iSTART: A WEB-BASED READING STRATEGY INTERVENTION THAT IMPROVES STUDENTS' SCIENCE COMPREHENSION

Tenaha O'Reilly
University of Memphis
202 Psychology Building
Memphis, TN 38152-3230 USA
t.oreilly@mail.psyc.memphis.edu

Grant P. Sinclair
University of Memphis
gsinclair@mail.psyc.memphis.edu

Danielle S. McNamara
University of Memphis
d.mcnamara@mail.psyc.memphis.edu

ABSTRACT

This study examined the impact of an automated reading strategy trainer called the Interactive Strategy Trainer for Active Reading and Thinking (iSTART) for improving students' reading comprehension of a science text. iSTART is an interactive trainer that utilizes animated agents to provide reading strategy instruction. The program contains both vicarious and interactive modules that provide adaptive feedback on the quality of students' self-explanations. Thirty-eight children from an east coast middle school were assessed in terms of their prior knowledge, reading ability, and reading strategy knowledge. Half of the participants were provided with iSTART training. Comprehension of a science passage was assessed with text-based and bridging-inference questions. The results indicated that children 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 over control students for bridging–inference questions. The results support the need for user-adaptive intelligent tutoring systems.

KEYWORDS

Reading Strategy Instruction, Animated Agents, User-adaptive Automated Tutors, Intelligent Tutoring Systems, Dialog-based Tutoring Systems

1. INTRODUCTION

Before the advent of modern technology, students had to rely on human tutors for their additional learning needs. While the effects of human tutoring are impressive (Bloom, 1984), there are several drawbacks including monetary cost, availability, and compatibility with the learner. Although intelligent tutoring systems have been available for several years (e.g., Carbonell, 1970), the integration of pedagogical agents and intelligent tutoring systems has only surfaced during the past 10 years (Chan & Baskin, 1990). Pedagogical agents, or animated characters, have been created to display a range of characteristics applicable to a wide set of tasks, from assisting instructors and students in virtual worlds (Johnson, 2001) to acting as content tutors in physics and computer literacy (Graesser, Person, et al. 2001). While successful systems such as AutoTutor (Graesser, Person, et al. 2001) have been developed to tutor students in a variety of content domains, there are few systems that utilize pedagogical agents to teach general comprehension strategies. Recently however, McNamara and her colleagues have developed a reading strategy trainer called the Interactive Strategy Trainer for Active Reading and Thinking (iSTART) to teach students reading comprehension strategies (McNamara, Levinstein, & Boonthum, 2004). The current version of iSTART was based on a reading strategy intervention called SERT (Self-explanation Reading Training). The goal of this study was to test the effectiveness of iSTART (the automated version of SERT) on improving middle-school students' science comprehension.

2. SERT

Self-explanation Reading Training (SERT) was developed by McNamara and her colleagues (McNamara, 2004; McNamara & Scott, 1999) to help students' understand difficult science texts. 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). SERT was designed to improve students' ability to self-explain difficult text by combining self-explanation training with metacognitive reading strategy training. SERT teaches readers to self-explain text and to use metacognitive reading strategies that improve self-explanation. 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. The first such strategy, *paraphrasing*, essentially helps students remember the surface structure of the text by transforming it into more familiar ideas. 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 draw upon logic and common sense, or domain-general knowledge, particularly when they do not have sufficient knowledge about the topic of the text. Research has established that both domain knowledge and elaborations are associated with improved learning and comprehension (e.g., Pressley et al. 1992; Spilich, Vesonder, Chiesi, & Voss, 1979). Elaboration essentially ensures 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 drawbacks to the training. Most notability, 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 cannot be tailored 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 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 schools with internet access.

