

## **IMPROVING ADOLESCENT STUDENTS' READING COMPREHENSION WITH iSTART\***

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### **ABSTRACT**

This study examines the benefits of reading strategy training on adolescent readers' comprehension of science text. Training was provided via an automated reading strategy trainer called the Interactive Strategy Trainer for Active Reading and Thinking (iSTART), which is an interactive reading strategy trainer that utilizes animated agents to provide reading strategy instruction. Half of the participants were provided with iSTART while the others (control) were given a brief demonstration of how to self-explain text. All of the students then self-explained a text about heart disease and answered text-based and bridging-inference questions. Both iSTART training and prior knowledge of reading strategies significantly contributed to the quality of self-explanations and comprehension. Adolescents with less prior knowledge about reading strategies performed significantly better on text-based questions if they received iSTART training. Conversely, for high-strategy knowledge students, iSTART improved comprehension for bridging-inference questions. Thus, students benefitted from training regardless of their prior knowledge of strategies, but these benefits translated into different comprehension gains.

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There is growing concern for U.S. students' ability to read, comprehend, and learn from text. For example, international comparisons show that students in the U.S. are falling behind students in other countries, especially on measures of reading comprehension. The National Assessment of Educational Progress (NAEP, 2003) indicates that 37% of fourth graders, and 26% of eighth graders cannot read at the *basic* level. The situation is even grimmer for minorities, with NAEP statistics indicating that over half cannot read at the basic level. These statistics indicate that a large proportion of adolescent students in the U.S. do not understand what they read.

From a reading perspective, there are two general classes of reading deficits: decoding problems, such that the individual is not able to convert the written word to its phonological or semantic referent (e.g., Brand-Gruwel, Aarnoutse, & Van den Bos, 1988; Lyon, 2002; Mommers, 1987; Perfetti, 1985; Roth, Speece, Cooper, & De La Paz, 1996; Taschow, 1969; Vellutino, 2003; Vellutino, Scanlon, & Tanzman, 1994) and comprehension problems, such that the reader is unable to integrate the words and sentences into a coherent understanding of the text (e.g., Cain, 1996; Cornoldi, De Beni, & Pazzaglia, 1996; Hoover & Gough, 1990; Stothard & Hulme, 1996). This study focuses on the latter problem—students who can read the words, but who do not fully comprehend what they read. The purpose of this study is to examine the effectiveness of an automated reading strategy intervention called Interactive Strategy Trainer for Active Reading and Thinking (iSTART; McNamara, Levinstein, & Boonthum, 2004) in helping adolescent readers learn reading strategies, and improve their comprehension of science text.

One approach to this problem is to examine the reading processes of better readers and to provide strategy instruction to poor readers to help them compensate for their deficits, or consciously enact the same reading processes as skilled readers. Thus, one goal of reading research has been to better understand what skilled readers do while reading, that less skilled readers do not, or cannot do. Although there is a good deal of research suggesting that better readers differ in terms of working memory capacity (Daneman & Carpenter, 1980; Daneman & Merikle, 1996; Daneman & Tardif, 1987; Just & Carpenter, 1992; cf. McNamara & Scott, 1999) or their ability to inhibit or suppress information (Conway & Engle, 1994; Engle, 1996; Gernsbacher, 1990; Gernsbacher & Faust, 1991; Gernsbacher, Varner, & Faust, 1990; Rosen & Engle, 1997, 1998), these notions do little to suggest remediations for comprehension deficits. Other research, however, indicates that both young and adult skilled readers make more inferences while reading (Long, Oppy, & Seely, 1994; McNamara & McDaniel, 2004; Oakhill & Yuill, 1996). Thus, one possibility is that poor comprehenders somehow fail to perceive texts as a connected discourse, and do not make inferences that help them process multiple sentences and paragraphs in a text as a coherently connected discourse. Accordingly, reading instruction that centers on providing guidance and training to make more and better inferences while reading

successfully improves less skilled readers' comprehension (e.g., Hansen & Pearson, 1983; Yuill & Oakhill, 1988).

Providing students with strategy training can help them acquire skills to circumvent their reading problems by using overt, conscious, and active reading processes that help them to work through difficult text. Empirical examinations of reading strategies have received particular attention at the elementary school level (e.g., Dalton, Tivnan, Riley, Rawson, & Dias, 1995; Guthrie et al., 2004; Magnusson & Palincsar, 1995; Yuill & Oakhill, 1988; see for a review, Rosenshine, Meister, & Chapman, 1996). The majority of these studies have yielded positive results, showing that reading strategies help young readers to improve their comprehension. However, less empirical research has been conducted to investigate whether reading strategy interventions help adolescent readers improve their text comprehension (cf., Deshler, Schumaker, & Woodruff, 2004). In this article, we report on results of a reading strategy intervention study conducted with adolescent readers, using an automated reading strategy training program, called iSTART.

iSTART is based on Self-Explanation Reading Training (SERT), which was developed by McNamara and her colleagues (McNamara, 2004; McNamara & Scott, 1999) to help young adult and adolescent students understand difficult science texts. SERT was designed to improve students' ability to self-explain difficult text by combining self-explanation training with metacognitive reading strategy training. Self-explanation involves having a reader type or say aloud what a sentence or portion of a text means to a reader. The training was motivated by empirical findings that show that students who self-explain text are more successful at solving problems, more likely to generate inferences, construct more coherent mental models, and develop a deeper understanding of the concepts covered in the text (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, De Leeuw, Chiu, & LaVancher, 1994). However, many students self-explain poorly and do not benefit from the self-explanation process. Thus, in SERT, the students are taught reading strategies to improve their ability to self-explain. In turn, the process of self-explanation helps the students learn how to use the reading strategies more effectively.

