DISCOURSE PROCESSES, *38*(1), 1–30

SERT: Self-Explanation Reading Training

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This study examined the effects of providing reading strategy instruction to improve the effectiveness of self-explanation (i.e., explaining the meaning of information to oneself while reading). The effects of the reading strategy instruction, called Self-Explanation Reading Training (SERT), were examined both in terms of comprehension scores and self-explanation quality. Half of the participants ($n = 42$) received SERT, which included reading strategy instruction and self-explanation practice with 4 science texts (SERT condition). The remaining participants read aloud the 4 science texts (control condition). During this training phase, self-explanation, as compared to reading aloud, only improved comprehension for the most difficult of the 4 texts. Prior domain knowledge consistently improved comprehension performance, whereas reading skill and reading span had minimal effects. After training, both SERT and control participants self-explained a difficult text about cell mitosis. SERT improved comprehension and self-explanation quality only for participants with low domain knowledge. However, the effects of SERT on low-knowledge participants' comprehension emerged only for text-based questions and not for bridging-inference questions. Protocol analyses indicated that SERT helped these participants to use logic, or domain-general knowledge, rather than domain-specific knowledge to make sense of the text.

Understanding and learning from written material is one of the most important skills to possess in modern society. The importance of understanding text ranges from being able to decipher the "three easy steps" for setting up your computer to understanding the ever-dreaded physiology textbook. Indeed, the ability to comprehend the challenging textbooks confronted in typical classrooms is one of the

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most important keys to success. Yet many of our students flounder (*National Assessment of Educational Progress,* 1998) and struggle to comprehend informational texts. Students' ability to comprehend the challenging textbooks typically used in classrooms is questionable, particularly those covering scientific material (Bowen, 1999; Snow, 2002). The purpose of this research is to address the pressing need to improve students' ability to comprehend and learn textbook material.

There are several directions that can be taken to tackle this problem. For example, the recent RAND report (Snow, 2002) presents four interactive components critical to reading comprehension: characteristics of the reader, the text, the comprehension activities, and the sociocultural context. Each of these components and their combinations offer potential avenues of research. This study, however, focuses on the reader's comprehension activities and how these activities interact with the reader's aptitudes. The approach taken here was to design and test a reading strategy intervention to help students better comprehend and learn from challenging text. This intervention is called Self-Explanation Reading Training, or SERT.

SELF-EXPLANATION AND READING STRATEGIES

The starting point for SERT was a technique called self-explanation (e.g., Chi & Bassok, 1989). Self-explanation refers to the process of explaining the meaning of text while reading. In a laboratory setting, self-explanation involves reading and explaining aloud sentences or sections from a text. Readers who explain the text either spontaneously, or when prompted to do so, understand more from the text and construct better mental models of the content (e.g., Chi & Bassok, 1989; Chi, de Leeuw, Chiu, & LaVancher, 1994; Magliano, Trabasso, & Graesser, 1999; Trabasso & Magliano, 1996). Unfortunately, some readers do not naturally self-explain text, or self-explain poorly, even when prompted to do so (e.g., Chi & Bassok, 1989; Chi et al., 1994). For example, rather than constructing an explanation of the meaning of the text, a poor self-explainer may be more likely to simply restate or paraphrase the text. One question addressed by this research is whether readers can be trained to more effectively self-explain text (see also Bielaczyc, Pirolli, & Brown, 1995). Specifically, can the quality of self-explanations and comprehension be improved by providing reading strategy instruction in combination with self-explanation, as opposed to self-explanation instruction alone?

The reading strategies covered in SERT were included because their use is particularly characteristic of successful, skilled reading. The strategies are monitoring comprehension, paraphrasing, predicting what the text will say, making bridging inferences to link separate ideas in the text, and elaborating by using prior knowledge and logic to understand the text. Examples of these strategies, from self-explanations collected in this experiment, are presented in Table 1.

TABLE 1
Examples of Strategies Used by Participants for Sentence 3 of Cell Mitosis

Strategy	*Self Explanation*
Comprehension monitoring	Example 1: “I don’t remember what DNA stands for.” Example 2: “So I guess daughter cells are a part of a larger cell or came from a larger cell—I don’t know."
Paraphrase	Example 1: “So each daughter cell will receive a duplicate copy of the same strand of DNA from the parent cell." Example 2: “Ok through this process of mitosis all the genetic information belongs in the DNA of the parent cell and that is transferred over to the daughter cell.”
Bridging inference	Example 2: “So mitosis—the first stage of cell division where each set of chromosomes goes to each daughter cell will contain DNA.” Example 1: “So, yeah, so all the genetic information is in the chromosomes and each cell gets a complete set, so that’s mitosis—when each cell has just as much DNA as the first mother cell—main cell—parent cell.”
Elaboration	Example 1: “Ok so there’s the daughter cell and then there’s a parent cell—mitosis it has to do with genetic information so when I’m thinking of cell division I’m thinking of maybe how a baby is made and how it’s developing.” Example 2: ”So by mitosis it guarantees that the chromosomes will get passed on so that the traits or whatever will be able to live on or whatever."
Using logic	Example 1: “Ok what they’re saying is that mitosis will make sure that an equal amounts of genetic information will go to each of the cells—equal amount will go to each daughter cell that way. They will develop basically the same—multiply the same.” Example 2: “OK, so the genetic information that must be the chromosomes because the chromosomes are going into each of the cells. And that is made up of the DNA. So a part of … a part of each of the … a part of genetic information which is the DNA goes into each of the two cells that come out of this.”
Prediction	Example 1: “Ok this is the separation of the cell—the DNA—the next one should be the RNA.” Example 2: “So that’s the first stage, now they’ll give the second one.”

Note. Sentence 3: “Mitosis guarantees that all the genetic information in the nuclear DNA of the parent cell will go to each daughter cell.”

Previous research has demonstrated that skilled readers are more likely to be aware of whether or not they understand what is being communicated by the text, because they closely monitor their comprehension (A. Brown, 1982; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Crain-Thoreson, Lippman, & McClendon-Magnuson, 1997). Moreover, they are more likely to use fix-up or repair strategies when comprehension is impaired or more difficult (e.g., Chi & Bassok, 1989). Inference making is also key to successful reading comprehension (e.g., A. Brown, 1982; Garnham, Oakhill, & Johnson-Laird, 1982; Long, Oppy, & Seely, 1994; Magliano, Millis, Miller, & Schleich, 1999; McNamara, 2001; McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara & Kintsch, 1996; Oakhill, 1984; Oakhill & Yuill, 1996; Oakhill, Yuill, & Donaldson, 1990; Yuill, Oakhill, & Parkin, 1989). Inferences are sometimes necessary while reading to make connections between separate clauses, sentences, and paragraphs of text. These are generally referred to as *bridging inferences*. Inferences are also made using world knowledge to construct new content beyond the text. These knowledge-based inferences are sometimes called *elaborations*. Inferences that focus on what might happen next in a story are referred to as *predictions*. Research has shown that skilled readers are more likely to generate inferences and that less skilled readers benefit from instruction to use strategies such as these (e.g., Baker, 1996; Baumann, Seifert-Kessell, & Jones, 1992; Bereiter & Bird, 1985; Bielaczyc et al., 1995; Davey, 1983; Dewitz, Carr, & Patberg, 1987; Hansen & Pearson, 1983; Palinscar & Brown, 1984; Yuill & Oakhill, 1988).

In sum, readers better understand and learn more from written material when they monitor their comprehension and use active reading strategies. One question posed here is whether self-explanation can be improved by training readers to use reading strategies while self-explaining. The primary hypothesis is that instruction to use effective reading strategies will improve readers' ability to self-explain text, and thereby improve comprehension. SERT combines the overt reading technique of self-explanation with training to use active reading strategies. As such, the reading strategies are externalized within the self-explanations, making them more tangible to the reader. So, self-explanation makes the strategies more concrete for the participant. In turn, the process of self-explanation is enhanced through the use of more effective reading strategies. That is, the use of reading strategies while explaining improves the quality of the explanations.