3. iSTART

iSTART is a web-based reading strategy trainer that provides young adolescent to college-aged students with reading strategy training (McNamara, Boonthum, & Levinstein, 2004). The system uses pedagogical agents to instruct trainees in the use of self-explanation and other active reading strategies to explain the meaning of text while they read. First, the trainee is provided with instruction concerning self-explanation and reading strategies. During the Introduction Module of iSTART, the trainee is interactively engaged by a trio of animated characters that cooperate with each other, provide information, pose questions, and provide explanations of the reading strategies. These are full-body figures with slightly exaggerated heads to make mouth movements and facial expressions more visible (see Figure 1a). The three characters (an instructor and two students) speak using a text-to-speech synthesizer and possess a repertoire of gestures. The interactions between the characters vicariously simulate the active processing necessary to learn the strategies; this is an improvement over the lecture version of SERT. The characters interact in several ways. The instructor character presents definitions and examples for each strategy and questions the student characters' knowledge of the strategies. The student characters banter among themselves as they ask the instructor for examples or clarifications. After the presentation of each strategy, the trainees complete brief multiple-choice quizzes to assess their learning. The quizzes are designed as learning tools to guide the trainee to a better understanding of each SERT strategy by providing hints, prompts, and explanations for incorrect choices.

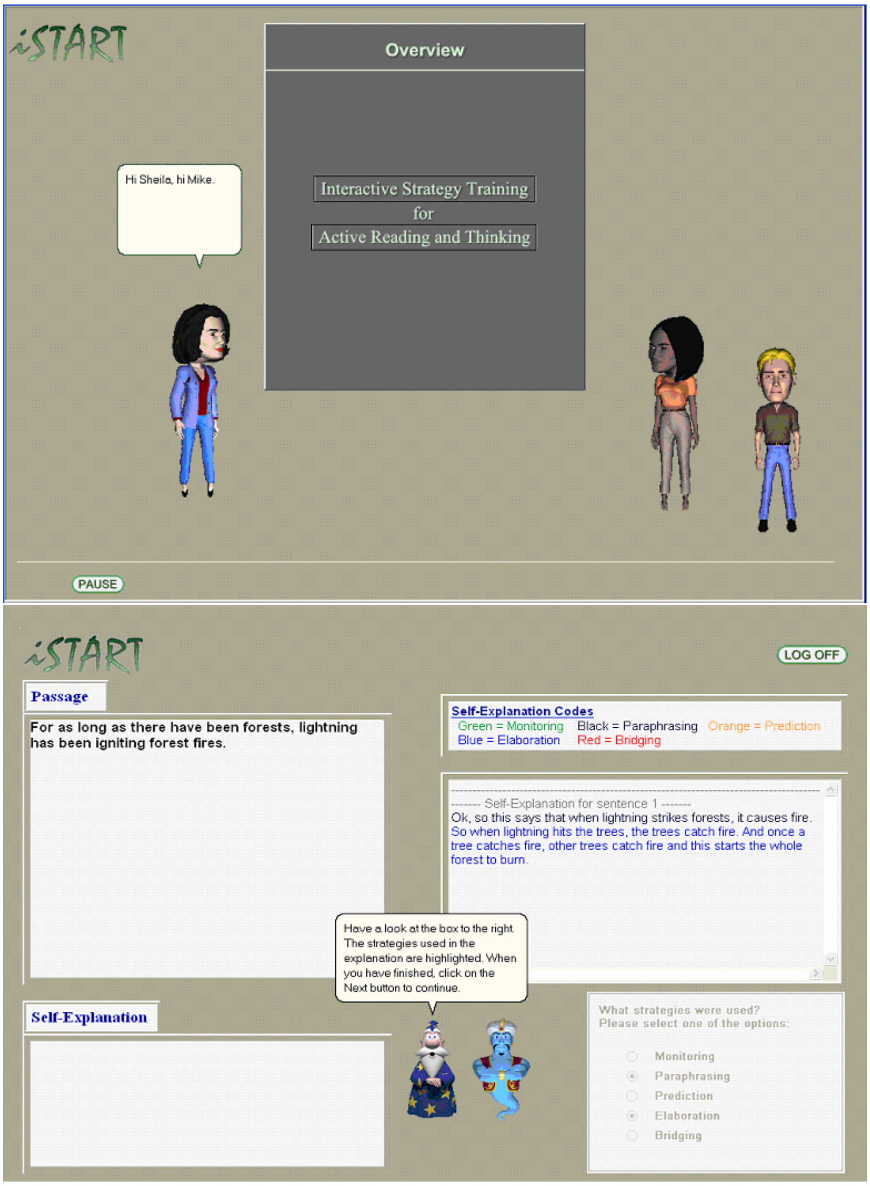

Figure 1a and 1b. Screen shots of the Introduction Module of iSTART (with three pedagogical agents Dr.Julie, Sheila, and Mike) and the Demonstration Module (with Merlin and Genie).

