Self-Explanation and Reading Strategy Training (SERT) Improves Low-Knowledge Students' Science Course Performance

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Abstract

This study demonstrates the generalization of previous laboratory results showing the benefits of self-explanation reading training (SERT) to college students' course exam performance. The participants were 265 students enrolled in an Introductory Biology course, 59 of whom were provided with SERT training. The results showed that SERT benefited students who began the course with less knowledge about science, but did not benefit students with greater prior science knowledge. Moreover, across the three exams in the course, low-knowledge students who received SERT performed as well as high-knowledge students, whereas low-knowledge students without SERT performed more poorly than high-knowledge students. Hence, instruction on how to self-explain and use comprehension strategies allowed low-knowledge students to overcome their knowledge deficits. These results provide further evidence that self-explanation in combination with instruction and practice using comprehension strategies helps students to more effectively process and understand science.

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While there is a global deficit in students who excel in science and who subsequently pursue STEM occupations, this deficit is particularly pronounced and disparaged in the United States (Casey, 2012). According to both international and national studies for the past two decades, performance on tests that assess knowledge of science indicate that well over a third of students in the United States score below basic levels of proficiency, and well below performance by students in other nations (National Assessment of Educational Progress, NAEP, 1996; 2011; National Center for Education Statistics, 1999, 2000, 2005). Indeed, many studies indicate that almost 50 percent of students in the United States do not possess prerequisite, basic knowledge and skills in science. In turn, few high-school students choose science majors in college. Moreover, of those who do, a good majority are either unable to complete their degree or eventually change majors to a non-science degree (National Science Board, 2003; Chen, 2013). Essentially, many students who enter college perform poorly in science courses. As a consequence, the number of STEM graduates has decreased across the past few decades while the number of STEM occupations continues to increase (Casey, 2012).

Difficulties comprehending science text may stem from several sources of problems. First, a student may lack sufficient reading ability to read and comprehend scientific content. Indeed, many researchers and educators have raised concerns regarding students' ability to read and understand challenging text (Bowen, 1999; Snow, 2002). These concerns are partially prompted by students' national reading proficiency scores, which paint a picture similar to the science scores. For example, NAEP reading scores between 1992 and 2013 have indicated that at least a quarter of 8th grade students cannot read at a basic level. This means that they are unable to comprehend relatively easy text, let alone challenging science text.

Second, students may lack sufficient knowledge about the science domain to be able to understand the concepts. Indeed, the challenges posed by challenging text are compounded for students with less knowledge about the domain (e.g., McNamara, Kintsch, Songer, & Kintsch, 1996; McNamara, 2001). For example, when a reader encounters a conceptual gap in a text, successful comprehension requires generating an inference to repair the gap. Readers who lack sufficient knowledge to make the necessary inferences will generally fail to understand the concepts.

To address these issues, McNamara (2004) examined whether teaching readers how to generate inferences more effectively would help them to better understand low-cohesion science texts. The intervention, called Self-Explanation Reading Training (SERT), was designed to improve students' ability to generate effective inferences while reading complex text. Self-explanation refers to the process of explaining aloud the meaning of written text to oneself. SERT was based on research showing the benefits of self-explanation (e.g., Chi & de Leeuw, Chiu, & LaVancher, 1994; Chi, Bassok, Lewis, Reimann, & Glaser, 1989) as well as research on the benefits of reading strategy instruction (e.g., Baker, 1996; Baumann, Seifert-Kessell, & Jones, 1992; Bereiter & Bird, 1985; Davey, 1983; Dewitz, Carr, & Patberg, 1987; Hansen & Pearson, 1983; Palincsar & Brown, 1984; Pressley et al., 1992; Yuill & Oakhill, 1988).

Self-explanation can improve deep-level comprehension of text. However, most readers do not naturally self-explain text and self-explain poorly if they are prompted to do so (e.g., Chi et al., 1994). Hence, not all students benefit from using self-explanation, and in fact, many do not. Therefore, McNamara (2004) developed SERT to examine the effectiveness of combining self-explanation with instructions to use reading strategies while explaining text. The question addressed by this research was whether instruction in reading strategies would help readers, particularly poor self-explainers, to more effectively explain text.

SERT (McNamara, 2004) is a teacher-led training that provides students with a description of self-explanation and six reading strategies. After being introduced to and given examples of the strategies, the participants then practice using self-explanation. The six reading strategies are: a) comprehension monitoring, b) paraphrasing, c) elaboration, d) logic or common sense, e) predictions; and f) bridging. These strategies represent reading processes that are characteristic of effective self-explanation. Examples of the use of each of the strategies are provided in Table 1 (adapted from McNamara, 2004).