The SERT intervention coaches students in five reading strategies: comprehension monitoring, paraphrasing, making bridging inferences, predictions, and elaborations. *Comprehension monitoring*, enables the reader to recognize a failure of understanding, and it is this recognition that triggers the use of additional active reading strategies (e.g., Baker & Brown, 1984; Everson & Tobias, 1998; Pressley & Ghatala, 1990). The first such strategy, *paraphrasing*, essentially helps students remember the basic ideas in the text by translating it into more familiar words. However, SERT encourages students to go beyond this basic sentence-focused processing by invoking knowledge-building strategies that link the content of the sentences to other information, either from the text or from the

students' prior knowledge. Making *bridging inferences* improves comprehension by linking the current sentence to the material previously covered in the text (e.g., Oakhill, 1984). Such inferences allow the reader to form a more cohesive, global representation of the text content (e.g., Kintsch, 1998). Students may also use *prediction* to anticipate the content of subsequent text, either by guessing what is coming next or by reminding themselves to watch out for some particular item that will aid comprehension (e.g., Hansen & Pearson, 1983). Finally, readers may associate the current sentence with their own related prior knowledge using a strategy called *elaboration*. Importantly, readers are encouraged to engage in logical or analogical reasoning process to relate the content of the sentence with domain-general knowledge or any experiences related to the subject matter, particularly when they do not have sufficient knowledge about the topic of the text. Research has established that both domain knowledge and elaborations based on more general knowledge are associated with improving learning and comprehension (e.g., Pressley et al., 1992; Spilich, Vesonder, Chiesi, & Voss, 1979). Elaborations essentially ensure that the information in the text is linked to information that the reader already knows. These connections to prior knowledge result in a more coherent and stable representation of the text content (e.g., Kintsch, 1998; McNamara, Kintsch, Songer, & Kintsch, 1996).

While SERT has been shown to successfully improve students' comprehension at both the college (McNamara, 2004) and high-school levels (O'Reilly, Best, & McNamara, 2004) there are some limitations to the training. Most notably, human delivered training is resource demanding. First it takes a considerable amount of time to train human tutors to teach SERT. Second, the delivery of the training may be inconsistent, despite best efforts. Third, human tutors cannot be made accessible to all students who need it. Finally, the training is delivered to students in groups and therefore it is difficult to tailor to the individual needs of the learner. A one-to-one automated version of SERT alleviates these shortcomings. It allows training to be adapted to individual students, and thus, is expected to maximize the effectiveness of the reading strategy training. Since it is web-based, it is possible to make the training available to virtually any school with internet access.

### **INTERACTIVE STRATEGY TRAINING FOR ACTIVE READING AND THINKING (iSTART)**

iSTART is an automated, interactive reading strategy trainer that includes three modules (*Introduction*, *Demonstration*, and *Practice*). The program is described in detail in McNamara et al. (2004). Animated pedagogical agents provide the reading strategy instruction by interacting with each other and with the user.

The Introduction module provides information about self-explanation and five reading strategies (comprehension monitoring, paraphrasing, prediction, elaboration, and bridging). The student watches and listens to a pedagogical teacher-agent who teaches self-explanation and the five reading strategies to two

student-agents. The teacher-agent provides examples of the strategies, and the student-agents ask her questions about the strategies and the examples. After each strategy description, the participant answers four multiple-choice questions for each strategy, and is provided with immediate feedback.

The Demonstration module provides examples of the ways in which the reading strategies can be used to self-explain expository texts. A student-agent self-explains a six-sentence text on forest fires. For each sentence, a teacher-agent asks the participant to identify the strategies used by the student-agent and provides more or less scaffolding according to the participant's performance.

During the Practice module, the participant types self-explanations for two science texts. The quality of the self-explanation is assessed (McNamara et al., 2004) and feedback is provided to students by the teacher-agent. The feedback is largely based on the degree of conceptual overlap between the students' self-explanation and the target sentence (i.e., the sentence just read). The system is designed such that it encourages students to use information that is not in the target sentence (e.g., elaboration based on students' knowledge and previous sections of the text) but related to the meaning of the target sentence. For example, the pedagogical agent might respond with "Try adding some more information that explains what the sentence means" when the self-explanation is too similar to the target sentence. Thus, feedback differs for each user, depending on the quality of self-explanations produced.

### **GOALS OF THE CURRENT STUDY**

The overarching purpose of the current study was to examine the effects of the iSTART program on adolescent students' comprehension of a science text. The question regarded whether adolescent students would benefit from reading strategy training administered via an automated training system. To explore this question, 39 students who had just completed grades 7 and 8 were randomly assigned to either the iSTART or Control group. All of the students self-explained and answered questions on a text about heart disease (see McNamara, Kintsch, Songer, & Kintsch, 1996). Students in the iSTART condition were provided with reading strategy training with the iSTART program prior to reading and self-explaining the text. The students in the Control condition were provided with a short module (from iSTART) that described the concept of self-explanation but did not provide training. It was expected that as compared to the control condition, iSTART would improve participants' ability to self-explain, and in turn, their ability to better comprehend the heart disease text.

Our second goal was to examine the role of students' prior knowledge of metacognitive reading strategies in moderating the effectiveness of iSTART. One aim of the iSTART project is to increase the adaptivity of iSTART to students' needs, for example, by determining whether they will potentially gain from iSTART training. Prior reading strategy knowledge is of course an important

individual difference to consider in this regard. One potential prediction was that iSTART would only benefit low strategy-knowledge students because those with more knowledge of strategies would already possess the necessary strategy knowledge to effectively learn from text. We doubted this would be the case because of the range and depth of the strategies covered in iSTART, and the opportunity to practice using the strategies. It seemed more likely that even those with greater (relative) knowledge of reading strategies would benefit in some way from iSTART. Although having a reasonable amount of reading strategy knowledge is beneficial, it does not guarantee that the student knows *how* and *when* to *use* and *apply* that knowledge (e.g., Ross, 1989; Gick & Holyoak, 1980). iSTART provides information about reading and reading strategies, more importantly, it also trains students how to effectively *use* the strategies. Accordingly iSTART should also help high-strategy knowledge students.