In the second phase, called the Demonstration Module, two agents demonstrate the use of self-explanation and the trainee identifies the strategies being used (see Figure 1b). We use two different Microsoft Agent characters, Merlin and Genie, to demonstrate the ways in which the five SERT strategies can be put to use when reading science texts. A science text is presented on the computer screen one sentence at a time. Genie (representing a student, or learner) reads the sentence aloud and produces a self-explanation. His self-explanation appears in the self-explanation box, as shown in Figure 1b. Merlin (the teacher character) continues by asking the trainee to indicate which strategies Genie employed in producing his self-explanation. The trainee answers by clicking on a strategy in the bottom-right corner (Figure 1b). Merlin follows up by asking the student to identify and locate the various reading strategies contained in Genie's self-explanation. The student answers by clicking on the self-explanation in the self-explanation box. For example, if the student answered that Genie had provided an elaboration in his self-explanation, then Merlin might ask the student to click on the part of the self-explanation that contained the elaboration. Finally, Merlin gives Genie verbal feedback on the quality of his self-explanation. This type of feedback mimics the interchanges that the student will encounter in the practice module. For example, sometimes Merlin states that the self-explanation is too short, prompting Genie to add to his self-explanation. After an exchange for a particular sentence that Genie has explained, his self-explanation appears in the upper-right box and is color coded by strategy. The student can then re-examine the self-explanation and the strategies used.

In the third phase, called practice, Merlin coaches and provides feedback to the trainee while the trainee practices self-explanation using the repertoire of reading strategies. The goal is to help the trainee acquire the skills necessary to integrate prior text and prior knowledge with the sentence content. For each sentence, Merlin reads the sentence and asks the trainee to self-explain it by typing a self-explanation. Merlin gives feedback, sometimes asking the trainee to modify unsatisfactory self-explanations. Once the self-explanation is satisfactory, Merlin asks the trainee to identify what strategy was used and where in the sentence that they used it; after which Merlin provides general feedback. During this phase, the agent's interactions with the trainee are moderated by the quality of the explanation. For example, more positive feedback is given for longer, more relevant explanations, whereas increased interactions and support are provided for shorter, less relevant explanations (see McNamara et al., 2004; and McNamara, Boonthum, Levinstein, & Millis, in press, for explanation of the feedback system).

The purpose of the current study was to examine the effect of iSTART on students' comprehension of a science text. Thirty-eight 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). Half of the students were provided with the complete iSTART training prior to reading and self-explaining the text. The students in the control condition were provided with a short module (from iSTART) that described self-explanation but did not provide information about reading strategies, reading strategy training, or self-explanation practice. It was expected that as compared to the control condition, iSTART would improve participants' ability to self-explain, and in turn, better comprehend the heart disease text.

A second focus of the study was to explore the impact of prior reading-strategy knowledge on the effectiveness of iSTART. Prior research has indicated that metacognition and the self-regulation of knowledge has a large impact on comprehension (e.g., Everson & Tobias, 1998). Given that iSTART training has an emphasis on teaching metacognitive strategies, our goal was to determine if the effectiveness of the iSTART program depended on the students' prior knowledge of metacognitive reading strategies. One prediction was that iSTART would help low strategy-knowledge students better understand the text by allowing them to more effectively monitor, manage, and integrate the information from the text with existing knowledge. However, it was less clear how iSTART would impact high strategy-knowledge students. One possibility was that iSTART would not impact high strategy-knowledge students because they may already possess the necessary strategy knowledge to effectively learn from text. Alternatively, iSTART might facilitate more strategic students' science comprehension. This prediction is based upon the notion of "access and use." Although having a reasonable amount of reading strategy knowledge is beneficial, it does not mean that the student knows *how* and *when* to *use* and *apply* that knowledge (e.g., Ross, 1989; Gick & Holyoak, 1980). iSTART not only provides information about reading and reading strategies, it also teaches students how to effectively *use* the strategies. In this manner, it was expected that iSTART would also help high-strategy knowledge students.