Prior Knowledge

Although reading strategically is important for comprehension, the amount of knowledge the reader possesses about the world and about the text content is also an important factor to consider. Indeed, the amount of prior knowledge a reader has about the text content can override deficits in reading abilities (e.g., Chiesi, Spilich, & Voss, 1979; O'Reilly & McNamara, 2002; Yekovich, Walker, Ogle, & Thompson, 1990). Prior knowledge provides a foundation for the reader's schema or mental model (Bransford & Johnson, 1972) and allows the reader to make connections between the new information in the text and long-term memory. When these connections are made, the reader has a greater likelihood of retaining the new information (e.g., Kintsch, 1988, 1998; Pressley et al., 1992; Willoughby, Waller, Wood, & MacKinnon, 1993). Indeed, texts can induce that process by forcing the reader to generate more inferences. However, without sufficient prior knowledge, the reader often fails to fill in conceptual gaps within texts (e.g., McNamara, 2001; McNamara & Kintsch, 1996; McNamara et al., 1996).

Readers' dependency on prior knowledge is particularly relevant to the understanding of and learning from expository texts, such as the typical textbook used for instructional purposes. One reason prior knowledge is important is because textbooks tend to include less familiar information—indeed that is a defining characteristic. They also tend to have numerous cohesion gaps (Beck, McKeown, & Gromoll, 1989). Thus, our educational system is frequently faced with low-knowledge readers who are expected to learn from low-cohesion text, resulting in a grim situation.

One question addressed in this study is whether SERT can help low-knowledge readers better cope with difficult texts containing cohesion gaps. On the one hand, cohesion gaps may be only surmountable with sufficient prior knowledge. Without the requisite knowledge, the reader may have no way to fill in the gaps and build a coherent mental representation of the text. On the other hand, reading strategy training may help the low-knowledge reader to use general knowledge, or logic, rather than domain-relevant prior knowledge to fill in conceptual gaps. That is, improved reading skills may compensate for a reader's knowledge gaps. Although prior knowledge may be the most direct and natural way to resolve cohesion gaps, the reader may be able to "work harder" to understand the text by generating more logic-based and text-based inferences (see Table 1 for examples).

Comprehension Assessment

The answers to the questions posed here regarding the effects of SERT and prior knowledge on comprehension may further depend on the type of measure used to assess comprehension (e.g., McNamara et al., 1996; Snow, 2002). Most text comprehension theories agree that there are multiple, interdependent levels of comprehension that comprise a reader's mental representation of a text (e.g., Kintsch, 1988, 1998). The most raw and transient level is the surface code, which contains the exact wording and syntax of the written text. This level of representation is generally more relevant to narrative texts such as poems. It is less relevant to expository texts, where the surface code is retained for so little time. The textbase level contains the meaning of the text, but not the exact wording and syntax. The textbase is generally represented in terms of propositions within instantiated models of text comprehension. For example, the sentence "She fixed the car" can be represented in terms of the proposition, FIX(SHE,CAR), which contains the meaning of the sentence, but does not include all of the words or the verb tense (see, e.g., Kintsch, 1998). In contrast, the reader's situation model is the understanding of the broader meaning of the text, represented by the integration of the text with the readers' prior knowledge or mental schemas of the text content. For example, the previous sentence may bring up information from memory about how cars may break down, tools that are used to fix cars, situations in which cars may break down, or the anguish "she" might have faced while fixing her car. This prior knowledge embellishes the meaning of an otherwise simple sentence. Thus, the development of a coherent situation model, or deep understanding, of a text is highly dependent on having sufficient prior knowledge.

We cannot completely isolate one level of comprehension from another, but we can ask questions that rely more or less on certain levels of comprehension. Hence, these levels of mental representation are generally assessed using different comprehension measures. Questions that require memory for only the information presented explicitly in the text are used to assess the reader's textbase level of representation. In contrast, questions that require understanding implicit relationships conveyed in the text tend to assess the reader's situation model level of understanding. Readers understanding implicit relations between ideas in the text, and developing a coherent situation model, requires the use of prior knowledge. For example, if the sentence, "She fixed the car" were followed by "It had taken an hour just to find some jumper cables," some readers may successfully infer that her car's battery had gone dead. A potential comprehension question to assess this inference would be "What was wrong with her car?" Answering this question correctly requires the knowledge that jumper cables are used to charge batteries, batteries are charged when they are dead, and charging the battery can fix a car.

In almost all circumstances, the development of a coherent situation model relies on the reader using prior knowledge to understand the text. Consequently, SERT may not benefit low-knowledge readers according to situation model measures of comprehension. That is, inferences that require prior domain knowledge may be impossible for readers who lack the domain-specific knowledge. In contrast, inferences necessary to understand single propositions in a text are more likely to be text-based, and less dependent on knowledge. Thus, observed benefits of SERT for low-knowledge readers should be more likely to be manifested in text-based measures than in inference questions.

Overview and Hypotheses

The primary purpose of this experiment was to examine the effects of providing self-explanation and reading strategy training (i.e., SERT). The effectiveness of SERT was examined with respect to the participants' comprehension and the quality of their self-explanations. During the training phase of the experiment, half of the participants received SERT and half read the texts aloud. This was followed by comprehension questions. SERT began with a brief instruction, including definitions and examples of self-explanation and reading strategies. After this brief instruction, the student read aloud and self-explained four science texts. After reading each text, the student answered questions about the text and watched a video of another student in the process of self-explaining the text. At particular points in the video, the student was asked to identify the strategies used by the student.

The control condition was designed to include as many elements of the training condition as possible, without providing self-explanation and reading strategy instruction. Hence, students in the control condition read aloud the same texts as did those in the training conditions and answered the same questions. In this way, the training phase afforded the comparison of reading aloud and self-explaining to simply reading aloud.

Following training, the effects of SERT were examined by having all of the participants self-explain a text aloud and answer comprehension questions about the text. If the reading strategy training is effective, then SERT participants should produce better self-explanations and show better understanding of the text. To examine how these effects depended on individual differences, participants were assessed in terms of reading skill, working memory capacity, and prior domain knowledge. Based on theories of comprehension (e.g., Kintsch, 1988), it was hypothesized that prior knowledge would have the largest effects on comprehension and self-explanation performance. It was further predicted that low-knowledge readers would show the largest benefits from SERT. However, the effects of SERT for low-knowledge readers was expected to be most dramatic for text-based comprehension questions, which rely less on prior knowledge and more on understanding the content within individual sentences of the text.

METHOD

Participants

The participants were 42 undergraduate psychology and biology students who participated for course credit. Half of the participants were randomly assigned to the SERT condition and the other half to the control condition.

Tasks and Materials

Text presentation. Participants read a total of five texts. Four texts were read during training; one was a posttraining target text. The texts were presented one sentence at a time on a computer monitor. Participants pressed the space bar to present each successive sentence, with preceding sentences remaining on the screen. Paragraphs were presented in running format such that each sentence was presented in the location it would occur in natural text. All but the fifth text (i.e., Cell Mitosis) fit onto a single screen. When the screen was filled for the fifth text, an asterisk indicated to the participant that the screen would be cleared and that the next paragraph would continue at the top of the screen.