Our third goal was to examine whether the effects of training depend on the level of comprehension assessed. Most reading researchers agree with the notion that reading comprehension involves multiple levels of comprehension. For example, Kintsch's construction-integration model (1988, 1998) proposes that reading primarily involves the surface, textbase, and situation model levels of comprehension. Most relevant here are the textbase and situation model levels. The textbase refers to memory and understanding for the information conveyed explicitly by the text. The situation model refers to an understanding that results from integrating the textbase with prior knowledge. The coherence of the situation model largely depends upon the extent to which the reader creates links between concepts in the text and with prior knowledge. We expected that less strategic readers would have more difficulties at both levels of comprehension, whereas more strategic readers (in middle school) may be capable of forming a coherent textbase, but less able to construct a coherent situation model of the content. That is, they may know the strategies, but still gain from training in terms of learning how to better use the strategies to integrate the text with prior knowledge. Thus, we expected to see gains at the lower textbase level for less strategic readers, and at the higher situation model level for more strategic readers.

The fourth focus of this research was on the relationship between the strategies used while reading, and the outcome, reading comprehension. Strategy intervention research using reciprocal teaching has shown improvements in reading comprehension without corresponding changes in strategy use following the training (see Rosenshine & Meister, 1994, for a review). For example, studies have found that there are no differences between reciprocal teaching and control groups on the depth of questions generated (Lysynchuk, Pressley, & Vye, 1990; Palincsar & Brown, 1984), the number of questions (Taylor & Frye, 1992), or rating of the quality of questions (Shortland-Jones, 1986). In other words, these studies indicate that reciprocal teaching improved reading comprehension without improving any measurable question generation skills. These findings point to a possibility that the actual strategies taught may not be the main factor that

influences comprehension. To test the link between comprehension and strategy use here, we analyze the students' self-explanation protocols generated while reading the target text, and relate the quality of the self-explanations to students' comprehension of the corresponding text. This allows us to make more direct conclusions concerning the effects of strategy use and comprehension.

## METHOD

### Participants

The participants were 39 children (11 males, 28 females) who were enrolled in a summer learning program in the Eastern United States. The average age of the children was 12.7 years ( $SD = 0.84$ ). Approximately half of the children were entering the eighth grade ( $n = 19$ ;  $M = 12.2$  years,  $SD = .59$ ) and half were entering the ninth grade ( $n = 18$ ;  $M = 13.2$  years,  $SD = .76$ ).

### Design

There were two experimental conditions: iSTART and Control. Approximately half of the children from each grade level were randomly assigned to either the iSTART condition ( $n = 18$ ;  $M = 12.6$  years,  $SD = 0.85$ ;  $n_{8\text{th grade}} = 9$ ;  $n_{9\text{th grade}} = 9$ ) or Control condition ( $n = 21$ ;  $M = 12.7$  years,  $SD = 0.84$ ;  $n_{8\text{th grade}} = 11$ ;  $n_{9\text{th grade}} = 10$ ). The unequal number of children per condition is due to three children assigned to the iSTART condition who were absent during the training sessions. Also, one of the ninth-grade children in the iSTART condition was not present when the Metacognitive Strategy Index was administered, and thus is not included in analyses that include that variable.

We assigned participants to a condition such that there was an equivalent representation of each grade level across conditions because the population comprised both grade levels. However, we did not expect differences as a function of grade level. As expected, there were no differences in comprehension or self-explanation quality as a function of grade level, and grade did not interact with any variables; thus, grade level is not included in any further analyses.

### Materials

#### *Reading Strategy Knowledge*

Reading strategy knowledge was assessed with the Metacomprehension Reading Strategy Index (MSI; Schmitt, 1990; Forget, 1999), which is a 25-item multiple-choice questionnaire designed to measure knowledge of metacognitive reading strategies such as predicting and verifying, previewing, purpose setting, self-questioning, drawing from background knowledge, and summarizing.

*iSTART Training Passages*

During the iSTART practice module, students generate self-explanations to two short passages taken from high-school science passages, called “Stages of Thunderstorm Development” and “Origin of Coal.” As shown in Table 1, the two training texts are comparable in terms of number of sentences and words, Flesch-Kincaid reading level, number of content words, and word frequency.

*Post-Training Self-Explanation Test*

After the training phase, the participants self-explained (without being provided feedback) a 19-sentence text on heart disease, which described the various causes and forms of common heart diseases. The passage was an excerpt from the low-cohesion version of the heart-disease text used in McNamara et al. (1996; Exp. 2). Various characteristics of the heart disease text are shown in Table 1 and the text is provided in Appendix A.

Students’ comprehension of the heart disease text was assessed with nine open-ended comprehension questions. Five of the questions were bridging-inference questions, and four questions were text-based. Bridging inference questions required the reader to bridge information across *two or more* sentences to form a correct answer. In contrast, the text-based questions could be correctly answered using information from a *single* sentence. The text is in Appendix A and the questions are in Appendix B. An example of a bridging-inference question is “Describe how a coronary thrombosis affects the heart”; while an example of a text-based question is “What causes rheumatic fever?” The answer to the former bridging inference question required four sentences to answer (i.e., The most common heart problem is a heart attack, or coronary thrombosis, which is caused when a coronary artery becomes blocked. The blood vessels that extend across the

Table 1. Descriptive Statistics for the Two Texts Read during Training (Thunderstorms, Coal) and the Post-Training Text (Heart Disease)

	Passages		
	Thunderstorms	Coal	Heart disease
Number of sentences	14	13	20
Number of words	198	209	293
Flesch-Kincaid grade level	9.35	10.33	7.96
Word frequency <sup>a</sup>	0.642	0.534	0.609

<sup>a</sup>Word frequency is expressed as the mean logarithm of the lowest word frequency content word in each sentence.

heart and supply it with blood are called the coronary arteries. They give the heart the oxygen it needs to carry on working. The blockage of a coronary artery is usually caused by a thrombus, or blood clot). The answer to the text-based question appeared within one sentence (i.e., For example, the disease called rheumatic fever follows a sore throat caused by bacteria called streptococci).