We further suspected that the effects of training would 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 greatly depends on the extent to which prior knowledge is applied to the text by the reader. 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.

4. METHOD

Participants

The sample consisted of 38 eighth and ninth grade children (11 males, 28 females) from an east coast suburban school in the United States. The students were enrolled in a summer learning program, called Learning Bridge, designed to motivate students from under-privileged backgrounds.

Materials

Individual differences were measured by three different tests: a modified version of the Gates-MacGinitie Reading Skill Test, a Prior Knowledge Test, and a reading strategy knowledge measure called the Metacomprehension Reading Strategy Index (MSI; Schmitt, 1990). The Gates-MacGinitie test is a standardized reading comprehension test, designed for grades 10-12. The test consisted of 40 multiple-choice questions designed to assess student comprehension on several short text passages (Cronbach's Alpha α=.91). Due to time constraints, the vocabulary section of the test was not administered, and the time limit for the comprehension question section was reduced to 15 minutes.

The prior science knowledge test consisted of 35 multiple-choice items, which tap knowledge of different science domains, including biology, scientific methods, earth science, physics, mathematics, and chemistry (Cronbach's Alpha α=.81). An example question is: "What force keeps the planets in orbit around the Sun?: a. the motion created from rotation; b. gravity; c. revolution of the planets; d. solar energy."

The reading strategy knowledge measure (MSI; Schmitt, 1990) 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. While the original scale was developed to be used with narrative passages, the scale is easily adapted for use with expository passages (see Schmitt, 1990). In this study, the Cronbach's Alpha for the MSI was α=.58.

The target text, on heart disease, was read and self-explained by participants in both conditions. The passage described the various causes and forms of common heart diseases (modified from McNamara et al., 1996). The text was 291 words in length and had Flesch-Kincaid Grade level of 9.3 and a Flesch Reading Ease 55. The passage was accompanied by nine open-ended comprehension questions. Five of the questions were bridging-inference questions, while the remaining 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 by selecting content from a *single* sentence. An example of a bridging-inference question is: "Describe how a coronary thrombosis affects the heart." An example of a text-based question is: "What causes rheumatic fever?" The answer to the bridging inference question required four sentences from the text ("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."). The answer to the text-based question appeared within one sentence ("For example, the disease called rheumatic fever follows a sore throat caused by bacteria called streptococci.").

Procedure

Participants were given the pretest aptitude assessments in the following order: the prior science knowledge (15min), the Gates-MacGinitie Reading Skill Test (15min), and the MSI reading strategy knowledge (approximately 5-10min). The first two were time-limited tests, whereas the MSI was not timed.

Participants in the iSTART condition were provided with training a week following the pretests. There were two training sessions on consecutive days that lasted approximately 1 hour each. The iSTART participants were told that the purpose of the study was to teach them strategies that would help them better understand and remember what they read. They completed the three modules of the program (i.e., introduction, demonstration, and practice) as described earlier. The practice module involved reading and self-explaining two texts, one about thunderstorms and one about coal. The sentences were presented one sentence at a time. Participants typed their self-explanations into the computer.

Participants in both conditions then read and self-explained the heart disease text. Participants in the control condition were given a description and examples of self-explanation, but were not given training or practice on the reading strategies. The students read each sentence of the text and were prompted to type a self-explanation of the sentence, but were not given feedback or encouragement by the iSTART system. After completing the text, the students answered comprehension questions about the heart disease text. The comprehension test was completed on paper and was not timed.