TABLE 2
Characteristics of the Four Texts Presented During Training and the Posttraining Text

	Words	*Paragraphs*	*Sentences*	*Flesch Reading Ease*	*Flesch–Kincaid Grade Level*
Acid rain	202	3	13	59.6	8.7
Carbon cycle	279	3	15	57.4	9.7
Forest fires	363	3	20	57.5	9.7
Petroleum	360	4	25	46.4	10.3
Cell mitosis	650	12	48	52.0	9.3

Texts. The texts were modified from texts appearing in middle-school biology textbooks. The training texts were presented in a fixed order that increased in length and apparent difficulty across trials. Table 2 shows the characteristics of the texts in terms of readability indexes. The topics of the training texts were (a) acid rain and it effects on the environment, (b) the role of plants in the carbon cycle, (c) the ecological importance of forest fires, and (d) the process of separating petroleum into useful substances (i.e., fractional distillation). The texts were chosen such that no information or topics overlapped between them or with the fifth, target text concerning cell mitosis. The cell mitosis text was the low-cohesion version of the texts used in McNamara (2001).

Comprehension and prior knowledge questions. After reading each of the five texts, participants answered written comprehension questions. The number of questions asked increased as a function of the length of the text (3, 4, 6, and 6 questions respectively). All of the questions were open-ended questions requiring the integration of separate ideas from the text. For example, one question for the second text concerning plants and the carbon cycle was, "If a plant was unable to form glucose, what would happen to the plant and its cell walls?" The answer was, "Without glucose, the plant would lack cellulose, which provides the plant's structural support. The plant would be weakened." This answer could be obtained from the following portion of the text: "Plants also use glucose to form another carbohydrate called cellulose. Cellulose molecules form a tough, rigid structure that makes up the cell walls of plants. Cellulose provides a structural support for the plants."

The comprehension test for the target text concerning cell mitosis comprised two types of comprehension questions: text-based and bridging inference questions. To answer text-based questions, the participant must only remember one particular sentence or idea from the text. However, for bridging inference questions, the participant must remember separate portions of the text and understand the relations between those ideas.

The participants also answered questions designed to assess their prior knowledge related to the cell mitosis text. These questions were related to cells and cell division, but the information to answer the questions was not presented in the text (e.g., "Name three reasons for, or purposes of, cell reproduction").

Training video. After reading the text and answering questions about it, the participants in the training condition watched a video of a student in the process of self-explaining the same text. The participant's task was to identify strategies used by the student in the video (this task is explained in greater detail in the Training Procedure section).

The training video for each text was created in a number of steps. First, graduate students self-explain each text aloud. The purpose was to collect skilled, but natural, self-explanations for each text. These self-explanations were then compiled and a self-explanation script was created for each text. Two volunteer undergraduate students were then filmed as they acted out these scripts as if they were in the process of self-explaining the text. Each volunteer student acted out two of the text scripts. These films were copyedited to create a video for each text of a student self-explaining aloud.

Reading skill. Reading comprehension was assessed using Forms G and H of the Nelson Denny Adult Reading Comprehension Test (J. I. Brown, Fishco, & Hanna, 1993). This measure included a total of seven passages and 38 questions. Participants' performance was scored as the number of correct answers. The participants read a passage and then answered comprehension questions concerning that passage. The reader could refer back to the passage to answer the questions. The participants were administered the standardized instructions and given the standard time of 20 min to complete the test. The test was administered before and after training, with the order of test form counterbalanced across conditions.

Reading span. The reading span test was developed by Engle and his colleagues (e.g., Engle, Cantor, & Carullo, 1992; La Pointe & Engle, 1990). The test was administered before and after training, with the order of test form counterbalanced across conditions. This test requires the participant to read two to six sentences, each followed by an unrelated word. After the sentences are presented, the participant is to recall the unrelated words. Sentence comprehension questions are randomly asked for one third of the sentences. Reading span was computed as terms the number of words recalled in the correct order on trials for which all of the words were recalled (i.e., perfect trials).

Participants were presented with three practice trials of set size two, followed by 15 experimental trials that included 3 trials of each set size. The order of set size presentation, or the number of sentences and target words presented on each trial for reading span tasks is often increased incrementally from two to six sentences (three trials of set size 2, three trials of set size 3, etc.). However, this procedure can inhibit performance on the higher set sizes due to proactive interference. Thus, a Latin-square ordering of set size was used here to reduce effects of proactive interference. The order of set size was as follows: 2, 3, 4, 3, 4, 2, 4, 2, 3.

Sentence order was randomly assigned by the computer for each participant. The experimenter controlled sentence presentation rate; as soon as the target word was read aloud by the participant, the next sentence was presented to be read aloud by the participant. One comprehension question was asked by the experimenter for each of the 15 trials immediately after word recall. The sentence within a trial for which a question was asked was randomly predetermined.

General Procedure

The experiment required a total of five experimental one-on-one sessions. The list of the tasks completed each session is provided in Table 3. In the first and fifth session, participants were administered counterbalanced forms of the Nelson Denny Reading Comprehension Test (J. I. Brown et al., 1993) and a reading span test. During the second and third training sessions, participants read the four training texts (each concerning a different topic in science) and answered three to six open-ended questions about each. SERT participants read aloud and self-explained each text, whereas control participants read aloud each text. After answering the questions, SERT participants also watched a video of another student self-explaining each text and identified strategies used by the student in the video. Each of the SERT sessions required approximately 75 to 120 min to complete. The control sessions each required between 30 to 50 min to complete.

In the fourth posttraining session, all of the participants self-explained a low-cohesion text about cell mitosis (see McNamara, 2001). The participants self-explained and read aloud the text, but were not provided with prompts or encouragement during the self-explanation process. The participants then answered open-ended comprehension questions and prior-knowledge questions.

Training Procedures

SERT condition. The participants in the SERT condition received the following four phases of instruction. Each participant was given testing and training in individual one-on-one sessions.

1. Introduction to self-explanation: Self-explanation was described as reading text aloud and explaining what the text means. The participant was provided with an example self-explanation to a sentence, after which the participant was asked to self-explain a sentence. The experimenter prompted the student to provide more explanation when necessary.

TABLE 3
Outline of Tasks Completed During Each Session for the Experimental and Control Conditions

	Experimental (SERT)	*Control*
1. Aptitude pretests	Nelson Denny	Nelson Denny
	Reading span	Reading span
2. Training	Introduction to self-explanation	Brief introduction
	Introduction to reading strategies	
	Self-explain Text 1 (acid rain)	Read aloud Text 1 (acid rain)
	Answer Text 1 comprehension questions	Answer Text 1 comprehension questions
	Watch self-explanation video of Text 2	
	Self-explain Text 2 (carbon cycle)	Read aloud Text 2 (carbon cycle)
	Answer Text 2 comprehension questions	Answer Text 2 comprehension questions
	Watch self-explanation video of Text 2	
3. Training	Self-explain Text 3 (forest fires)	Read aloud Text 3 (forest fires)
	Answer Text 3 comprehension questions	Answer Text 3 comprehension questions
	Watch self-explanation video of Text 3	
	Self-explain Text 4 (petroleum)	Read aloud Text 4 (petroleum)
	Answer Text 4 comprehension questions	Answer Text 4 comprehension questions
	Watch self-explanation video of Text 4	
4. Posttraining assessment		Introduction to self-explanation
	Self-explain Text 5 (cell mitosis)	Self-explain Text 5 (cell mitosis)
	Answer Text 5 comprehension questions	Answer Text 5 comprehension questions
	Answer cell prior knowledge questions	Answer cell prior knowledge questions
5. Aptitude posttests	Nelson Denny	Nelson Denny
	Reading span	Reading span

Note. SERT = Self-Explanation Reading Training.

2. Introduction to reading strategies: Six reading strategies were presented to the participants as means for improving the self-explanation process. For each strategy, a description of the strategy and examples of self-explanations using the strategies were provided. The following strategies were presented: (a) comprehension monitoring—being aware of understanding; (b) paraphrasing—restating the text in different words; (c) elaboration—using prior knowledge or experiences to understand the sentence (i.e., domain-specific knowledge based inferences); (d)

logic or common sense—using logic to understand the text (i.e., domain-general knowledge based inferences); (e) predictions—predicting what the text will say next; and (f) bridging—making reference to an idea presented in a previous sentence in the text to better understand relations between sentences. Comprehension monitoring was presented as a strategy that should be used all of the time. Paraphrasing was presented as a basis or jumpstart for self-explanation, but not as a means for self-explaining text. The remaining strategies were various forms of inferences (i.e., domain specific, domain-general, predictive, and bridging) that were expected to enhance comprehension and explanation.