## Procedure

### *Metacognitive Strategy Index*

Participants were administered the MSI at their school as a group, one week prior to the training session. The assessment required approximately 5 to 10 minutes to complete.

### *iSTART Training*

Details concerning iSTART are provided in the introductory section. Participants in the iSTART condition were provided with training during two sessions on two consecutive days. They completed the three modules of the program (i.e., introduction, demonstration, and practice) as described in the introductory section of this article. The practice section involved reading and self-explaining two texts, one about thunderstorms and one about coal. The sentences were presented one sentence at a time and participants typed their self-explanations. The entire iSTART training lasted for an average of 1 hour 44.4 minutes ( $SD = 5.6$  min). Broken down by module, the average times in minutes were the following:  $M_{\text{introduction}} = 38.59$ ,  $SD = 5.32$ ;  $M_{\text{demonstration}} = 12.13$ ,  $SD = 2.47$ ;  $M_{\text{thunderstorms-practice}} = 27.09$ ,  $SD = 7.62$ ; and  $M_{\text{coal-practice}} = 26.3$ ,  $SD = 6.84$ .

Participants in the control condition were provided with a description of and examples of self-explanation via the iSTART system, but they were not provided with strategy training or practice using the reading strategies. That is, they were provided only with the initial portion of the iSTART introduction which describes the concept of self-explanation and provides an example of a self-explanation.

### *Post-Training*

Participants in both the iSTART and control conditions read and self-explained the heart-disease text one day following the training phase. The students read each sentence of the heart disease text and were prompted to type a self-explanation of the sentence, but were not given feedback or encouraged by the iSTART system. After completing the text, the students answered comprehension questions on paper about the heart disease text.

## RESULTS AND DISCUSSION

The analyses examine the effects of iSTART on students' ability to self-explain and comprehend science texts. Three sets of analyses were conducted. The first set of analyses compares iSTART and Control students' performance on the self-explanation tasks. The second set of analyses examines students' comprehension on the post-training heart disease text. The final set of analyses explores relationships between the self-explanations produced for the heart disease text and successful performance on the heart disease comprehension task.

Analyses were conducted to assess whether the effects differed as a function of prior strategy knowledge level (i.e., MSI). There were no significant differences between control and trained students on the MSI test,  $F(1, 36) = .60, p = .44$ , before training. Thus, the effects of training are not confounded by differences in prior strategy knowledge between participants in the iSTART and Control conditions.

### Self-Explanation

#### *Self-Explanation Scores*

Two independent coders analyzed the self-explanations for the heart disease text that was completed by all of the subjects after practice phase of the experiment.

Preliminary analyses indicated that the difference between iSTART and Control participants in terms of the proportion of self-explanations that contained paraphrases was not reliable ( $M_{\text{iSTART}} = .71, SD = .15; M_{\text{Control}} = .81, SD = .15, F = 2.37$ ). Therefore, our focus here was on whether the self-explanations contained elaborations, and on the quality of those elaborations. The coding scheme for elaborations was based on whether the self-explanations included any ideas that were not explicitly present in the target sentence. Explanations that contained no elaborations were given a score of 0 points. If a self-explanation was found to contain an elaboration, it was scored for quality in terms of its *contribution* and *accuracy*. As shown in Table 2, we identified how the elaborations contributed to comprehension using four distinctions: 1) irrelevant for the comprehension of the target sentence or the text in general; 2) relevant, but the content of the elaboration was inaccurate; 3) relevant and accurate, but the content of the elaboration contributed to the comprehension of only the target sentence; or 4) relevant, accurate, and contributed to a global level of comprehension that goes beyond the current sentence (e.g., actively building the larger picture depicted by the overall text). The latter type of elaboration, which we call "knowledge building," typically contains information located in multiple sentences (see Coté, Goldman, & Saul, 1998). Examples of the four types of elaborations in terms of their point value, contribution, accuracy, and frequency are reported in Table 2. The examples

Table 2. Examples of the Elaborations to the Sentence "The blood becomes purplish, and the baby's skin looks blue" as a Function of Quality, and the Frequency of Each Type as a Function of Condition

Elaboration type	Sample self-explanation	iSTART	Control
(0 pt) No elaboration	The baby's blood turns purple and the skin is blue.	206	340
(1 pt) Irrelevant	<u>They would have to call a code blue.</u>	16	5
(2 pts) Relevant, inaccurate	<u>When massive amount of carbon dioxide is in the blood stream and lungs it causes your blood to be purple instead of the regular red and then it changes the color of the skin making that turn blue.</u>	24	6
(3 pts) Relevant, accurate, current sentence focused	<u>When a baby starts to suffocate the blood in the body becomes very purplish and the baby's skin looks blue.</u>	69	45
(4 pts) Relevant, accurate, knowledge building	<u>The sign of the baby not getting enough oxygen and eliminating the carbon dioxide through the lungs is that the baby's blood will turn purple and the skin turns blue.</u>	27	3

**Note:** Elaborated information is underlined.

are taken from explanations for the sentence: "The blood becomes purplish, and the baby's skin looks blue."

