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Cognitive Precursors to Science Comprehension

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Abstract

This study examined the ability of cognitive factors (i.e., prior domain knowledge, reading ability, and metacognitive reading strategies) to predict students' comprehension of science texts and students' performance in an introductory psychology course. Both prior knowledge and reading ability reliably predicted comprehension of the science text (about sensory memory). Prior knowledge was the best predictor for exam performance. However, greater knowledge provided no benefit for students who did not use certain types of metacognitive reading strategies. Also, the tendency to use previewing strategies only benefited students if they possessed sufficient prior knowledge.

Introduction

What cognitive abilities are most important to a student entering a college level science course? If we assume that science course performance relies on factors related to science comprehension, then cognitive factors such as the students' level of reading ability, their prior knowledge of the domain area, and students' knowledge and use of metacognitive reading strategies should play key roles in students' course performance. Hence, the purpose of this research was to establish whether these cognitive factors were predictive of students' comprehension of science texts as well as their performance in a science course (in this case, introductory psychology).

There is no doubt that better readers better comprehend text (Perfetti, 1985) – because, of course, that is the underlying definition of reading skill. Skilled readers also tend to experience the reading process as more automatic and effortless than less skilled readers (Underwood, 1997). Skilled readers tend to make reading process decisions below the level of consciousness, particularly when reading familiar material. Thus, skilled readers unconsciously, or with very little conscious effort, understand the thoughts communicated through the texts and are reminded of the knowledge they have regarding the topic covered within a text (Underwood, 1997). Furthermore, skilled readers approach confusing sentences or passages by incorporating their prior domain knowledge to help them better understand the text (Collins, 1994). Thus, it would be expected that not only reading skill, but also prior knowledge would provide considerable benefits to science text comprehension and by consequence to students' course performance.

Researchers have established that prior domain knowledge has a strong effect on text comprehension and memory. Bransford and Johnson (1972) first established that prior knowledge improves readers' memory for written information. They showed that when readers were provided with a prior schema via a passage title or a picture, readers recalled twice as much from the passage compared to those who were not provided with prior schematic information. Essentially, the passage title activated the appropriate prior knowledge, or schema, that allows the reader to understand and thus remember the passage. Chiesi, Spilich, and Voss, (1979) demonstrated that readers with greater prior knowledge of baseball better understood and remembered a passage concerning baseball, regardless of the participants' age or reading ability. Further research has demonstrated that prior knowledge has a pronounced effect on comprehension of difficult expository texts, such as those found in science textbooks. Readers with greater prior knowledge exhibit superior comprehension and thus enhanced learning compared to those with less prior knowledge (Alexander, Kulikowich, & Schulze, 1994; Chiesi et al., 1979; McNamara, 2001; McNamara & Kintsch, 1996; McNamara, Kintsch, Songer, & Kintsch, 1996). Therefore, we can expect that prior knowledge will have a substantial effect on science course performance, perhaps more so than reading skill.

Whereas prior knowledge is certainly critical for successful text comprehension and course performance, students' metacognitive knowledge, such as their knowledge of metacognitive reading strategies, may also play an important role. Generally, metacognition refers to an individual's ability to think about thinking. More specifically, metacognition can be defined as an individuals' ability to self-monitor, self-assess, and self-evaluate. These processes help a learner determine why a process such as reading a science textbook is difficult, and then potentially overcome the difficulty.

Metacognition when applied to reading refers to the process of monitoring comprehension and the use of strategies to improve comprehension (Forget & Morgan, 1997). Reading strategies such as summarization, mental imagery, mnemonic imagery, question generation, answering self-generated questions, and look-backs have all been shown to enhance text comprehension (Pressley & Woloshyn, 1995). Chi and Bassok (1989) found that successful students tended to employ reading strategies such as generating elaborations and paraphrases, monitoring and creating statements, and producing self-explanations. In turn, these strategies enhanced their understanding of the text material (see also, Chi, DeLeeuw, Chiu, & LaVandcher, 1994). Chi and Bassok also found that the students were more likely to generate explanations of the material covered within a text when they monitored and detected the points that they did not successfully understand. In addition, more successful students' self-explanations tended to include additional knowledge compared to less successful students who were more likely to simply paraphrase the text material.