3. Practice using and identifying the self-explanation strategies. The participants in the training condition then read and self-explained aloud the four science texts, two texts during each of the two training sessions. During this training phase, the experimenter prompted the subject to provide additional explanation for the text whenever necessary.

After answering questions about each text, the participants in the training condition watched a video of another student self-explaining the text. The participant's task was to identify strategies used by the student in the video. The participant was provided with a transcript of the video to follow along with the film and a list of the strategies. The experimenter stopped the video at predetermined stop points for the participant to identify and discuss the strategy being used by the student in the video. These self-explanations generally included a combination of strategies. Depending on the length of the text, there were between four and six stop points, with a total of 20 stop points.

Control condition. Control participants read the same four texts aloud and answered questions about the text, but did not self-explain the texts and did not watch the video. After the training phase, all of the participants self-explained a text about cell mitosis. For this phase, control participants were given the same instructions concerning self-explanation that were provided in Phase I for the training group. However, control participants were not provided with a description of the strategies (Phase 2).

RESULTS AND DISCUSSION

The first of the following sections describes the results during training, comparing the effects of self-explanation to reading aloud on comprehension of the four training texts. The second section describes the posttraining effects of SERT and prior domain knowledge on comprehension of a science text about cell mitosis, which participants in both conditions self-explained. The final section examines participants' strategy use on the basis of a subset of the verbal protocols collected during the final session. For all analyses, the alpha level was set at .05.

TABLE 4
Participants Performance as Function of Training Condition

	SERT	*Control*	*Difference*
Skill and knowledge			
Nelson Denny pretest	28.33 (1.417)	26.71 (1.267)	1.620
Nelson Denny posttest	29.57 (1.344)	29.05 (1.114)	0.520
Reading Span pretest	11.43 (1.558)	12.42 (1.274)	–0.990
Reading Span posttest	11.19 (1.453)	13.48 (1.702)	–2.290
Prior Knowledge (Cells)	0.256 (0.037)	0.281 (0.046)	–0.025
Training texts			
Acid rain	0.766 (0.046)	0.683 (0.047)	0.083
Carbon cycle	0.396 (0.050)	0.205 (0.041)	0.191
Forest fires	0.614 (0.037)	0.593 (0.035)	0.021
Petroleum	0.470 (0.043)	0.385 (0.038)	0.085
Average training	0.561 (0.032)	0.467 (0.029)	0.094
Target text			
Text-based questions	0.565 (0.044)	0.448 (0.049)	0.117
Bridging questions	0.314 (0.044)	0.260 (0.061)	0.054

Note. Nelson Denny performance is in terms of the number of questions correctly answered. Reading Span performance is in terms of the total number of words correctly recalled including only perfect trials. Text comprehension performance is proportion of correctly answered questions. Standard errors are presented in parentheses.

As shown in Table 4, three individual difference measures were collected (Nelson Denny reading skill, reading span, and cell prior knowledge). Reading skill and reading span were examined before and after training to examine possible changes as a function of session and condition. Neither of these two measures varied as a function of session or training. Thus, the pretest and posttest assessments were averaged together to form a single, more robust measure of reading skill and reading span. Reading span was not correlated to reading skill or prior knowledge. Prior knowledge and reading skill were moderately correlated ($r = 0.325$, $p = .035$).

Comprehension and prior knowledge questions were scored by two raters blind to condition. There was an average of 88% agreement between the two sets of scores. Discrepancies were decided via discussion with a third rater, yielding a final set of scores, which were used for these analyses. Reliability of the protocol analysis to code self-explanations was established at 90% agreement between two coders for 20% of the protocols. One coder scored the remaining protocols, which were checked by the second coder.

Training Sessions: Self-Explanation Versus Reading Aloud

During the training sessions of the experiment, participants in the SERT condition read aloud and self-explained the four training texts, whereas those in the control condition read aloud the four texts. This section describes the differences between those two conditions to better understand the effects of self-explanation in comparison to simply reading aloud.

Proportional accuracy for the four training texts is presented in Table 4. A mixed factorial ANOVA was conducted on the proportion of questions answered correctly during training, including the between-subjects variable of condition (self-explain, read aloud) and the within-subjects variable of text. There were reliable effects of condition, $F(1, 40) = 5.46$, and text, $F(3, 38) = 78.7$. These results confirmed that participants who self-explained while they read the text answered more questions correctly ($M = 0.56$) than those who simply read aloud ($M = 0.47$).

Additional analyses were conducted to examine whether individual differences mediated effects during training. Reading span did not; it failed to correlate with comprehension performance during training, and did not interact with any of the variables. However, reading skill, as measured by Nelson Denny (J. I. Brown et al., 1993) performance, reliably correlated with overall comprehension during training ($r = .35$, $p = 0.05$). There was better comprehension by skilled readers (i.e., according to a median-split, $n = 20$, $M = 0.58$) than less-skilled readers ($n = 22$, $M = 0.49$), $F(1, 40) = 4.70$. Interestingly, prior knowledge of cell biology also correlated with overall comprehension performance during training ($r = .44$, $p < .01$). This topic-specific knowledge of cell biology seemed to also reflect knowledge in other domains of science. This correlation reflects the finding that high-knowledge readers (according to a median split) better understood the training texts ($n = 21$, $M = 0.58$) than did low-knowledge readers ($n = 21$, $M = 0.48$), $F(1, 40) = 4.82$. Moreover, when both prior knowledge and reading skill were included as covariates in a multivariate analysis of variance (MANOVA), only prior knowledge emerged as reliable. These results indicate that prior knowledge of a specific domain within science is correlated with knowledge from other science domains. Furthermore, these results confirm the importance of prior domain knowledge for expository text comprehension.

Posttraining Session: Comprehension

To determine the benefits of self-explanation training, participants in both conditions self-explained a fifth text about cell mitosis after the training phase. The effects of SERT and the control condition are first compared in terms of comprehension of the cell mitosis text and then in terms of strategy use.

Comprehension. A central question addressed here was whether individual differences, including reading span, reading skill, and prior domain knowledge, would interact with training effectiveness. Neither reading span nor reading skill showed strong correlations with comprehension performance, and training effectiveness did not depend on those abilities. In contrast, the following analyses confirmed that the effects of training varied as a function of prior knowledge and question type. An analysis of variance (ANOVA) was conducted with the between-subjects variables of condition (SERT, control) and knowledge (high, low) and the within-subjects variable of question type (bridging inference, text-based). There was a significant effect of question type, $F(1, 38) = 54.36$, and prior knowledge, $F(1, 38) = 23.47$, and a marginal effect of condition, $F(1, 38)= 3.67$, $p = .063$. Most importantly, as shown in Figure 1, there was a reliable three-way interaction of question type, condition, and knowledge, $F(1, 38) = 4.17$.

To further explore the three-way interaction, separate analyses—including the between-subjects variables of condition and prior knowledge—were conducted on proportion correct for bridging inference and text-based questions. For bridging inference questions, only prior knowledge affected performance, $F(1, 38) = 20.79$. For text-based questions, there were reliable effects of training condition, $F(1, 39) = 4.20$, and prior knowledge, $F(1,38) = 15.16$. In addition, there was a marginal interaction between condition and prior knowledge, $F(1,38) = 3.99$, $p = .053$. Training had little effect for high-knowledge participants ($F < 1$), but had a substantial effect for low-knowledge participants, $F(1, 19) = 11.07$.