It is important to note that we used a rather conservative criterion for distinguishing irrelevant elaborations from relevant current sentence focused elaborations. Elaborations were only classified as relevant when the contents directly contributed to a coherent understanding of the information contained in the target sentence, or the overall text; elaborations that were incoherent, incomprehensible, or overly ambiguous such that they could not be evaluated in terms of their accuracy were coded as irrelevant. For elaborations that were judged as relevant, the accuracy was determined based on the extent to which the elaborations were scientifically correct.

Reliability between the coders was 85% or above for all coding dimensions, indicating a reasonably high-level of agreement. Disagreements were resolved via discussion between the coders.

*Post-Training Heart Disease Explanations*

Table 2 presents the frequencies of each type of elaboration for the two conditions ( $\chi^2 = 69.72(4)$ ,  $p < 0.001$ ). Students in both conditions produced a large number of self-explanations with no elaborations. However, students trained with iSTART produced more explanations of sentences containing elaborations (i.e.,  $n = 136$ ). In contrast, students in the control condition generated only 59 explanations with any type of elaboration.

These data were analyzed in terms of self-explanation scores in the following analysis. The score for each explanation of a given sentence ranged from 0 to 4 (see Table 2). These scores were transformed into proportions by dividing the total scores by the number of sentences self-explained to produce a single score for each student.

The self-explanation scores by both condition and prior reading strategy knowledge are presented in Table 3. A  $2 \times 2$  ANOVA including *condition* (iSTART, Control) and *strategy knowledge* (high, low) yielded main effects of condition,  $F(1, 34) = 17.2$ ,  $p < .001$ , and prior reading strategy knowledge,  $F(1, 34) = 9.41$ ,  $MSE = .259$ ,  $p < .01$ , but a nonsignificant interaction,  $F(1, 34) = 2.25$ ,  $p = .14$ . These results reflect the finding that iSTART students produced better quality elaborations ( $M = 1.11$ ,  $SD = 0.79$ ) than control students ( $M = 0.41$ ,  $SD = 0.38$ ), Cohen's  $d = 1.13$ , and students with high reading strategy knowledge generated more elaborations ( $M = 0.90$ ,  $SD = .80$ ) than students with low reading strategy knowledge ( $M = 0.49$ ,  $SD = .39$ ), Cohen's  $d = 0.65$ .

In summary, the analysis of the quality of self-explanations for the heart disease text indicated that iSTART training resulted in self-explanations that included more relevant elaborations. Further, better quality self-explanations tended to be produced by students with greater prior reading strategy knowledge. Thus, both prior strategy knowledge and training contributed to self-explanation quality, but both high and low strategy-knowledge students benefitted from the training.

Table 3. Self-Explanation Scores (for Presence and Quality of Elaborations) as a Function of Training Condition and Prior Reading Strategy Knowledge

Condition	Low strategy knowledge			High strategy knowledge		
	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>
Control	0.27	0.21	10	0.54	0.45	11
iSTART	0.72	0.41	10	1.48	0.90	7

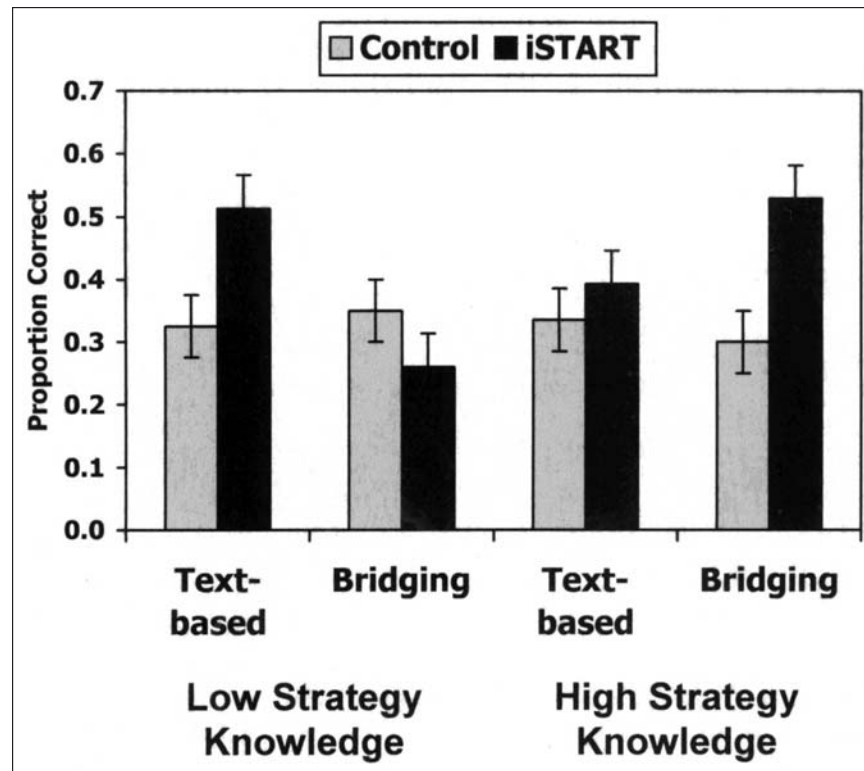


Figure 1. Comprehension as a function of reading strategy knowledge and question type.

### Comprehension

Two graders scored the data independently and resolved all disagreements by discussion. The comprehension questions were scored as either correct or incorrect, and partial credit (.25, .5, or .75) was given for partially correct answers. Comprehension performance was analyzed using a  $2 \times 2 \times 2$  mixed ANOVA including *condition* (iSTART, Control) and *strategy knowledge* (high, low) as the between-subjects factors and *question type* (text-based, bridging-inference) as the within-subjects variable. The dependent variable was the proportion correct on the comprehension questions for the heart disease text.