Chi, Bassok, Lewis, Reimann, and Glaser (1989) found that successful students showed a tendency to use strategies such as explaining and justifying example-exercises in a science textbook to themselves whereas less successful students were not as likely to show this tendency. When the less successful students explained the exercise to themselves, they did not seem to connect their prior knowledge with the information covered within the science textbook. The study also found a tendency for the successful students to accurately monitor and detect when they understood a concept as well as when they did not fully comprehend or understand a concept. The less successful students did not show this tendency when attempting to detect comprehension failures of concepts covered within a science text.

Reading strategy instruction also improves reading comprehension. Bereiter and Bird (1985) found that when readers were taught strategies such as restatement, backtracking and problem solving, there was a significant increase in reading comprehension. McNamara and Scott (1999) found that when students in a college level science course were trained to use reading strategies to improve self-explanation, they had superior course grades compared to their counterparts who did not receive this training. Moreover, this training was more beneficial to students with less prior knowledge than for those who had greater prior knowledge. In essence, the training helped the students to overcome their knowledge deficits.

Collins (1994) also notes that metacognition affects an individual's ability to integrate prior knowledge with incoming novel information from a textbook, such as those textbooks used in science courses. As indicated earlier, prior knowledge assists an individual's ability to comprehend incoming information. Thus, an individual's metacognitive skills may assist him or her in incorporating their prior knowledge with the new information from the textbook.

In summary, the literature indicates that reading skill, prior knowledge, and the knowledge and use of metacognitive reading strategies are important tools in science comprehension. Thus, the current study examines whether reading ability, prior domain knowledge, and metacognitive reading strategies are related to course performance in an introductory psychology course at Old Dominion University. These factors were assessed at the beginning of a semester to determine their ability to predict students' comprehension of a science text and students' course performance. Our secondary goal was to reveal whether specific metacognitive reading strategies were more or less associated with reading ability, science text comprehension, and prior knowledge.

Reading ability was expected to facilitate readers' comprehension of text material and thus improve course performance. Additionally, it was expected that prior knowledge would have a profound effect on science course performance as well as comprehension of a science text. Those students who have prior knowledge of the domain of a text should perform better on comprehension measures of that material because they have the opportunity to incorporate that prior knowledge with the text material. However, knowledge and use of metacognitive reading strategies should enhance that ability by the reader strategically incorporating his or her prior knowledge with the novel material from the text. However, for those students who lack the adequate knowledge needed to comprehend difficult texts, such as science textbooks, the use of metacognitive reading skills may compensate for the lack of prior knowledge (see e.g., O'Reilly and McNamara, 2002). Metacognitive reading strategies may assist the learner to monitor their comprehension of the text material and thus actively attempt to understand the material.

Method

Participants

The sample consisted of 144 undergraduates enrolled in Introduction to Psychology at Old Dominion University. The participants included 57 males and 87 females with a mean age of 19 years. The majority of the participants were freshman (n=111). The remaining sample consisted of 21 sophomores, 8 juniors, and 4 seniors. They were given extra credits points in the psychology course of their choice for their participation.

Procedure

The experiment involved two sessions, which took place during the regularly scheduled class periods. In the first session, participants were invited to participate and given the Metacognitive Strategies Index (MSI) to complete at home. (There was no instruction of metacognitive reading strategies.) In the second session, participants were administered the prior knowledge test (19 min), the Nelson Denny reading test (15 min), and the sensory memory text with the comprehension questions (8 min). Students' grades were provided by the instructor at the end of the semester.

Materials

Metacognitive Reading Strategies Knowledge and use of metacognitive reading strategies was assessed using the Metacognitive Strategies Index (MSI; Forget, 1999). This was a 25-item multiple-choice questionnaire. Studies conducted by Forget in content areas at the high-school level found validity and test-retest reliability to be high (Forget, 1991; Forget & Morgan, 1997; Forget, 1999). The questions determine what the student does before, during, and after reading a text. For the purpose of this study, four sub-factors were examined (1) predicting and verifying (predicting the content and evaluating predictions and creating new ones), (2) previewing the text, purpose setting, and self-questioning, (3) drawing from background knowledge (activating and incorporating information from background knowledge), and (4) summarizing the content. The reliability of the MSI computed by Cronbach's Alpha was .66. Reliability of sub-factor (1) predicting and verifying was .30, of sub-factor (2) previewing, purpose setting, and self-questioning was .38, of sub-factor (3) drawing from background knowledge was .46, and for sub-factor (4) summarizing and applying fix-up strategies was .29.