These results confirm the prediction that SERT would show the greatest benefits for low-knowledge readers, but only at the textbase level of comprehension. Comprehension assessed with bridging inference questions relies heavily on prior knowledge. Bridging inference questions tap into comprehension of implicit relations between separate ideas in the text and the inferences necessary to connect these ideas rely primarily on domain-specific prior knowledge. Hence, SERT did not affect performance on bridging-inference questions. In contrast, both knowl-

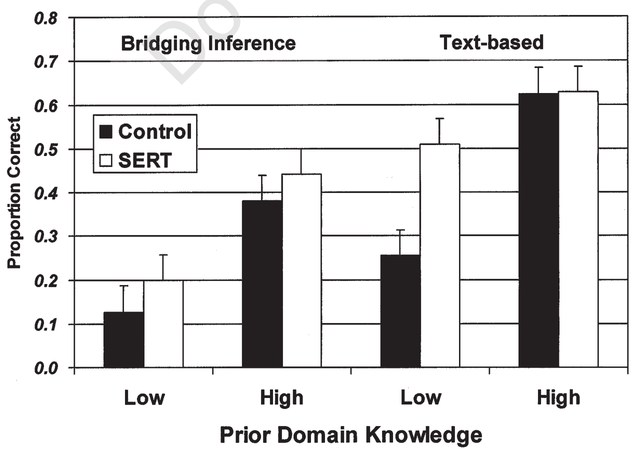

FIGURE 1 Comprehension of the posttraining text about cell mitosis, self-explained by both control and Self-Explanation Reading Training participants as a function of condition, knowledge, and question type. This three-way interaction shows reliable effects of training only for low-knowledge participants' performance on text-based questions (Cohen's D = 1.92).

edge and condition affected performance on the text-based questions, for which the answers rely on single sentences within the text. These results show that self-explanation in combination with reading strategy instruction helps the low-knowledge reader to use what they do know (e.g., common sense, logic, prior text information) to make sense of the text.

Posttraining Session: Self-Explanation Strategies

Protocol analysis scoring. The verbal protocols during self-explanation of the fifth text about cell mitosis were scored for a random selection of 26 of the 42 participants (i.e., 13 control, 13 SERT). Each utterance was divided into idea units and each idea unit was categorized as one of the following strategies:

1. Rereading the sentence.
2. Correctly paraphrasing the sentence.
3. Incorrectly paraphrasing the sentence.
4. Correctly bridging to previous text.
5. Incorrectly bridging to previous text.
6. Correctly elaborating the text with prior knowledge that is domain-relevant.
7. Incorrectly elaborating the text with prior knowledge that is domain-relevant.
8. Correctly using logic or common sense to elaborate the text (using prior knowledge that is domain-irrelevant).
9. Incorrectly using logic or common sense to elaborate the text.
10. Making predictions about what the text will say next.
11. Comprehension monitoring.
12. Self-explanation score (including elaborations, logic, predictions, and comprehension monitoring).

The average rate of strategies (i.e., frequency of the strategy divided by the number of text sentences) within each category as a function of condition and knowledge is presented in Table 5. A MANOVA was conducted on the rate of strategy use within each category, including the between-subjects variables of condition and knowledge. Correlations between comprehension scores and the types of strategies are presented in Table 6.

Table 7 presents the strategy co-occurrence rates in terms of the number of self-explanation attempts within which two strategies co-occurred, and the results of the chi-square tests for independence of the strategy pairs. Chi-square tests of independence for all pairs of strategies were conducted. For each pair of strategies, a 2×2 table can be constructed depicting the frequency that both strategies are present in a self-explanation, that both strategies are absent, or that one strategy is present and the

TABLE 5
The Average Rate of Strategies (i.e., Frequency Divided by the Number of Sentences) During Self-Explanation as a Function of Condition and Knowledge Levels

	SERT		*Control*	
	High K[a]	*Low K*[b]	*High K*[a]	*Low K*[b]
Rereading	3.4 (2.0)	8.3 (6.8)	19.7 (12.0)	14.7 (5.2)
Correct paraphrases	71.7 (4.4)	77.0 (8.1)	75.1 (10.7)	80.0 (7.0)
Incorrect paraphrases	12.0 (3.2)	11.0 (2.9)	10.3 (2.6)	18.3 (1.0)
Correct bridging inferences	36.3 (6.7)	30.3 (4.7)	48.0 (18.7)	35.7 (6.0)
Incorrect bridging inferences	12.9 (5.3)	10.0 (3.0)	8.0 (5.1)	11.7 (3.4)
Correct elaborations	16.3 (2.1)	6.7 (2.4)	17.4 (6.4)	2.7 (0.8)
Incorrect elaborations	2.0 (0.4)	1.7 (0.8)	2.0 (1.2)	0.3 (0.3)
Correctly using logic	30.9 (5.7)	15.3 (4.2)	24.9 (6.6)	2.0 (0.5)
Incorrectly using logic	9.1 (2.8)	5.7 (1.9)	3.7 (1.5)	1.3 (1.3)
Making predictions	3.1 (1.1)	3.3 (1.0)	0.3 (0.3)	0.3 (0.3)
Comprehension monitoring	15.4 (5.0)	9.7 (4.2)	6.3 (2.4)	3.0 (1.9)
Self-explanation score[c]	65.7 (11.2)	35.0 (9.0)	48.9 (11.8)	8.0 (2.6)

Note. SERT = Self-Explanation Reading Training. Parentheses indicate standard deviations.
[a]$n = 7$. [b]$n = 6$. [c]Correct elaborations, correctly using logic, making predictions, and comprehension monitoring.

TABLE 6
Correlations Between Strategies and Performance on Text-Based and Bridging Inference Comprehension Questions, Nelson Denny (i.e., Reading Skill), and Prior Knowledge

	Text-Based	*Bridging*	*Nelson Denny*	*Prior Knowledge*
Rereading	0.25	0.08	–0.31	0.06
Correct paraphrases	0.18	0.06	–0.14	–0.12
Incorrect paraphrases	–0.40*	–0.46*	–0.51**	–0.48*
Correct bridging inferences	0.47*	0.41*	–0.03	0.35
Incorrect bridging inferences	0.11	0.07	–0.52**	–0.13
Correct elaborations	0.57**	0.52**	0.21	0.77**
Incorrect elaborations	0.42*	0.21	0.04	0.28
Correctly using logic	0.73**	0.74**	0.24	0.69**
Incorrectly using logic	0.32	0.24	–0.37	0.17
Making predictions	0.00	–0.06	0.20	–0.08
Comprehension monitoring	0.29	0.21	0.13	0.24
Self-explanation score[a]	0.67**	0.63**	0.25	0.70**

Note. $N = 26$.
[a]Correct elaborations, correctly using logic, making predictions, and comprehension monitoring.
*Correlation is significant at the 0.05 level. **Correlation is significant at the 0.01 level.