Insert Table 1

Comprehension monitoring is the process of being aware of one's own understanding (McNamara, 2007; National Reading Panel, 2000; Palincsar & Brown, 1984, 1986; Paris, Wixson, & Palincsar, 1986). In effect, the process of comprehension monitoring is a natural consequence of using effective reading strategies. That is, to use a strategy the readers must be at least somewhat aware of their level of understanding. And, ideally, a reader's awareness of low understanding can often lead to the use of reading strategies to repair understanding. Usually comprehension monitoring does not manifest in self-explanations, but when it does, the reader may say 'I don't understand what that means', or 'I see what that means now.' Many students do not understand that reading text does not necessarily result in deeply understanding and learning from text, and as a consequence display poor ability to calibrate the success of comprehension (e.g., Glenberg, Wilkinson, & Epstein, 1982; Hacker, Dunlosky, & Graesser, 1998; McNamara, 2010; Snow, 2002). The primary purpose of instruction on comprehension monitoring in the

SERT program is to help the reader to understand that deep comprehension, rather than shallow reading, is the ultimate goal.

The first step toward comprehension is the process of paraphrasing. Paraphrasing is restating the text in different words, and preferably, in the reader's own words. It is an important part of the explanation process because readers often paraphrase the sentence in order to begin an explanation (McNamara, 2004). Paraphrases are important because they help the reader to better understand the information in the sentences, and thus help the reader, particularly less skilled readers, to develop a better textbase level understanding of the text (McNamara, O'Reilly, Best, & Ozuru, 2006). Essentially, the act of paraphrasing externalizes the reader's understanding. This process can force the reader to fill in conceptual gaps and facilitates the activation of relevant concepts that are necessary to generate inferences (Best, Rowe, Ozuru, & McNamara, 2005).

The remaining four strategies are the heart of self-explanation because they are strategies for generating inferences while reading. Elaboration is the process of making inferences that link what is in the text or sentence to related knowledge. For example, when reading this sentence about heart disease, 'Coronary artery disease occurs when the arteries become hardened and narrowed,' the reader might make a connection to prior knowledge that arteries supply blood to the heart muscle.

The reader might also use general knowledge or logic to infer that narrowed arteries would reduce blood flow to the heart muscle and result in a lack of oxygen supply and potentially lead to a heart attack. Encouraging students to use logic and common sense helps them to understand that it is possible to make sense of the text, and go beyond the text, without knowing a lot about the topic (McNamara, 2004). This is an important aspect of SERT because its purpose is to help low-knowledge readers make sense of challenging, unfamiliar text. The use of logic and general knowledge is a means of elaborating, but explicitly encourages the reader to rely on knowledge that may not be directly related to the text domain.

The prediction strategy involves thinking about what might be coming next in the text. Although predictions are relatively uncommon when reading science texts (Magliano, Baggett, Johnson, & Graesser, 1993; Magliano, Dijkstra, & Zwaan, 1996; McNamara, 2004; van den Broek, 1994), instructions on making predictions were included in SERT because exposure to this strategy encourages the student to think ahead and think more globally while reading.

Finally, generating bridging inferences is the process of linking ideas and understanding the relations between separate sentences in the text. Deep comprehension requires more than merely interpreting individual sentences; the reader must also be able to integrate individual sentence meanings into a coherent text level representation (Gernsbacher, 1997; Kintsch, 1988; 1998). Making bridging inferences is critical to text comprehension because texts normally do not (or cannot) state all of the relevant information (e.g., McNamara et al., 1996). Therefore, to successfully comprehend a text, the reader must generate bridging inferences to build a coherent mental model that connects the separate ideas across the text.

The primary objective of SERT is to help readers learn how to construct coherent understandings of text. Paraphrasing helps the reader to form a more coherent textbase and the inference strategies lead to a more coherent situation model (e.g., McNamara et al., 2006). Self-explanation helps the student to externalize the process of using comprehension strategies, and helps the reader to think about the text more deeply. However, self-explanation is not sufficient by itself. McNamara (2004) examined the effects of self-explanation, comparing students who were provided with strategy training to those who were not. All of the participants (SERT and control) were asked to self-explain a difficult text about cell mitosis. Those students who were prompted to self-explain (as in Chi et al., 1994) were compared to those who were provided with training to self-explain using the reading strategies (i.e., SERT). Those who received the additional training on reading strategies (i.e., SERT) showed significantly better comprehension than those who were merely prompted to self-explain (see also, McNamara et al., 2006).

The effects of SERT on comprehension were also most evident for low-knowledge participants. McNamara (2004) examined the self-explanations produced by the participants after training, and found that SERT's primary role was in helping students with less knowledge about science to use logic and common sense to self-explain the text. Thus, the results showed that SERT helped the low-knowledge students to more effectively self-explain the text by using more effective strategies. As a consequence they showed considerably better comprehension than the low-knowledge participants in the control condition who had not received training. Moreover, low-knowledge participants who received SERT showed comprehension performance comparable to the high-knowledge participants.