Demographics Demographics, motivation, effort, and education were assessed using a questionnaire consisting of 15 questions. The questions assess how much time and effort the students devote to the course as compared to how much time and effort they devote to other courses (i.e., "How many hours per week do you plan to devote to reading and studying for this course?"). The questions also determine how many science courses the participants have completed and how much they enjoy reading and learning scientific material as well as non-scientific material. Examples are: "How much do you enjoy reading?" and "How much do you enjoy learning information about science?"

Prior Knowledge Prior knowledge was assessed using an unpublished prerequisite knowledge test developed in collaboration with Linda Buyer at Governors State University in Illinois. The 48 multiple-choice questions were developed based on the concepts covered within three textbooks used for introductory psychology courses that were assumed known to the reader by the textbook authors. The questions included psychology specific questions (i.e., "Which person is most closely associated with the concept of the unconscious?"), general knowledge questions (i.e., "Which of the following is a logarithmic scale?"), and research methodology questions (i.e., "How is sample size related to the accuracy of population estimates derived from sample data?"). The questions were presented in random order. Reliability of the prior knowledge test computed by Cronbach's Alpha was .67.

Reading Ability Reading ability was evaluated using form G of the Nelson Denny adult reading comprehension test (Brown, Fishco, & Hanna, 1993). The measure consists of seven passages and 38 questions. The participants were instructed to read a passage and then answer the comprehension questions regarding that particular passage. They were permitted to look back on the passages to answer the comprehension questions. Reliability computed by Cronbach's Alpha was α=.88.

Science Comprehension The text consisted of a 307-word passage on the topic of sensory memory adapted from Lefton (pp. 195-196; 2000). The reading ease was 31.3 and the Flesch-Kincaid Grade level was 12. Twelve open-ended comprehension questions were used to measure comprehension of the passage. Six of the 12 questions were bridging questions, which require the reader to make inferences from two or more sentences in the text (i.e., "What was the dependent variable in Sperling's experiment? That is what did he measure") and the remaining 6 were text-based questions which require the reader to use only one sentence in order to successfully answer the question (i.e., "What is sensory memory?"). The students were allotted 8 minutes to read the passage and answer the questions, but were allowed to refer back to the passage to answer the questions. Therefore, performance on the questions assesses comprehension, but does not necessarily assess memory or learning. The participants were allotted 8 minutes to complete the exercise. Reliability of the science text comprehension questions computed by Cronbach's Alpha was .33.

Results

The alpha level was set at .05; hence, probability values are only reported for marginal results. As might be expected, knowledge and reading skill were highly correlated (R=.63), but were not reliably correlated with performance on the MSI. Text comprehension performance was measured in terms of proportion correct on the open-ended questions. Two raters scored the comprehension questions and discrepancies (12% of the scores) were resolved via discussion, yielding a final set of scores.

Demographics

A standard multiple regression was computed to determine whether variables such as the students' amount of effort in the class, motivation, enjoyment for leaning science and non-science material as well as the number of previous science courses taken by the student were associated with comprehension of the sensory memory text as well as course performance. For comprehension of the sensory memory passage, the overall regression model was significant, F(15,121)=2.29 accounting for 12% of the variance. Total points on the SAT in high school was the only significant predictor, β=.35, sr_i^2=.09. For average exam performance, the overall regression model was reliable, F(15,121)=1.93 accounting for 9% of the variance. The only reliable predictor was high school grade point average, β=.33, sr_i^2=.08. Hence, neither course effort nor reading enjoyment were significant predictors of performance in this study.

Predicting Comprehension and Exam Performance

Our first question regarded the ability of prior knowledge, reading ability, and the MSI to predict science text comprehension and course performance. Regression analyses were performed for each dependent measure including prior knowledge, reading ability, and metacognitive reading strategies as predictor variables.

Science Text Comprehension For science text comprehension, the overall regression model was reliable, F(3,140)=30.70, accounting for 38% of the variance. Performance on the MSI did not predict performance, whereas both prior knowledge, F(1,140)=9.54; β=.27, sr_i^2=.04, and reading ability, F(1,140)=23.68; β=.41, sr_i^2=.10, reliably predicted comprehension. High-knowledge students scored significantly higher on the comprehension questions (M=49% correct) than low-knowledge students (M=33% correct); and similarly, skilled readers showed better comprehension (M=50% correct) than less-skilled readers (M=31% correct). Separate analyses did not reveal any interdependencies between prior knowledge and reading ability.