TABLE 7
Strategy Occurrence and Co-occurrence Within Self-Explanations

Strategy	*Rereading*	*Paraphrases*	*Bridging Inferences*	*Elaborations*	*Using Logic*	*Predictions*	*Comprehension Monitoring*
Rereading	129 (10%)	$\chi^2 = 9.8$ 114[a] (100)	$\chi^2 = 8.0$ 66[a] (51)	$\chi^2 = 0$ 15 (15)	$\chi^2 = 3.5$ 38 (30)	$\chi^2 = 0.8$ 1 (2)	$\chi^2 = 0.2$ 12 (11)
Paraphrases	278	1,007 (77%)	$\chi^2 = 20.1$ 432[a] (399)	$\chi^2 = 4.3$ 107[b] (117)	$\chi^2 = 30.2$ 196[a] (230)	$\chi^2 = 5.9$ 13[b] (18)	$\chi^2 = 18.7$ 65[a] (82)
Bridging inferences	722	210	515 (40%)	$\chi^2 = 5.1$ 47[b] (60)	$\chi^2 = 3.1$ 131 (118)	$\chi^2 = 4.8$ 4[b] (9)	$\chi^2 = 6.5$ 30[b] (42)
Elaborations	1,035	249	681	151 (12%)	$\chi^2 = 3.7$ 44 (35)	$\chi^2 = 2.3$ 5 (3)	$\chi^2 = 1.3$ 16 (12)
Using logic	911	191	618	895	298 (23%)	$\chi^2 = 1.3$ 3 (5)	$\chi^2 = 1.7$ 30 (26)
Predictions	1,149	283	766	1,131	982	23 (2%)	$\chi^2 = 5.7$ 5[b] (2)
Comprehension monitoring	1,076	251	708	1,058	925	1,175	107 (8%)

Note. The diagonal portion presents the strategies' base rate as the number of self-explanations containing one or more instances of the strategy and, in parentheses, the overall percentage of the strategies used out of all 1,300 responses. The bottom portion of the matrix represents the number of self-explanations in which neither strategy occurs. The top portion of the matrix represents the number of co-occurrences of the strategy pairs. In each of these cells, the chi-square value for the test of independence (with $df = 1$), which is reliable if it exceeds 3.84. The number preceding the parentheses is the observed co-occurrences of the two strategies and the number in parentheses is the expected co-occurrence under the independence assumption. When the observed value is significantly higher or lower than the expected value, the occurrence of the two strategies is not stochastically independent.

[a]Chi-square test for independence was reliable at $p < .01$. [b]Chi-square test was reliable at $p < .05$.

other is not. Each of these twenty-one 2 × 2 tables is derivable from the data provided in Table 7. Strategies are independent when the probability of their co-occurring is equal to the probability of one being present in a self-explanation and the other not present, and when the latter probability is equal to both not being present. The strategies are dependent if either of these contingencies is not met.

Referring to Table 7, the top half of the matrix presents the co-occurrence rates for the strategy pairs. The number preceding the parentheses is the observed co-occurrences of the two strategies and the number in parentheses is the expected co-occurrence under the chi-square assumption of independence. When the observed value is significantly higher or lower than the expected value, the occurrence of the two strategies is not stochastically independent. Table 7 shows 11 pairs of strategies that were not stochastically independent. Of these, 4 pairs were more likely to occur together than by chance (reread–paraphrase, reread–bridging, bridging–paraphrase, and prediction–comprehension monitoring). The remaining 7 pairs were less likely to occur together than by chance (paraphrase–elaboration, paraphrase–logic, paraphrase–prediction, paraphrase–comprehension monitoring, bridging–elaboration, bridging–prediction, bridging–comprehension monitoring).

The following sections discuss the results from Tables 5, 6, and 7 in relation to each of the strategies.

Rereading. Rereading the sentence is a low-level strategy that does little by itself to enhance comprehension. This is evidenced here in the low correlations between rereading and comprehension in Table 6. Rereading was also not reliably correlated with reading skill or prior knowledge. Although it is apparent from Table 5 that rereading decreased as a function of training, this decrease was not reliable, probably because it was relatively infrequent. Indeed, rereading appeared in only 10% of the self-explanations.

As shown in Table 7, rereading was most likely to occur in conjunction with paraphrasing. Specifically, of 129 self-explanations in which rereading occurred, 88% (i.e., $n = 114$) co-occurred with paraphrasing, compared to the expected rate of 100. Rereading may serve as a good starting point for many readers to paraphrase the sentence. Rereading was also associated with bridging. Specifically, 51% of the self-explanations containing rereading also contained bridging. This result also makes sense. Essentially, rereading a sentence may help to retain it in memory to make a bridging inference to a previous sentence.

Paraphrasing. Paraphrasing, like rereading, is a relatively low-level strategy that does little, by itself, to aid comprehension. This is again evidenced by the unreliable correlations with comprehension, as shown in Table 6. In contrast to rereading, paraphrasing was relatively frequent, with an overall probability of 77% (see Table 7). Also unlike rereading, paraphrasing can go awry, and incorrect paraphrasing was negatively correlated with both text-based and bridging-inference questions, as well as reading skill and prior knowledge. Thus, incorrectly paraphrasing sentences could arise from either low reading skills or a lack of knowledge, and it affected both levels of comprehension.

Nevertheless, SERT had a positive effect on low-knowledge participants in terms of reducing the number of incorrect paraphrases. Table 5 shows that low-knowledge SERT participants were less likely to incorrectly paraphrase the text than were low-knowledge control participants, $F(1, 10) = 5.90$. Hence, learning to more actively process text reduces miscomprehensions, despite knowledge deficits.

Paraphrasing was common and dispersed across strategies. Indeed, Table 7 shows that all of the chi-square tests were reliable. As previously mentioned, paraphrasing and rereading were reliably dependent, indicating that rereading tended to occur along with paraphrasing. In the same fashion, bridging inferences were likely to occur with paraphrasing (as discussed more fully in the following section). However, the co-occurrence of paraphrasing with the remaining strategies was found to be below the expected rate of co-occurrence (as indicated in parentheses in the top half of the Table 7 matrix). These results indicate that the strategies that go beyond the text-based information, including elaboration, logic, prediction, and comprehension monitoring, tended to not co-occur with paraphrasing.

Bridging. Participants tended to make a substantial number of bridging statements, only surpassed by paraphrases (see Table 7). Interestingly, training had little effect on participants' use of bridging, regardless of prior knowledge or reading skill. As expected, however, bridging inferences positively correlated with comprehension (see Tables 5 and 6). This latter result concurs with previous literature, showing the importance of bridging inferences for successful comprehension. Along those lines, reading skill negatively correlated with incorrect bridging inferences. However, correct bridging inferences did not correlate with reading skill or prior knowledge. This result is counterintuitive in the sense that bridging inferences rely to some extent on prior knowledge, particularly when an inference links more distant ideas in the text. Therefore, a finer grained analysis was conducted that distinguished between near bridges (between successive sentences) and distant bridges. This analysis indicated that prior knowledge correlated positively with distant bridges ($r = .446$, $p < .05$) but not near bridges ($r = .183$, $p > .3$). Likewise, the correlation between bridging inferences and comprehension was carried by the distant bridges. There was a positive correlation between distant bridges and both text-based questions ($r = .476$, $p < .05$) and bridging inference questions ($r = .512$, $p < .01$), compared to unreliable correlations between near bridges and comprehension measures. Nonetheless, neither reading skill nor training influenced the frequency of either distant or near bridges. These results indicate that understanding distant, implicit relations between ideas in text relies on prior knowledge, and that SERT did little to relieve low-knowledge readers of this particular handicap.

As discussed previously, bridging inferences were likely to occur along with rereading and paraphrasing. Indeed, 84% of the self-explanations containing bridges also contained paraphrases. By definition, bridging necessarily requires restating at least some of the current sentence; hence, these results are hardly surprising. Both rereading and paraphrasing can serve the functional purpose of relieving memory bottlenecks. Moreover, both strategies seem to be essential to bridging in the sense that comprehension of the current sentence is necessary before linking it to a previous idea in the text.

The chi-square tests pairing bridging inferences with elaborations, predictions, and comprehension monitoring were also reliable; however, the rates of co-occurrence were below the base rates for the strategies. Thus, these results indicate that the strategies were independent and less likely to co-occur than by chance.

Bridging inferences seemed likely to occur in conjunction with logic (i.e., 25% of all bridging inferences occurred with logic); however, this co-occurrence was not reliable according to the chi-square test for independence. Thus, although they were seemingly likely to occur together, they were just as likely to occur separately. Their stochastic independence indicates that the use of logic and common sense does not rely on understanding more distant relations in the text, and vice versa; understanding relations does not depend on the use of logic.