The analysis revealed a marginal interaction of question type and reading strategy knowledge,  $F(1, 34) = 3.35$ ,  $MSE = .037$ ,  $p = .08$ , indicating that low-strategy knowledge participants scored marginally higher on the text-based questions than the bridging inference questions ( $M_{TB} = .42$ ,  $SD_{TB} = .20$ ;  $M_{BR} = .31$ ,

$SD_{BR} = .18$ ),  $t(20) = 1.75$ ,  $p = .10$ , Cohen's  $d = 0.58$ , while high-reading strategy knowledge participants scored significantly higher on the bridging-inference questions than on the text-based questions. ( $M_{TB} = .36$ ,  $SD_{BR} = .27$ ;  $M_{BR} = .39$ ,  $SD_{BR} = .17$ ),  $t(20) < 0.5$ , Cohen's  $d = .11$ . There was also a marginal main effect for that condition,  $F(1, 34) = 2.72$ ,  $MSE = 0.062$ ,  $p = .11$ , Cohen's  $d = 0.41$ , indicating that iSTART participants scored somewhat higher ( $M = .42$ ,  $SD = .23$ ) than the control participants ( $M = .33$ ,  $SD = .21$ ). However, this main effect was qualified by a significant three-way interaction,  $F(1, 34) = 6.26$ ,  $MSE = 0.037$ ,  $p = .017$ .

Figure 1 shows proportion correct on the heart disease text as a function of reading strategy knowledge, condition, and question type. Among low-strategy knowledge participants ( $n = 20$ ), iSTART participants ( $M = .51$ ,  $SD = .19$ ) outperformed controls ( $M = .33$ ,  $SD = .18$ ) on text-based questions,  $t(18) = -2.26$ ,  $p = .018$  (one-tail test), Cohen's  $d = 1.00$ , whereas there were no differences between the conditions on bridging questions. In contrast, high-strategy knowledge participants showed no effects of condition on the text-based questions, whereas those in the iSTART condition ( $M = .53$ ,  $SD = .28$ ) performed better on bridging questions as compared to control participants ( $M = .30$ ,  $SD = .22$ ),  $t(18) = -1.90$ ,  $p < .038$  (one-tail test), Cohen's  $d = 1.04$ .

In summary, the comprehension data suggest that iSTART helped students learn more from text as compared to the Control condition which consisted of self-explaining the text, but without having had reading strategy training. In addition, the results also suggest that iSTART helps readers within their zone of proximal development (Vygotsky, 1978). For low strategy knowledge students, iSTART participants scored higher on the text-based questions; on the other hand, for high strategy-knowledge students, iSTART was most beneficial for bridging-inference questions. Thus, iSTART helped less strategic readers to better understand the basic ideas in the text, and helped more strategic readers to generate the inferences necessary to more accurately answer the bridging inference questions.

### **Post-Training Self-Explanation and Comprehension Relationships**

The analyses in this section explore the relationships between the quality of self-explanations and comprehension performance for the heart disease text. The first analysis was correlational. The second analysis was a GEE (Generalized Estimating Equation) analysis. GEE was introduced by Liang and Zeger (1986) as a method of estimation of regression model parameters when dealing with correlated data. It is essentially a non-parametric HLM. Regression analyses with the GEE methodology is a common choice when the outcome measure of interest is discrete. The use of this analysis here allows us to more directly test

whether self-explanation of a particular sentence led to better performance on the question that tapped that sentence.

### *Correlations*

We explored the relationship between self-explanation and comprehension by identifying whether the self-explanation contributed to the performance of text-based or bridging inference questions. This was achieved by categorizing sentences in terms of whether they contributed to the answer of a comprehension question. Two independent raters identified each sentence that related to the comprehension questions. For the text-based questions, only one sentence from the text could possibly relate to the comprehension question. In contrast, between two and four sentences could be related to the answer for a bridging inference comprehension question. There was a high level of agreement among raters (above 85% agreement across all the coding dimensions) regarding which sentences corresponded to the comprehension questions. Disagreements were resolved via discussion. Note that some sentences related to both the text-based and bridging inference comprehension questions. In such cases, the self-explanation quality for that sentence was used to calculate the correlations for both types of questions.

Table 4 shows the correlations between the self-explanation score of the sentence relevant to the comprehension question and students' performance on the comprehension questions for all participants, and separately for those in the control and the training conditions. The correlations for all participants indicate that the quality of self-explanations was significantly correlated with performance on comprehension questions, and that the correlations with the bridging questions were somewhat higher than with the text-based questions. The correlations by condition indicate that the overall relationship between comprehension and self-explanation quality was stronger for those in iSTART condition than for those in the Control condition, though the difference between these two correlations was marginal ( $p < .08$ ). The correlations further show that self-explanation was related to better performance on the bridging questions if the participants had received iSTART training, whereas self-explanation quality was related to performance on the text-based questions for those in the Control condition. Thus, self-explanation improves comprehension, and self-explanation training seems to help readers develop a deeper understanding of the text.

### *Generalized Estimating Equation (GEE)*

To further establish whether there is a direct relation between comprehension and self-explanation quality, we performed a GEE (Liang & Zeger, 1986). GEE allows us to examine the effect of iSTART on comprehension performance through self-explanation quality by partialing out the ability to self-explain text at the level of individual differences. Participants' comprehension performance

Table 4. Correlations between the Target Self-Explanation Scores and Comprehension Scores as a Function of Training Condition and For All Participants

	Condition	Comprehension score	Comprehension score (text-based questions)	Comprehension score (bridging questions)
Self-explanation score	iSTART	.727**	.232	.753**
	Control	.400	.539*	.146
	All participants	.610**	.397*	.538**
Self-explanation score (text-based questions)	iSTART	.622**	.009	.784**
	Control	.477*	.561*	.242
	All participants	.594**	.337*	.565**
Self-explanation score (bridging questions)	iSTART	.680**	.249	.680**
	Control	.141	.363	-.093
	All participants	.533**	.361*	.459**

\* $p < .05$ . \*\* $p < .01$ .