High-knowledge readers were not expected to gain from training to self-explain primarily because their knowledge to understand the text is readily available. Science texts place particular demands on readers because the words tend to be less familiar and the sentences are more complex than in narrative texts (McNamara, Graesser, & Louwerse, 2012). Students can more effectively manage the demands of science texts when they have relevant knowledge that is readily available and accessible. When knowledge is readily accessible, there is little need to engage in a cognitively-demanding task such as self-explanation.

The results from McNamara (2004) imply that providing students with SERT should improve science performance in science courses. If performance in science courses depends, at least in part, on students' ability to understand the concepts in their textbook, then improving their ability to understand the text should improve their performance. Moreover, the results imply that SERT should be most beneficial to the students performing most poorly – those with less prior knowledge of scientific concepts.

One question examined in the current study is the extent to which the benefits of SERT will extend beyond the well-controlled confines of a laboratory. Demonstrations of transfer of training in the broader context of skill and knowledge acquisition are difficult to achieve (Singley & Anderson, 1989). More specific to the current study, demonstrations of far transfer of *reading strategy training* to contexts and assessments independent of the context of the strategy training are also quite rare. Many studies of reading strategy training demonstrate effectiveness solely on experimenter-derived assessments, compared to relatively few on standardized assessments, and even fewer to performance in the classroom (Rosenshine & Meister, 1994; Rosenshine, Meister, & Chapman, 1996). Thus, a principle purpose of this study is to examine transfer of training to a context and test far removed from the experiment.

To this end, this study examines the benefits of SERT for students from an introductory college Biology course. Specifically, 59 of 265 students were provided with SERT before the students' first exam. This study examines the extent to which SERT has a positive impact on exam performance. Thus, this study provides a test of far transfer of training. It is a test of far transfer because during training the students are guided to use the strategies with single texts that are independent of their science course. Transfer of training to their course exams is then examined. The exams exemplify a situation in which the students are not explicitly instructed to use the strategies and there are multiple sources of information to process (i.e., multiple chapters, lectures, notes).

This study also examines the extent to which the effects of SERT depend on students' reading ability. McNamara (2004) found that reading ability (as assessed by the Nelson Denny and a reading span measure) did not have significantly affect science text comprehension. In addition, the effectiveness of SERT did not depend on reading ability: SERT was beneficial for both low and high skilled students. The latter finding runs counter to theories of comprehension that have a greater emphasis on abilities related to understanding the words and sentences in text (i.e., reading ability) as compared to making connections with prior knowledge. A question asked here is whether the effectiveness of SERT on exam performance will depend on reading ability.

Most importantly, this study examines the impact of students' prior knowledge of science. It is predicted that students' prior knowledge will have a strong influence on their performance in the science course (O'Reilly & McNamara, 2007b). High-knowledge students will have higher exam scores than low-knowledge students. In addition, high-knowledge students are not expected to benefit from SERT because they can successfully understand the material and generate necessary inferences using their available knowledge (e.g., McNamara et al., 1996). By contrast, low-knowledge students are expected to benefit from SERT and they are expected to perform equivalently to the high-knowledge students if they have received the reading strategy training, thus replicating the results reported in McNamara (2004) in a real-world setting.

Method

Participants

The participants were 265 students enrolled in an undergraduate college-level Introductory Biology course who volunteered to participate for extra credit in their course. Of the

265 students, 206 students volunteered to participate in only the testing sessions (Control condition). The remaining 59 students volunteered to further participate in the SERT sessions (SERT condition).

The age of the participants was collected via a multiple-choice question (via scantron). The majority of the participants were between the ages of 16 and 20 years old (n=197, 74.3%; Control n=156, 75.6%; SERT n=41, 69.5%). Of the remaining participants, 44 were between 21 and 25 years old (16.6%; Control n=34, 16.5%; SERT n=10, 16.9%), 19 were between 26 and 30 years old (7.2%; Control n=12, 5.8%; SERT n=7, 11.9%), and 5 were between 31 and 45 years old (1.9%; Control n=4, 2.0%; SERT n=1, 1.7%). Thus, the distribution in ages was similar across the two conditions ($\chi^2(3, 265) = 2.1$, $p=0.55$).

The majority of the participants were first year students in college (n=139, 52.5%; Control n=116, 56.3%; SERT n=23, 39.0%). Of the remaining participants, 61 were second year (23.0%; Control n=45, 21.8%; SERT n=16, 27.1%), 42 were third year (15.8%; Control n=28, 13.6%; SERT n=14, 23.7%), 23 were fourth year students (8.7%; Control n=17, 8.3%; SERT n=6, 10.2%). The distribution in class was similar across the two conditions ($\chi^2(4, 265) = 6.2$, $p=0.10$).