Elaboration. There is a trend showing an increase in elaborations for low-knowledge participants as a function of training; however, this 4% increase was not reliable, $F(1, 10) = 2.47$. As one might expect, elaborations depended highly on participants' prior knowledge (see Tables 5 and 6; low $K = 4.7$, high $K = 16.9$), $F(1, 22) = 10.10$. Given that elaborations are defined as the use of domain-specific prior knowledge, this result is hardly surprising.

Elaborations also correlated with comprehension for both types of questions. Interestingly, even incorrect elaborations positively correlated with performance on text-based questions. This result should be interpreted with caution, however, given the low rate of incorrect elaborations (i.e., 1.5%). Nonetheless, the correlations of elaborations with both comprehension and prior knowledge further support the assumption that making connections to prior knowledge while reading is key to comprehending and learning from expository texts.

The chi-square co-occurrence tests for elaborations were reliable for paraphrasing and bridging inferences (see Table 7). However, as discussed earlier, these dependencies indicated that the co-occurrence rates were below the base rate of co-occurrence for the strategies. Thus, elaborations are less likely to co-occur with paraphrasing and bridging inferences than alone or with other strategies. These results indicate that elaborations, which go beyond the text, will tend to not occur with text-based strategies, such as paraphrasing and bridging inferences.

Logic and common sense. The use of logic and common sense is essentially the use of domain general knowledge. It goes beyond the sentence, but the information necessary is not contained in either previous text or domain relevant information. This strategy was highly correlated with comprehension. Indeed, although elaborations and bridging inferences were also positively correlated with comprehension scores, regression analyses entering the three strategies together indicated that using logic and common sense was the only reliable predictor of comprehension scores for both text-based questions, $t(22) = 2.71$, and bridging inference questions, $t(22) = 3.32$.

A main effect of knowledge (see Tables 5 and 6) further indicated that high-knowledge participants were more likely to correctly use logic, $F(1, 22) = 14.03$. There was also a marginal effect of training on correct logic use, $F(1, 22) = 3.56$, $p = .07$, and a reliable effect on incorrect logic use, $F(1, 22) = 5.77$, indicating that SERT participants generated slightly more correct, and significantly more incorrect explanations using logic than control participants. The effect of condition on correct logic use was carried primarily by the low-knowledge participants. That is, the low-knowledge participants in the SERT condition were significantly more likely than those in the Control condition to correctly use logic to explain the text, $F(1, 10) = 10.15$. This result is important because it indicates that the comprehension advantages for low-knowledge participants who received training were at least partially attributable to their increased use of logic, or domain-general knowledge. This increased use of logic, combined with the observed improvement in paraphrasing, seem to be the keys to their comprehension advantages after training. Notably, the chi-square test for independence for logic and paraphrasing indicated that the use of logic is not stochastically independent of paraphrasing the sentence, but that they tend to not co-occur. Thus, the participants tended to paraphrase or use logic, but not both.

Predictions. Although predictions were highly infrequent (1.8%), there was a reliable effect of condition on the use of predictions, $F(1, 24) = 14.70$. However, the use of predictions was not correlated with comprehension. This latter result, and their lack of frequency—particularly for the control participants—indicates that predictive inferences are not germane to science text comprehension, at least for the text used in this experiment. This conclusion is bolstered by the lack of impact of SERT on the rate of predictions.

Looking at Table 7, the chi-square tests for predictions yielded three reliable results. These results indicated that predictions were less likely than chance to occur with paraphrases and bridging inferences. Hence, if the reader is thinking forward of the text (i.e., using prediction), it is unlikely that the reader is at the same time thinking backward in a text (i.e., using bridging). On the other hand, the chi-square result for predictions and comprehension monitoring indicates that the two strategies were reliably dependent. The co-occurrence rate of these strategies is quite low—they co-occurred in only five self-explanations. Yet, this rate is higher than the expected rate of two. It is difficult to place a lot of weight on this result, given the low frequencies of occurrence.

Comprehension monitoring. There was a reliable effect of condition on the rate of comprehension monitoring statements, $F(1, 22) = 4.62$. To examine whether the effect of condition was restricted to a certain type of comprehension monitoring statement, they were further categorized as (a) queries (e.g., “I wonder what that means?”), (b) confirmations of understanding (e.g., “I understand what that means”), or (c) confirmations of a comprehension problem (e.g., “I don’t understand what that means”). Of those, the effect of condition was reliable only for confirmations of comprehension problems, $F(1, 22) = 4.52$ (control = 2.60; SERT = 6.62). This result is encouraging, given that self-explanation is most appropriately used when the reader encounters a comprehension problem. Although comprehension monitoring does not directly impact comprehension, it allows the reader to recognize comprehension problems, which can be repaired using other reading strategies.

The use of comprehension monitoring, as one might expect, was distributed relatively evenly across the strategies. Comprehension monitoring is inherent to self-explanation, be it implicit or explicit. Table 7 shows that the three co-occurrence tests were reliable with paraphrases, bridging inferences, and predictions. As discussed previously, though the rate of co-occurrence was low, comprehension monitoring and predictions were indeed likely to co-occur. In contrast, comprehension monitoring was not likely to co-occur with paraphrasing and bridging. These results collectively indicate that comprehension monitoring is relatively independent from the other strategies.

Self-explanation score. A self-explanation score was calculated based on the sum of (a) elaborations, (b) using logic, (c) making predictions, and (d) comprehension monitoring. This score was calculated to examine the combined effects on comprehension for strategies that go beyond the text, as opposed to paraphrasing and bridging inferences, which rely directly on the text. An ANOVA was conducted including the between-subjects factors of condition and knowledge. There was a main effect of condition, $F(1, 22) = 4.97$, reflecting higher scores by trained participants than control participants. There was an effect of knowledge, $F(1, 22) = 13.22$, reflecting higher scores for high-knowledge than low-knowledge participants. Although the interaction was not reliable, $F < 1$, it is notable that the effect of condition was reliable for low-knowledge participants, $F(1, 10) = 8.32$, but not for high-knowledge participants, $F(1, 12) = 1.07$.

A regression analysis indicated that self-explanation scores predicted performance on both the text-based questions ($R^2 = .45$), $F(1, 24) = 19.46$, and the bridging inference questions ($R^2 = .39$), $F(1, 24) = 15.55$. These results reflect better performance on comprehension questions by participants with high self-explanation scores (text-based = 0.68; bridging = 0.47) than participants with low self-explanation scores (text-based = 0.41; bridging = 0.21), $F(1, 24) = 12.68$.

CONCLUSIONS

This experiment examined the effectiveness of self-explanation in two ways. First, comprehension during the training phases was examined to compare self-explanation to reading aloud. Second, after the training phase, all of the participants self-explained a difficult text about cell mitosis. The performance of SERT participants who had received SERT-explanation and reading strategy instruction was compared to the performance of control participants who had read aloud the texts during the training phase. Previous studies have examined the benefits of self-explanation to other reading conditions. However, this study uniquely examined the effects of prior reading strategy training on the effectiveness and quality of self-explanation. In addition, participants' prior knowledge of concepts related to cells, reading skill, and reading span were measured to examine whether knowledge or skills mitigated the effects of self-explanation or self-explanation training.

As expected, self-explanation enhanced comprehension during training in comparison to reading aloud. Prior knowledge was also related to comprehension scores during training, despite the fact that the prior knowledge test was designed to assess knowledge specific to cellular biology and not general science. As one might expect, this result indicates that prior knowledge of a specific domain within science is related to knowledge from other science domains. This result, combined with the absence of strong correlations between the reading skill measures and comprehension scores, confirms the importance of prior knowledge for expository text comprehension.