(correct or incorrect) on each comprehension question was the dependent variable. Condition (training versus control), participants' reading strategy knowledge (RSK) (high or low), and the self-explanations (SE) (i.e., elaborations) produced for the sentence(s) relevant to each comprehension question were the independent variables. Specifically, we examined two models of comprehension (Comp):

1. Comp = Condition (Training vs. Control) + SE Quality + (Condition  $\times$  SE Quality);
2. Comp = RSK + SE Quality + (RSK  $\times$  SE Quality).

The first model tests whether comprehension is affected by training and self-explanation quality; the second model tests whether comprehension is affected by prior reading strategy knowledge and self-explanation quality. Further, we used two different independent variables to represent the self-explanation in the model: 1) presence/ absence of elaboration; and 2) the 0-4 self-explanation score.

GEE estimates regression model parameters when dealing with correlated data. Regression analysis with the GEE methodology are appropriate when the outcome measure of interest is discrete (e.g., binary or count data, possibly from a binomial or Poisson distribution) rather than continuous (Liang & Zeger, 1986). Thus, we recoded participants' performance on some of the comprehension questions into binary scores when the original scoring system was not binary (e.g., a partial score such as 0.50). In other words, for each comprehension question, all the answers

originally scored as partially correct were re-scored as either correct or incorrect. Two judges agreed that all the answers originally scored as 0.50 or greater could be consistently re-scored as correct (i.e., 1) whereas answers scored as 0.25 could be re-scored as incorrect (i.e., 0).

Analyses were performed separately for performance on text-based questions and bridging questions because earlier analyses indicated these two types of questions showed different patterns of correlations with self-explanations. For text-based questions, there were no significant main effects of, or interactions between, condition and self-explanation, or between reading strategy knowledge and self-explanation (whether the presence/absence of elaborations or quality of self-explanations were used as the independent variable).

On the other hand, likelihood ratio chi-square statistics for bridging questions indicated a main effect of self-explanation, whether quality of self-explanation,  $\chi^2(1) = 4.8, p < .05$ , or presence/absence of elaborations,  $\chi^2 = 6.93, p < .01$ , was used as the independent variable. The effect of self-explanation quality did not interact with training condition,  $\chi^2(1) < 1.0$ . However, there was a marginal interaction between self-explanation and reading strategy knowledge for both the quality of self-explanation measure,  $\chi^2(1) = 3.06, p = .08$ , and presence/absence of elaborations measure,  $\chi^2(1) = 3.73, p = .05$ . Thus, the results indicate that comprehension items were more likely to be correct when associated with both the production of elaborations and high level reading strategy knowledge (OR = 3.18: *indicating that the Odds Ratio is significantly larger than 1.0*). However, the presence of elaborations (OR = 0.86) or high level of reading strategy knowledge (OR = 0.76) alone did not increase the probability that the comprehension score was correct.

Overall, the GEE analyses indicated that both reading strategy knowledge and the quality of self-explanation significantly affect comprehension. However, the quality of self-explanations, or presence of elaborations, does not interact with training condition in moderating the likelihood that participants provide the correct answer to a comprehension question. Thus, regardless of condition, the quality of the self-explanation provided for the sentences relevant to answer a question, together with the prior level of reading strategy knowledge affect the likelihood that participants provide the correct answer to a particular comprehension question.

## SUMMARY AND CONCLUSIONS

### Does iSTART Improve Comprehension?

This study examined the effect of reading strategies on adolescent students' comprehension in two ways. First we examined the effect of providing reading strategy training via the iSTART system. Second, we examined the students' prior knowledge of reading strategies. We found that both the training and prior knowledge of reading strategies improved the quality of self-explanations, and in

turn, comprehension. In addition, we saw that the benefits of reading strategy instruction depended on prior reading strategy knowledge. Whereas the benefits of iSTART were most apparent on the text-based questions for students with less knowledge of reading strategies, the benefits appeared on the bridging inference questions for those with greater prior knowledge of reading strategies. Thus, it appears that the majority of the students benefitted from iSTART, but in different ways, and according to their zone of proximal development. Those with less knowledge of reading strategies needed to learn how to develop a coherent understanding of the basic information conveyed in each sentence of the text. In contrast, those with more prior knowledge of reading strategies were able to make more bridging inferences and elaborations, which translated to better performance on the bridging inference questions.

Magliano et al. (2005) similarly found that with college students that the benefits of iSTART depended on the students' prior reading skill. In their study, the students read and self-explained two science texts before receiving iSTART training, and two after training. After reading the two texts, the students answered eight short-answer comprehension questions for each text. Magliano and colleagues found that skilled readers (according to the Nelson Denny Comprehension Test) answered more bridging questions correctly after training, whereas less skilled readers improved on the text-based questions. Thus, better readers learned how to make more connections within the text, and this ability became apparent on the bridging inference questions. In contrast, the less skilled readers needed to learn how to make sense of the individual sentences, and self-explanation training helped them to develop this ability. Future research will reveal whether additional, extended training will help less skilled or less strategic readers to go beyond sentence-level understanding and develop the skills necessary for a coherent, global understanding of challenging text.

### **Are Strategies Important?**

In contrast to some previous studies of strategy training, we saw here that iSTART translated to better performance both in the use of strategies and comprehension. Some prior studies of reciprocal training have found comprehension benefits but have not observed strategy changes (e.g., Lysynchuk et al., 1990; Palincsar & Brown, 1984; Shortland-Jones, 1986; Taylor & Frye, 1992). Here we are able to observe the strategies more *directly* via the self-explanation protocols, and as such, can track a more direct relationship between strategy use and comprehension.