Design and Procedure

All participants were given the ability measures in a large group. Participants first took the prior knowledge test (20 minutes) followed by the Nelson Denny reading skill test (20 minutes; Brown, Fishco, & Hanna, 1993). The students then completed a demographics questionnaire concerning the number of science courses previously taken, GPA, and how much they enjoy science, non-science and reading. The students then signed up to participate in the training sessions. The SERT training sessions were conducted with groups of 10-20 students and the sessions lasted for approximately 2 hours.

The dependent measure in this study was students' performance on the three exams administered across the semester in the introductory Biology course in which the students were enrolled. The first exam was administered to the students approximately 1 week after training and approximately 1 month after the beginning of the course. The remaining two exams were administered at relatively equal intervals across the remainder of the semester. None of the exams were cumulative.

Materials

Reading skill. Reading comprehension skill was assessed using form G of the Nelson Denny adult reading comprehension test (Brown et al., 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 twenty minutes to complete the test.

Prior knowledge. Prior science and general knowledge were measured by a 54-item multiple-choice test. The multiple-choice questions were taken from published test banks (e.g., GMAT). Five possible answers were given for each question. There were 20 questions from general knowledge domains such as literature (e.g., A 20th century novel which made the public aware of the plight of migrant workers is: *The Grapes of Wrath*) and history (e.g., At the end of the Civil War, the vast majority of freed slaves found work as: *tenant farmers*). There were 34 science questions regarding science topics such as biology (e.g., A process which can only take place in living cells containing chlorophyll is: *photosynthesis*) and geology (e.g., Fossilized resin from ancient coniferous trees is called: *amber*).

Demographics Questionnaire. The students completed a questionnaire which asked them their age, year in college, how many science courses they had taken in high school and college, their grade point average (GPA) in high school and college, and three Likert scale questions concering how much they a) enjoy learning information about science, b) enjoy learning about non-scientific information, and c) enjoy reading. The Likert scale choices were presented from 1 (not at all), 2 (not very much), 3 (somewhat), 4 (quite a bit), to 5 (very much).

Training materials. Participants in the SERT condition were given a short list of six reading strategies (i.e., comprehension monitoring, paraphrasing, elaboration, logic and common sense, prediction, and bridging), a booklet with more detailed descriptions of the strategies and examples of their use in self-explanations, a video transcript and note sheet (used during the video segment of training), and a copy of a science text used during self-explanation practice. The text used during practice was titled 'Origin of the Universe.' It contained 425 words, four paragraphs, 20 sentences, with an average of 21.25 words per sentence. The Flesch-Reading Ease Score as reported from the Coh-Metrix site (cohmetrix.memphis.edu) was 42.34, which translates to a Flesch-Kincaid Grade Level of 12. Its referential cohesion (semantic overlap between sentences) was slightly lower than average for a 12th grade science text according to several Coh-Metrix indices (e.g., Argument Overlap = .42; TASA-based Norm = 0.47; Latent Semantic Sentence Overlap = 0.35; TASA-based Norm = 0.47). The word difficulty was also slightly greater than average (Minimum Content Word Frequency = 10.05; TASA Norm = 26.69; Syllables per Word = 1.69; TASA Norm = 1.60). In sum, it was a challenging text on a challenging topic.

SERT Training

SERT training was modified from McNamara (2004) to be administered to groups of students (rather than individually), and within a 2-hour period. The modifications included using one video to demonstrate the strategies (rather than four videos), going over the video as a group, and paired practice with another participant at the end of training.

Participants were told that the purpose of the study was to teach them strategies that would help them to better understand and remember what they read. The first phase of training was administered in a lecture format during which the students were provided with instruction concerning the process of self-explanation and reading strategies. Students listened to a lecture and followed a handout that described and provided examples of each strategy. Self-explanation was described as reading text aloud and explaining what the text means. The strategies focused on the benefits of using knowledge and logic to understand the text, predicting what the text would say, making bridging inferences, and monitoring comprehension.

Specifically, six reading strategies were presented to the participants as a 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 in lecture format. 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 and common sense -- using general knowledge and 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 relationships 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 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.

The students then watched one video of another student self-explaining a text about forest fires. The instructor (i.e., the experimenter) stopped at four predetermined points in the video and asked all of the students to write down the strategies the student in the video had been using to self-explain the text. After all of the students had done so, the instructor led a discussion concerning which strategies were used.

