textbase to the inappropriate interpretation are included. These links are included because a purely phonetic interpretation of the sentence could not discriminate between *He has lots of patience* and *He has lots of patients*. This aspect is expected to increase interference from the incorrect interpretation.

For the processing of the sentence, the skilled comprehender network settled after 12 iterations, and the less-skilled comprehender network after 10 iterations. The simulation accurately predicted that both groups of participants would correctly interpret the sentence. The predicted activation of HAS(HE,CLIENTS) was 0.796 for skilled comprehenders, and 0.589 for less-skilled comprehenders. The activation of the inappropriate interpretation, IS(HE,CALM), was 0.388 for skilled comprehenders, and 0.446 for less-skilled comprehenders. In this case, the activation of the appropriate interpretation for the less-skilled comprehenders is relatively low (0.589), and the activation of the inappropriate response is relatively high (0.446) and thus the difference between the two is small compared to that for skilled comprehenders. Therefore, the model predicts greater competition between the two interpretations for less-skilled than for skilled comprehenders.

The second cycle of the simulation is the processing of the target word and the decision task (see Figure 5). The network settled after 17 iterations for the skilled comprehenders, and after 20 iterations for the less-skilled comprehenders. For skilled comprehenders, the activation level of the incorrect response is high early in the process, but drops relatively quickly to a final activation value of

0.118. In contrast, for less-skilled comprehenders, the activation level of the incorrect response is also high early in the process but decreases more slowly to a value of 0.261. This simulation correctly predicts that both skilled and less-skilled comprehenders will have slow responses for an immediate test, but that only less-skilled comprehenders will show interference from the inappropriate meaning at the delayed test.

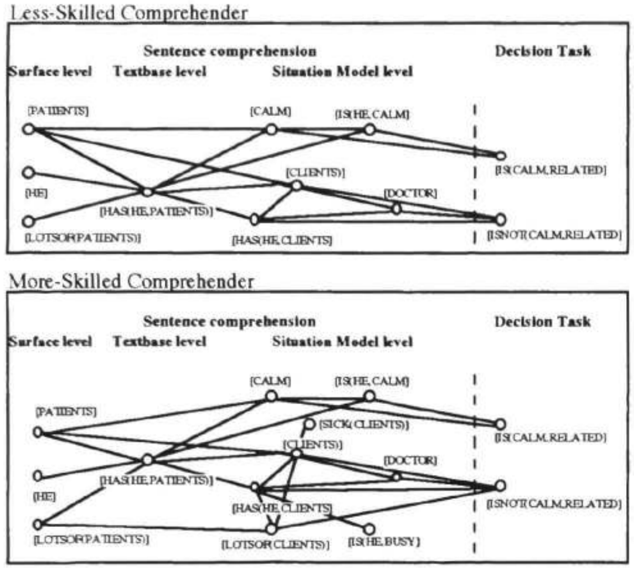

Figure 4. Comprehenders' representations of *He had lots of patients* and the decision task for whether CALM was related.

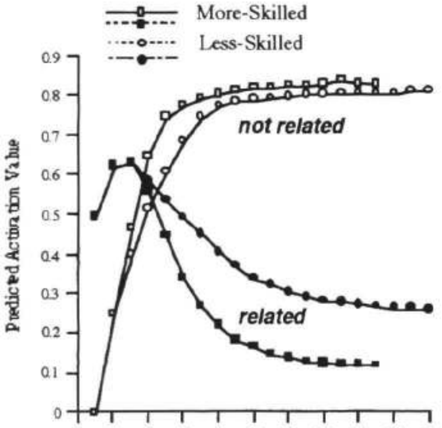

Figure 5. Predicted activation levels of the decision that CALM was related or not related to *He had lots of patients*.

Discussion

Two simulations based on the CI model of comprehension (Kintsch, 1988) demonstrated that the activation of more knowledge leads to an initial activation of an inappropriate meaning of a concept which quickly decays. Without the activation of associative or causal knowledge, the inappropriate meaning of an ambiguous word either remains activated or loses its activation more slowly. These simulation results correctly predict findings by Gernsbacher and colleagues (Gernsbacher & Faust; 1991; Gernsbacher et al., 1990) showing that the inappropriate meaning of a word quickly decays for skilled comprehenders, but remains active in memory for at least 1 second for less-skilled comprehenders. The networks used for these simulations differed only in the amount of prior knowledge available in the situation model--skilled comprehenders were assumed to have activated a greater amount of prior knowledge during sentence comprehension. Therefore, only the enhancement of the appropriate meaning of the sentence and target word had an effect on the response time for the decision. Essentially, nodes with numerous connections in a network are funneled more activation, while nodes with fewer links lose their activation. There was no suppression mechanism used, or needed, to affect the outcome of these simulations.

Research on comprehension skill and learning from text has indicated that making inferences based on prior knowledge is a critical component of comprehension, and that the active use of knowledge may provide a critical distinction between skilled and less-skilled comprehenders (e.g., Long et al., 1994; Oakhill & Yuill, 1996). These simulations indicate that the assumption of additional knowledge activation by skilled comprehenders is also sufficient to explain results reported by Gernsbacher and her colleagues.

Just and Carpenter (1992) have proposed that reading skill is a function of working-memory capacity and that good readers have a large capacity whereas poor readers have a smaller capacity. On the surface it may seem that the present knowledge-based explanation of Gernsbacher's results is compatible with a working-memory capacity explanation because the skilled comprehenders activated more information--perhaps this is because they simply had more capacity to do so. However, for the present simulation model, if a capacity limitation were set on the less-skilled comprehenders' networks, it could not correctly predict both the high activation levels of the appropriate meanings of the target words and the high activation levels of the inappropriate meanings. That is, the present simulation results depended on the less-skilled comprehenders' "less strategic" use of their "equally" limited capacity. On the other hand, the skilled comprehenders' generation of additional inferences must have some cost in terms of the processing demands. Indeed, skilled comprehenders may be capable of engaging in additional inference processes because the fundamental task of reading itself does not require as much capacity allocation as for less-skilled readers. Thus, while a working-memory limitation per se may not account for these simulation results, processing capacity, and capacity allocation more generally may be important considerations. However, as mentioned earlier, determining the source or causes of increased knowledge activation during the comprehension process remains an empirical question.

One important vehicle of knowledge acquisition is texts. We depend on texts for a variety of information, and moreover, they are an integral component to the process of educating ourselves and others. One important question that we ask as cognitive scientists is why some individuals are able to learn more from texts while others learn less. Identifying the critical components of this skill is important, not only so that we can better understand human cognition, but also so that we can potentially enhance comprehension skill in less-skilled readers. The present work at least questions the hypothesis that less-skilled readers or comprehenders should be trained to suppress information. At best, it lends additional support to the hypothesis that prior knowledge is a critical component for comprehension and learning, and that encouraging learners to actively use prior knowledge should play an important role in any educational or training program.

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