The analyses of self-explanation protocols indicated that the students who were provided with iSTART generated higher quality self-explanations in that they were more likely to include elaborations of the sentence. These elaborations in turn translated to better performance on the comprehension questions corresponding to the self-explanations. Likewise, there was a positive relationship between self-explanation and comprehension for students with greater prior

knowledge of reading strategies. Thus, both prior reading strategy knowledge and training contributed to students' ability to self explain and in turn, comprehend the text.

Intervention research such as the current study feeds back to theoretical explanations of reading. The current study supports the notion that strategy use is a critical component of successful reading. This conclusion is supported both from the assessment of prior knowledge of strategies, as well as the effect of providing strategy training. Here we saw that both sources of strategy knowledge and training improved performance, both in terms of post-training self-explanation quality and comprehension of a low-cohesion science text. These results thus support theories of reading that emphasize the importance of inferencing and knowledge use for successful comprehension.

### **Future Modifications to iSTART**

Our current efforts are being directed on expanding the iSTART program so that it is more adaptive to student needs and can be more easily used in a classroom. This study tells us, for example, that assessing prior knowledge of reading strategies will allow us to better tailor training. In future versions of iSTART, less skilled and low strategy knowledge students will receive more training in lower level strategies, and more positive feedback for strategies such as paraphrasing. In contrast, we will continue to push more skilled students to go beyond the text by using strategies such as elaboration to create coherence.

We are also increasing the number and variety of texts that can be self-explained. In this way, students will have the opportunity to have more training and training with a wider variety of text genres. A greater amount of training will allow less skilled students to develop higher level skills necessary to build a deep understanding of difficult text. The use of a wider variety of text genres will help the student to learn when and how to use self-explanation and other reading strategies in multiple contexts.

Finally, we are developing a teacher interface to help manage what the students read and to monitor their progress. The interface will allow teachers to more easily implement iSTART according to their own needs.

### **What Can a Teacher Do Now?**

The modifications described above will require several years. So, what can a teacher do who does not have access to the iSTART program? First, it's important to note that iSTART stemmed from an experimenter-delivered program (i.e., SERT)—thus we have evidence that human-delivered training is effective (McNamara, 2004; McNamara & Scott, 1999; O'Reilly, Best, & McNamara, 2004; O'Reilly, Sinclair, & McNamara, 2004). The core of this training is that

the students learn to self-explain text, particularly when the going gets rough, and that the students learn reading strategies that help this process.

A teacher can implement the SERT program by explaining and demonstrating self-explanation. Paraphrasing is important because it helps the students to start the explanation. Elaboration, of course, helps the student construct a more coherent understanding. Elaborations can be generated using a number of sources: previous text, general knowledge or common sense, and topic-specific knowledge. It's not necessarily important that the student distinguishes between these sources, but it is important that the student learns that when topic-specific knowledge deficits are encountered, elaborations can be made using general knowledge, logical/analogical reasoning, common sense, and information from previous sentences in the text. These alternative sources of knowledge are essential to the success of SERT for low-knowledge readers (McNamara, 2004).

It is also important that the students practice using self-explanation. This can be achieved in a classroom in numerous ways. For example, as in SERT, the students can be placed in pairs and asked to take turns self-explaining the text. 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. The teacher, however, needs to be aware that for some students (e.g., less skilled readers), a good paraphrase is an accomplishment to be praised, whereas others (e.g., skilled readers) need to be pushed further to elaborate the text for a coherent, integrated understanding. Eventually, however, the goal is for all of the students to understand that a coherent understanding of text emerges from making connections within the text and to related information. Self-explanation along with reading strategies makes this possible when the student reaches an impasse in understanding.

## **APPENDIX A**

### **Heart Disease**

The heart is the hardest-working organ in the living body. Any disorder that terminates the body's blood supply is a threat to life. A congenital disease is one with which a person is born. Most babies are born with perfect hearts, but something can go wrong for approximately one in 200 cases. Sometimes a valve develops the incorrect shape causing it to be too tight or fail to close properly. Sometimes a gap is left in the septal wall between the two sides of the heart.

When a baby's heart is badly formed, it cannot work efficiently. If the baby's blood does not receive enough oxygen and cannot eliminate carbon dioxide through the lungs, the baby is in danger of suffocating. The blood becomes purplish, and the baby's skin looks blue. Diseases also cause the heart to form

improperly. For example, the disease called rheumatic fever follows a sore throat caused by bacteria called streptococci.

The tissues of the heart become inflamed and, if badly affected, can cause it to stop. Usually the heart recovers, but the heart valves are left with scars. Years later, they may fail to work properly and cause the heart to stop. The most common heart problem is a heart attack, or coronary thrombosis, which is caused when a coronary artery becomes blocked.

The blood vessels that extend across the heart and supply it with blood are called the coronary arteries. They give the heart the oxygen it needs to carry on working. The blockage of a coronary artery is usually caused by a thrombus, or blood clot. Whether heart disease is congenital, caused by other diseases, or the result of a blood clot, it is a very serious problem that requires medical attention.

## APPENDIX B

1. Describe an example of a defective valve.
2. How often does congenital heart disease occur?
3. What causes rheumatic fever?
4. What are two common defects occasionally found in the hearts of newborn babies?
5. If a person has a congenital heart problem, at which stage of life did it most likely occur?
6. If an infant's skin begins to turn blue, what is the most likely physical cause?
7. What is the main function of the coronary arteries?
8. Why is rheumatic fever, which is rarely fatal, considered such a serious condition?
9. Describe how a coronary thrombosis affects the heart.

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