After the video was completed, the students were given two texts to self-explain in groups of two. Thus, in pairs, the students took turns self-explaining each paragraph of the text. After one student had self-explained each sentence of an entire paragraph, the second student summarized that paragraph. The second student then self-explained the following paragraph, and so on. The summarization procedure was introduced into the training procedure to ensure that the "listening" student was attentive while the other student self-explained.

Results

Prior Abilities and Demographics by Condition

The first set of analyses was geared toward establishing that there were no differences between the two conditions on variables that were not related to training (see Table 2). There were no differences between the two groups of students in terms of either reading ability or general knowledge. The only difference that approached statistical significance was in terms of prior knowledge of science, but this difference favored the students in the control condition.

Two students in the control condition did not complete the demographics questionnaire and thus are not included in the data. As shown in Table 2, the demographics data indicate that the two groups of participants, those in the SERT condition and those in the control condition, were statistically equivalent in terms of their background, their academic performance, and their motivation levels (as reflected by how much they enjoy learning and reading).

Insert Table 2

Correlations among Prior Ability and Exam Scores

One question addressed by this study regards the extent that students' prior abilities influenced their exam scores. First, however, correlations were calculated to establish the extent that the three ability measures were redundant. General knowledge was correlated with both science knowledge ($r=.51$; $p<.01$) and reading skill ($r=.44$, $p<.01$). The correlation between science knowledge and reading skill was lower, but also significant ($r=.39$, $p<.01$). Thus, the three ability measures were correlated, but not redundant.

Correlations between the prior ability measures and the students' average exam performance indicated that prior science knowledge was most highly related to exam performance ($r=.33$, $p<.001$), compared to lower correlations to exam performance for prior general knowledge ($r=.19$, $p<.001$) and prior reading skill ($r=.10$, $p<.10$). Moreover, a regression analysis including the three ability measures, $F(3,261)=10.83$, $r^2=.11$, confirmed that only prior science knowledge significantly predicted average exam score, $t(261)=4.67$, $p<.001$. Hence, these correlation analyses indicate that prior knowledge of science significantly impacted students' performance in the course, over and above general knowledge and reading skill.

Insert Table 3

How do the Benefits of SERT depend on Prior Science Knowledge?

The principle goal of this study is to replicate the findings reported in McNamara (2004) showing that low-knowledge students benefited from SERT and performed equivalently to high-knowledge students if they received reading strategy training[1].

As a first step, the overall effects of SERT were confirmed on percent correct for exam scores using a repeated-measures ANOVA including the within-subjects variable of Exam (Exams 1, 2, and 3) and the between-subjects variable of condition (SERT, control). These results are presented in Table 3. This analysis showed that students who received training scored better on the exams than students who had not, $F(1,260)=4.22$, $MSe=0.33$, $p=.041$ ($M_{Control}=0.73$; $M_{SERT}=0.77$), though students' performance decreased across the three exams, $F(1,260) = 73.63$, $MSe= .004$, $p<.001$ ($M_{Exam1}=0.78$, $M_{Exam2}=0.75$, $M_{Exam3}=0.72$). In addition, there was an interaction between exam and condition, $F(1,260)=10.12$, $MSe=.004$, $p=.002$, reflecting the finding that the benefits of training were particularly strong on Exam 1, immediately after training was provided, but waned across exams such that the overall differences were not reliable on Exams 2 or 3[2].

To examine the effects of knowledge, a median-split on science knowledge was used to categorize the students as low-knowledge ($N_{Control} = 89$, $N_{SERT}=32$) or high-knowledge ($N_{Control} = 117$, $N_{SERT}=27$). Separate mixed ANOVAs were conducted for the two groups. Separate ANOVAs by group afford observations of the effectiveness of SERT in terms of the training effect sizes for both high and low knowledge students separately. These data are shown in Figure 1 and Table 3.

Insert Figure 1

[1] Analysis of variance as well as correlational and regression analyses confirmed that reading skill did not significantly contribute to exam performance and did not interact with the effectiveness of training.
[2] These effects and the interaction remained reliable when the ability measures were entered as covariates.

In contrast to the overall analysis, there were reliable benefits of SERT on all three exams for the low knowledge students (see Table 3). For low-knowledge students, there was a main effect of training, $F(1,119)=9.31$, $MSe=0.029$, $p=.003$; a linear effect of exam, $F(1,119)=43.40$, $MSe=.004$, $p<.001$; and a marginal interaction of exam and training, $F(1,119)=3.57$, $MSe=.004$, $p=.061$. Low-knowledge students' performance decreased across exams, but the benefits of SERT remained reliable at the end of the semester on Exam 3.