Average Exam Performance Average Exam performance in this course was based on the top five of six exams. Analyses included students who completed at least four of the six exams (n=136). In terms of average exam performance, the overall regression model was reliable, F(3,132)=13.46, accounting for 25% of the variance. Neither reading ability, F(1,132)=2.38, nor performance on the MSI, F(1,132)=3.24, reliably predicted exam performance. Prior knowledge, in contrast, accounted for 21% of the variance, F(1,132)=30.85; β=.48, sr_i^2=.14. Students with greater prior knowledge about concepts related to psychology when beginning the course scored significantly higher on the exams (M=0.80) than did low-knowledge students (M=0.72). In addition, the effect of knowledge on exam performance remained stable across exams, thus, prior knowledge affected performance equivalently across all of the exams.

Metacognitive Reading Strategies

Our second question regarded whether the sub-factors of the MSI differentially predicted reading skill, science text comprehension, and course performance. The sub-factors included (1) predicting and verifying, (2) previewing, purpose setting, and self-questioning, (3) drawing from background knowledge, and (4) summarizing and applying fix-up strategies.

Reading Ability None of the four metacognitive sub-factors reliably predicted scores on the Nelson Denny reading test.

Science Comprehension Performance on the science text comprehension questions was reliably predicted by sub-factor 3 (drawing from background knowledge), F(1,140)=4.37; β=.21, sr_i^2=.03. The students who were more likely to use prior knowledge while reading scored significantly higher on the comprehension of the science text (M=42%), than those students who were less likely to use knowledge (M=37%). This relationship remained significant when prior knowledge and reading ability were included in the regression equation. Although, one might expect that drawing on background knowledge would depend on the student's prior knowledge, this interaction was not reliable.

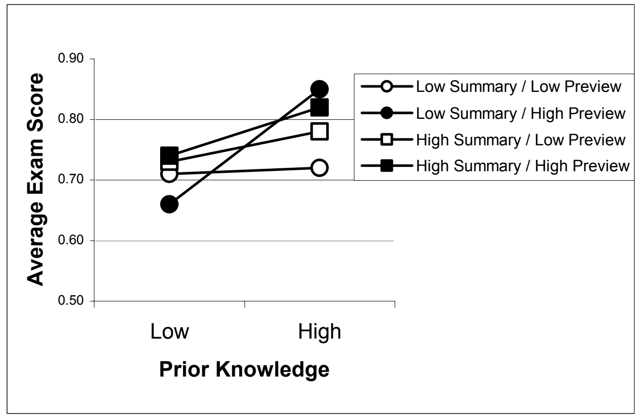

Figure 1. Exam Performance as a Function of Prior Knowledge, Summarization Reading Strategies, and Previewing Reading Strategies

Exam Performance Performance on exams was reliably predicted by sub-factor 2 (previewing, purpose setting, and self-questioning), F(1,131)=4.16; β=.19, sr_i^2=.03 (High M=0.77; Low M=0.73) and by sub-factor 4 (summarizing and applying fix-up strategies), F(1,131)=4.33; β=.19, sr_i^2=.03 (High M=0.77; Low M=0.73). However, these effects were not reliable when prior knowledge was also included in the regression model indicating that prior knowledge is more predictive of exam performance. Moreover, further analyses revealed that these factors were interdependent. An interaction between knowledge and previewing indicated that students who were more likely to use previewing strategies (i.e., sub-factor 2) only benefited from these strategies on the exams if they possessed sufficient knowledge, F(1,128)=7.95. In addition, there was a three-way interaction between knowledge, previewing, and summarization, F(1,128)=4.65 (see Figure 1). Students who were less likely to use previewing strategies but more likely to use summarization strategies showed a marginal effect of prior knowledge, F(1,36)=3.31, p=.08, Students who were more likely to use previewing strategies, regardless of the extent of their use of summarizing strategies significantly benefited from their prior knowledge on exams (High Summary F(1,46)=14.33; Low Summary F(1,19)=21.36). Finally, greater knowledge provided no benefit for students who did not use either type of reading strategies, F<2. Looking at the interaction from a different angle, the effects of strategy use were not reliable for low-knowledge students. In contrast for high-knowledge students, there was a reliable effect of previewing, F(1,47)=7.84, and marginal interaction of previewing and summarizing, F(1,47)=3.61, p=.06.