The principle question addressed in this study was whether knowledge deficits might be overcome with reading strategy training. A three-way interaction confirmed the effectiveness of reading strategy training for some participants. Although high-knowledge participants did not benefit from training, low-knowledge participants' accuracy on text-based questions doubled as a function of reading strategy training. As expected, low-knowledge participants who were asked to self-explain the texts without having received SERT understood little from the texts. In contrast, those who received training were able to build a solid understanding of the text, at least at the textbase level of comprehension. As predicted, SERT training provided readers who would normally flounder when confronted with such a demanding text with the means to successfully construct a meaningful explanation and representation of its content. Most importantly, SERT afforded low-knowledge participants the ability to use paraphrasing and general knowledge (i.e., logic and common sense) to form a coherent textbase representation of the text.

Protocol analyses confirmed that low-knowledge SERT participants were less likely to incorrectly paraphrase and more likely to use logic and common sense. The reduced number of incorrect paraphrases indicates that the active processing induced by SERT reduces miscomprehension, regardless of the reader's level of prior knowledge. The increased use of logic and common sense indicates that the readers actively processed the text using whatever knowledge they could access to make sense of it. This active processing was particularly beneficial to low-knowledge readers' textbase level of comprehension. However, logic and common sense have their limitations. Without sufficient knowledge, readers cannot understand distant relations in text that require knowledge-based inferences. The absence of training effects on bridging inference questions and the low number of distant bridging inferences by low-knowledge readers in both conditions supports the conclusion that these readers were unable to understand distant relations in the text. Although local inferences were less influenced by prior knowledge, inferences that were more distant or global depended heavily on prior knowledge (rather than reading span, reading skill, or training condition). There are some gaps in difficult text that can only be filled by domain specific information. Hence, low-knowledge readers' comprehension gains from SERT training occurred only for the text-based questions. These questions tap information that can be gleaned directly from the text, if it is processed actively and strategically.

SERT was not expected to yield significant effects on comprehension for high-knowledge readers, because the knowledge activation encouraged with SERT can be induced in other ways for these readers. Specifically, the low-cohesion, cell mitosis text stimulated active processing, and the high-knowledge readers possessed the necessary knowledge to successfully explain the text without being provided strategy training to do so (see e.g., McNamara, 2001; McNamara & Kintsch, 1996; McNamara et al., 1996). This conclusion is supported by the greater number of knowledge-based elaborations made by high-knowledge than by low-knowledge participants, as well as the positive effect of elaborations on comprehension. The knowledge use promoted by self-explanation occurs automatically for the high-knowledge reader, particularly given a challenging text. In contrast, the low-knowledge reader flounders when faced with such a text. The lack of necessary knowledge to generate the inferences required by low-cohesion text can stymie the low-knowledge reader. Unfortunately, readers who have been faced repeatedly with such situations may finally concede defeat and approach difficult texts with only half-hearted attempts at comprehension. In essence, learned helplessness surrenders the reader to minimalist processing. Self-explanation training provides the reader with effective tools to combat difficult text, with success. SERT teaches the reader to use what knowledge is available when domain specific knowledge is lacking.

Knowledge use, or going beyond the text, was not likely to co-occur within the same explanation as the more text-based strategies. Specifically, the co-occurrence analyses indicated that the text-based strategies, such as rereading, paraphrasing, and bridging, tended to co-occur. These text-based strategies tended to not co-occur with strategies that led the reader away from the text, such as elaborations, using logic, making predictions, and comprehension monitoring. Likewise, if a reader is thinking forward of the text (i.e., using prediction), it is unlikely that the reader is at the same time thinking backward in a text (i.e., using bridging). Thus, the participants tended to either focus on the text or focus away from the text, but not both.

Going beyond the text by making connections to prior knowledge or distant ideas in the text is essential to deep comprehension of text. The self-explanation score was reflective of that process. The self-explanation score was created to reflect the use of *knowledge building* as proposed by Coté, Goldman, and Saul (1998). Knowledge-builders tend to explain how text sentences are related to what they know about the world and to the overall theme of the text. Doing so requires using multiple reading strategies, such as those emphasized in SERT. The self-explanation score indicated that both training condition and knowledge enhanced self-explanations.

The self-explanation score included predictions because they are a type of inference that goes beyond the text. Although training reliably increased the number of predictions, this increase did not impact comprehension. This latter result may fall from the overall low rate of predictions made by the participants. However, previous research has indicated that predictive inferences may support comprehension under limited circumstances (e.g., Graesser, Singer, & Trabasso, 1994; Magliano, Baggett, Johnson, & Graesser, 1993; Rosenshine, Meister, & Chapman, 1996). For example, Magliano et al. (1993) found evidence using a lexical decision task that readers generate few predictions during the normal course of reading. Furthermore, Magliano et al. (1999) found that predictions can also deter from comprehension during narrative text comprehension. They had participants read with specific inference goals such as explain, predict, associate, or read to understand. Reading to predict led to a decrease in the generation in explanations when thinking aloud. In addition, recall was poorer when reading to predict, relative to other strategies.

Nonetheless, predictions may be more likely and more supportive of comprehension under other circumstances. For example, during narrative film comprehension, Magliano, Dijkstra, and Zwaan, (1996) found that movie viewers will generate predictions when cinematic devices provide a high degree of constraints on possible outcomes. This finding is consistent with a growing body of research in text comprehension, which suggests that readers do generate predictions when predicted outcomes are highly probably or sufficient (e.g., van den Broek, 1994). This situation is not likely to be characteristic of science texts.

A final, but important issue regards the impact of mistakes, miscomprehensions, or errors on the learning process. Should learning be error free? Or, are errors a necessary component of the learning process. Didactic, rote learning approaches implicitly assume that errors should be avoided, whereas constructive learning approaches tend to assume the contrary. Evidence in this study could be interpreted from both standpoints. On the one hand, incorrectly paraphrasing the text negatively correlated with comprehension. This result is indicative of a negative effect of errors and lends to the conclusion that explanation errors may deter from comprehension. However, this result cannot be interpreted causally because incorrect paraphrases could have resulted from miscomprehensions (rather than leading to them). On the other hand, incorrect explanations (elaborations and using logic) were related positively to comprehension at the textbase level. In addition, SERT participants used logic incorrectly more often than did control participants. These results indicate that making errors while engaging in the active processing encouraged by SERT does not necessarily inhibit comprehension. Moreover, the finding that low-knowledge SERT participants were less likely than control counterparts to express incorrect paraphrases indicates that this active processing improves comprehension. Collectively, these results indicate that self-explanations combined with reading strategies reinforced the text representation, even if those explanations were not always correct. In sum, errors are a necessary part of active learning (see also, McNamara, 1995).

In closing, one defining aspect of active processing is the integration of new information with prior knowledge. If the use of prior knowledge is essential to active processing, the learner's level of prior knowledge should be expected to have an important impact on the effectiveness of active processing during learning. Moreover, the learner's level of prior knowledge and skills can determine whether a certain learning environment will induce frustration, boredom, or, optimally, active processing. However, our understanding of these relations remains incomplete, and thus we are unable to reliably predict the specific conditions under which prior knowledge and skill will play critical roles during learning. One premise of this research is that developing a better understanding of the relation between reader aptitudes and instructional techniques is a key to improving training methodologies. The challenge we face as researchers is to continue the investigation of these complex relations to improve our understanding of reading comprehension and learning from text, and moreover to develop more effective, adaptive learning environments.

ACKNOWLEDGMENTS

This project was funded by a Career Development award from the James S. McDonnell Foundation, Grant No. IERI REC–0089271 from the National Science Foundation, and from a Research award from Old Dominion University College of

Sciences. I am grateful to a number of students who helped with this project, including Jennifer Scott, Bryan Hayes, Sharon Kruzka, Susan Lee, Ann Rumble, and Quinn Schroeder. I am also grateful to Tenaha O'Reilly, Rachel Best, and Yasuhiro Ozuru for their helpful comments on earlier versions of this article. Finally, I thank Xiangen Hu and Lun Mo for their invaluable help in conducting and interpreting the chi-square analyses.

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