As predicted, there were no benefits of SERT for high-knowledge students. Performance decreased across the exams, $F(1,119)=30.47$, $MSe=.004$, $p<.001$, though a significant interaction between condition and exam, $F(1,119)=5.93$, $MSe=.004$, $p=.016$, indicated that there was a greater decrease in performance from Exam 1 to Exam 3 for those who received SERT, $F(1,24)=28.09$, $MSe=.003$, $p<.001$, than for those in the control condition, $F(1,115)=12.59$, $MSe=.004$, $p<.01$. This decrease is attributable to better performance on Exam 1, though the difference between the control and SERT groups was not significant on Exam 1. Indeed, for these students, the effect of training was not reliable on any of the exams separately. In sum, training did not have an effect for high-knowledge participants.

Another way of looking at the data presented in Figure 1 is to examine the effects of knowledge in each condition. Training was expected to mediate the effects of knowledge. That is, low-knowledge students who were provided with SERT were expected to perform equivalently to high-knowledge students. To test this prediction, separate analyses were conducted for the Control and SERT participants to examine the effects of prior science knowledge on exam performance. As expected, for the Control participants, there was a linear effect of exam, $F(1,203)=31.74$, $MSe=.005$, $p<.001$, a main effect of prior knowledge, $F(1,203)=27.98$, $MSe=0.029$, $p<.001$, and no interaction ($F<2$). For SERT participants, there was an effect of exam, $F(1,55)=65.41$, $MSe=.003$, $p<.001$, but no effect of knowledge and no interaction (both $F<1$). While the effect of knowledge was reliable and substantial on all three exams for the control participants, it was non-significant on all three exams for the SERT participants. Thus, SERT training was effective for low-knowledge students on all three exams, and the training mediated knowledge differences such that low-knowledge students performed equivalently to high-knowledge students.

Discussion

This study examined the effectiveness of a reading strategy intervention called SERT, which teaches students to use reading strategies in the context of self-explanation. The effects of SERT were assessed based on the students' performance on their three exams in an introductory biology course. The results showed that the low-knowledge students who were in the SERT condition not only showed an effect of training compared to control students on all three exams, but they also performed equivalently to their high-knowledge counterparts. Thus, the results show that SERT can help students overcome knowledge deficits when learning about science (O'Reilly & McNamara, 2007b). This further supports the notion that reading comprehension and learning are a function of a number of factors, some of which can compensate for others. In particular, these results show that a reader can better understand challenging text by engaging in inference-making activities.

McNamara (2004) similarly found that SERT improved low-knowledge students' ability to self-explain and comprehend a difficult science text. However, the study conducted by McNamara (2004) was conducted in a controlled laboratory, with one-on-one SERT training. In contrast, the current study was conducted in large groups in a classroom setting. Further, in McNamara (2004), the targeted variable was comprehension of a text, which all of the participants had been directed to self-explain (and only the SERT participants had been provided with prior training). In contrast, in this case, the dependent variable was performance on exams, which were constructed by the professor and administered in class, and had no apparent link to the training provided to the students, other than their being told during training that the strategies should help them to understand what they read in their science course. Also, in the previous study, comprehension of only one text was assessed, immediately after reading it. In this case, the exam assessed learning from multiple sources including chapters, lectures, and notes.

Thus, an important contribution of the current study is that it provides a test of far transfer to the results reported by McNamara (2004). Many aspects of the learning environment affect the probability of transfer, but perhaps the most important one is the degree to which people learn with understanding, rather than merely memorize sets of facts or follow a fixed set of procedures (Bransford, Brown, & Cocking, 2000). Also important is the amount and quality of practice (e.g., Ericsson, Krampe, & Tesch-Romer, 1993; Singley & Anderson, 1989). There are few demonstrations of far transfer of strategy training to assessments that are independent of the training context (e.g., Rosenshine et al., 1996). As such, this study provides a rare contribution to research on reading strategy training by showing transfer of training to a context and assessment that is far removed from the experiment.

The results here further indicate that the students' performance on exams was best predicted by their knowledge of science. The importance of prior knowledge to comprehension and learning cannot be over emphasized (Shapiro, 2004). These results corroborate the findings reported by McNamara (2004) who found that comprehension of the science passages was most related to domain knowledge and was not predicted by either reading span or Nelson Denny performance (see also, O'Reilly & McNamara, 2007a, 2007b).

One particular concern regarding the current study is that students were not randomly assigned to condition; the students in the SERT condition volunteered to participate in the training sessions. This design is partially a by-product of the interest here in classroom data in contrast to controlled laboratory data and the constraints of the particular course that agreed to participate in the study. While this is a potential concern, it is quite unlikely that the results of these two studies are due to a Hawthorne effect, or the effect of virtually any additional interaction with the students. If that were the case, and simply, additional interactions with students, regardless of their nature could improve students' performance, we would have long ago solved the many education problems in the United States. Additionally, there were no significant differences found between the two groups of participants on a variety of measures of knowledge, reading skill, GPA, prior science courses, and how much they enjoy learning and reading. There was a marginal difference between the groups on science knowledge, indicating that the control condition knew slightly more about science than did those in the SERT condition. However, this difference was non-significant and could only have worked against the potential effects of SERT.