Discussion

The purpose of this study was to determine which cognitive abilities were precursors to science comprehension, and by consequence to students' performance in a science course (in this case, introductory psychology). Hence, we examined students' prior knowledge, reading ability, and metacognitive reading strategies at the beginning of a semester and related performance on these measures to students' ability to comprehend a science text (about sensory memory) and students' average exam scores. In addition, we determined whether specific metacognitive reading strategies differentially predicted reading ability, science text comprehension, and course performance.

As hypothesized, prior knowledge strongly predicted students' comprehension of the sensory memory passage as well as their exam performance. High-knowledge students showed a 16 percent advantage on comprehension questions in comparison to low-knowledge students. Similarly, students with greater prior knowledge about basic psychological concepts performed about 8 percent better on the course exams than low-knowledge students. Indeed, prior knowledge was the only reliable predictor of exam performance, accounting for 21 percent of the variance. Moreover, there was not a decline in the effect of prior knowledge throughout the semester. Hence, students did not overcome their knowledge deficits as the course proceeded.

Reading ability was a strong predictor of text comprehension, even more so than prior knowledge. The fact that reading ability did not predict exam performance could imply that the exams did not include information covered solely within textbooks rather was primarily based on information covered within the lectures; thus reading comprehension would not be necessary to succeed in the course. In addition, this would mean that our reading ability measure would be a poor predictor of lecture comprehension. Alternatively, the type of reading ability measure could be at fault. That is, perhaps the Nelson Denny reading test does not tap into the same processes involved in comprehending a course textbook. To contradict that argument, however, it was found that reading ability was the strongest predictor of comprehension of the science text, which was derived from an introductory psychology textbook.

In addition, it was found that neither the overall score nor the four metacognitive sub-factors predicted reading ability. This result indicates that the Nelson Denny reading test does not rely heavily on strategy use. This result may be expected because the Nelson Denny reading test primarily covers relatively familiar material, whereas metacognitive reading strategies may be most helpful for less familiar or difficult material.

Students' overall score on the Metacognitive Strategies Index (MSI) did not reliably predict either exam scores or science text comprehension. However, when the sub-factors were considered, it was found that *drawing from background knowledge* was predictive of science text comprehension. The influence of this type of reading strategy was positive regardless of students' prior knowledge and reading ability. This result further supports the importance of teaching both high- and low-knowledge students to integrate prior knowledge with new information when reading difficult texts such as science textbooks (e.g., McNamara & Scott, 1999).

The two sub-factors, *previewing, purpose setting and self-questioning* as well as *summarizing and applying fix-up strategies* predicted exam performance; however, this was dependent on the amount of knowledge the students' possessed. The students' use of previewing strategies was only beneficial on the exams when they possessed sufficient prior knowledge. The purpose of previewing is to activate knowledge schemas. These schemas presumably help the student to prepare for the learning process – just as a story title helps the reader understand a passage (Bransford & Johnson, 1972). However, without the necessary knowledge about the topic, previewing is of little utility.

In addition, it was found that students with low-knowledge did not benefit reliably from strategy use on exams (cf., O'Reilly & McNamara, 2002). Thus, in contrast to the results for text comprehension, it was found for exams that strategy use did not help to compensate for knowledge deficits. High-knowledge participants benefited from strategies, and most importantly, having more prior knowledge did not benefit students who did not use either of the metacognitive reading strategies. Hence, knowledge and strategy use are critically intertwined.

There are several limitations to this study. First, this study was correlational, and thus causal relationships cannot be assumed. Clearly, additional experimental studies are necessary to more completely understand these issues (cf., McNamara & Scott, 1999). Second, the sample was college students all enrolled in the same introductory psychology course and most of the students were freshmen in their second semester of college. Thus, the results of this study may not generalize to other populations. Additionally, this study may not adequately tap into science comprehension per se since the students are enrolled in a psychology course and the sensory memory text was derived from an introductory psychology textbook. The predictors of comprehension of passages within a psychology textbook may differ from those predictors of comprehension of a biology textbook or textbooks used in other hard sciences. Future research in this area could be to examine what factors predict comprehension of texts and course performance in other science courses such as biology or chemistry (e.g., see O'Reilly & McNamara, 2002). Finally, it may be beneficial to examine predictive factors of science comprehension for college students compared to younger students such as those in high school.

In conclusion, these results underline the notion that students should be taught to utilize strategies when reading texts, particularly those found in science courses. It is important, though, to understand which strategies may be more or less helpful under different circumstances. This study is a small step toward better understanding what these circumstances may be.

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