Nonetheless, this study did not include measures of students' motivation to succeed academically, willingness to work hard, or other goal-oriented/motivational factors. Hence, the possibility remains that these findings reflect a selection bias: those who volunteered for additional training (of any kind) might be people who would naturally work harder and attend more deeply even without the training, or who would benefit just as much or even more from a different kind of training. This is somewhat unlikely given the lack of differences in terms of GPA, knowledge, and reading skill, because motivational differences are likely to have manifested within the students' cumulative records across time. In sum, while the data indicate that the SERT participants were largely equivalent to the control participants before training, additional research with randomized control trials would more clearly disentangle possible effects of learner motivation that could be involved in the effects demonstrated here.

An additional concern regards the challenges of providing SERT to groups of students, particularly within the context of content area courses where the primary focus is on providing content-specific instruction. In these contexts, SERT may not always be practical. In these cases, an effective alternative to SERT is its automated counterpart called Interactive Strategy Training for Active Reading and Thinking (iSTART; McNamara, Levinstein, & Boonthum, 2004; McNamara, O'Reilly, Rowe, Boonthum, & Levinstein, 2007; Jackson & McNamara, 2013). iSTART provides automated strategy instruction via instructional videos, games, quizzes, and practice using the strategies with automated feedback (McNamara, Boonthum, Levinstein, & Millis, 2007). Like SERT, iSTART also has a positive impact on reading strategies and comprehension for middle school, high school, and college students (e.g., Jackson & McNamara, 2013; Magliano et al., 2005; O’Reilly, Taylor, & McNamara, 2006), with effect sizes that have varied between 0.50 and 2.00.

One advantage of iSTART over SERT is its ability to provide immediate and appropriate feedback to the student (Levinstein, Boonthum, Pillarisetti, Bell, & McNamara, 2007). By consequence, it affords greater practice on using the strategies than does SERT and allows the students to continue to practice using the strategies with a wide variety of texts across a school year. Nonetheless, while iSTART facilitates practice, this can also be achieved in classrooms using a variety of approaches. For example, the students can be placed in pairs and asked to take turns self-explaining a portion of the textbook. The teacher can also have the students self-explain as a class – calling on students to begin or continue self-explanations, and asking the students to write out self-explanations for selected sentences in text. These simple exercises may have important benefits, particularly for the struggling students. The more that these types of strategies are embraced by the teacher, and become part of the classroom culture, the more effective they will become. As with all classroom activities, SERT is likely to be most effective if the teacher encourages the student to practice the strategies and engages in classroom activities that encourage the strategies.

In conclusion, this study addressed the question of whether SERT can help students improve not only their reading comprehension under guided circumstances, but also their performance in science courses. While this study focused on science, there is little theoretical reason to believe that SERT would not also be effective within other challenging domains. Science is a complex topic, but there are many others that are knowledge demanding and challenging for students. Students are highly likely to gain from using SERT strategies in a variety of subject domains such as history and social studies, as well as science.

SERT is a relatively simple training that requires only a couple of hours. However, SERT will certainly be most effective if the student practices the strategies. iSTART may provide some advantages because it affords a greater amount of practice, and feedback is automated. However, the training can be provided in the context of a classroom, without computer support. If the student practices and uses the strategies, the potential benefit to performance in difficult, knowledge demanding courses is substantial. For many students, these strategies could translate to the difference of passing or failing the course.

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Table 1. Examples of Strategies Used by Participants in McNamara (2004) for Sentence 3 of Cell Mitosis: "*Mitosis guarantees that all the genetic information in the nuclear DNA of the parent cell will go to each daughter cell*."

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."
Paraphrasing	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."
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."
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."

Note: Table adapted from McNamara (2004)

Table 2

Average performance on the three ability measures (number correct on the Nelson Denny and percent correct on the two knowledge tests) as a function of condition and Fs indicating the significance of the difference between the SERT and control conditions.

	SERT	Control	Difference
Nelson Denny	27.14 (6.13)	27.75 (6.25)	F(1,263)=0.45
Science Knowledge	47.21 (11.55)	50.41 (11.26)	F(1,263)=3.67, p=.057
General Knowledge	50.25 (15.55)	52.91 (17.15)	F(1,263)=1.15
High School GPA	3.00 (0.54)	3.04 (0.48)	F(1,259)=0.27
College GPA	2.75 (0.80)	2.74 (0.70)	F(1,263)=0.13
Number High School Science Courses Taken	3.39 (0.97)	3.54 (0.92)	F(1,261)=1.15
Number College Science Courses Taken	1.12 (0.72)	0.97 (0.69)	F(1,261)=2.20, p=.139
Enjoy Learning Science (1 = not at all; 5 = very much	3.25 (0.96)	3.24 (1.05)	F(1,261)=0.02
Enjoy Learning Non-Science (1 = not at all; 5 = very much	3.93 (1.05)	3.78 (0.77)	F(1,261)=1.42
Enjoy Reading (1 = not at all; 5 = very much	3.71 (1.12)	3.49 (1.15)	F(1,261)=1.79

Note: Standard deviations are in parentheses

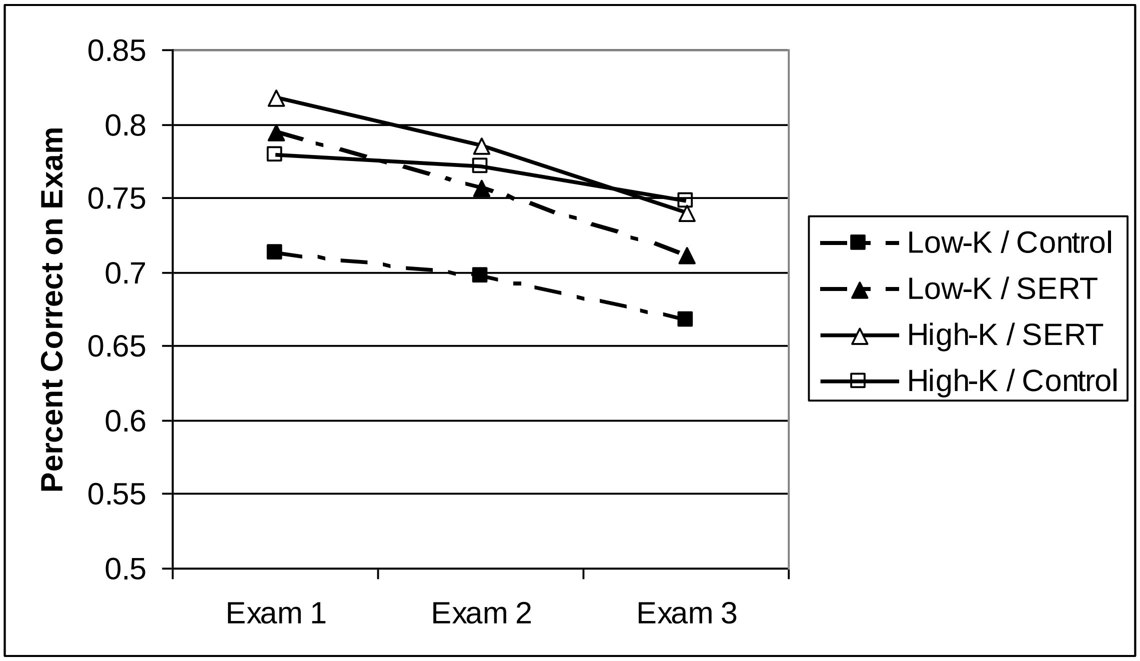
Table 3

Exam performance (percent correct) as a function of condition (Control vs. SERT) for all participants and separately for students high and low in science knowledge.

	Control		SERT		Statistics	
	Mean	Se	Mean	Se	ANOVA	Cohen's *d*
All Participants						
Exam 1	0.75	0.008	0.80	0.016	F(1,262)=7.69, MSe=.014, p=.006	0.47
Exam 2	0.74	0.009	0.77	0.016	F<2	0.25
Exam 3	0.71	0.008	0.72	0.015	F<1	0.10
High Knowledge						
Exam 1	.79	.011	.82	.024	F(1,139)=2.28, MSe=.014, p=.142	0.34
Exam 2	.77	.011	.79	.023	F<1	0.12
Exam 3	.75	.009	.74	.020	F<1	-0.09
Low Knowledge						
Exam 1	0.71	0.012	0.79	0.020	F(1,119)=12.55, MSe=.012, p<.001	0.74
Exam 2	0.70	0.013	0.76	0.022	F(1,119)=5.77, MSe=.015, p=.018	0.50
Exam 3	0.67	0.011	0.71	0.019	F(1,119)=4.14, MSe=.011, p=.044	0.43

Figure Captions

Figure 1. Performance on course exams as a function of prior science knowledge and condition (SERT, Control). The low-knowledge students benefited from SERT training, whereas the high-knowledge students did not.



Percent Correct on Exam
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
Exam 1
Exam 2
Exam 3
Low-K / Control
Low-K / SERT
High-K / SERT
High-K / Control