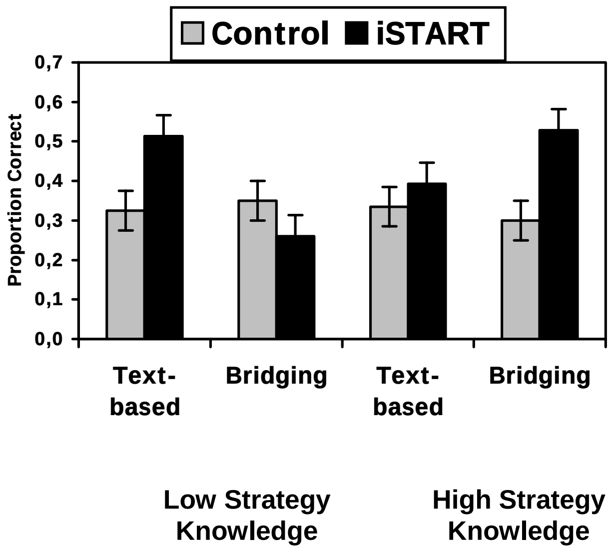

Figure 2. Proportion correct on heart disease text comprehension questions as a function of condition (control, iSTART), question type (text-based, bridging inference), and strategy knowledge (low, high).

Results

Separate analyses of variance verified that the two conditions did not differ as a function of the three aptitude measures (i.e., prior science knowledge, reading strategy knowledge, and reading skill), $Fs<1$. Participants were categorized as high- and low-strategy knowledge using a median split on MSI performance. A mixed ANOVA was conducted with condition (iSTART, control) and strategy knowledge (high, low) as the between-subjects variables and question type as the within-subjects variable. The analysis revealed a marginal interaction of question type and reading strategy knowledge, $F(1,34)=3.35$, $MSE= .124$, $p=.08$, indicating that low-strategy knowledge participants scored higher on the text-based questions ($M_{TB}=.42$, $SD_{TB}=.19$; $M_{BR}=.31$, $SD_{BR}=.18$), while high-reading strategy knowledge participants scored higher on the bridging-inference questions ($M_{BR}=.41$, $SD_{BR}=.25$; $M_{TB}=.36$, $SD_{TB}=.27$). There was a marginal main effect for condition, $F(1,34)=2.72$, $MSE=0.220$, $p=.11$, 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, $F(1,34)=6.26$, $MSE=0.232$, $p=.017$, Cohen's $d=0.43$. Figure 2 shows proportion correct on the heart disease text as a function of reading strategy knowledge, condition, and question type. Among low-strategy knowledge participants, iSTART participants ($M=.51$, $SD=.19$) outperformed controls ($M=.33$, $SD=.18$) on text-based questions, $t(18)=-2.26$, $p=.018$, Cohen's $d=1.00$. In contrast, for high-strategy knowledge participants, those in the iSTART condition ($M=.53$, $SD=.28$) performed better on bridging questions as compared to control participants ($M=.30$, $SD=.22$), $t(18)=-1.90$, $p<.038$, Cohen's $d=1.04$.

5. CONCLUSION

The results of this study are important in at least two respects. First, the findings extend prior work showing an advantage of SERT for comprehension (McNamara, 2004) by demonstrating that an automated version of the training, iSTART, enhanced science comprehension. Thus, an automated, web-based trainer that uses multiple pedagogical agents significantly impacted young readers' ability to comprehend science text. This result further supports the view that reading strategy training can help students better understand what they read (Brown, 1982). Research clearly indicates that better readers more actively and strategically process difficult text (e.g., Bereiter & Bird, 1985). iSTART was designed based on constructivist principles to help students learn these strategies. As such, iSTART combines recent advances in computing technology with our current theoretical understanding of text comprehension to improve educational practices. Current technology provides the ability to hold a meaningful dialogue with the student, to engage the student, and to accurately interpret the student's input into the system. As such, the use of computational linguistic modules allows us to accurately interpret the students' self-explanations and to respond appropriately (see e.g., McNamara et al., 2004; McNamara, Boonthum, Levinstein, & Millis, in press; Millis et al., 2004; Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002).

Second, the results of this study are important because they further support the need for adaptive training, and technology provides the means to achieve this goal. Specifically, the results demonstrate that iSTART helps both high and low strategy-knowledge students in different ways. Low strategy-knowledge students outperformed control participants on text-based questions, whereas high strategy-knowledge students scored higher on bridging-inference questions. These findings are in line with Vygotsky's theory of zone of proximal development (Vygotsky, 1978). That is, iSTART helps students in a manner that is closest to their proximal level of development, or the highest level they can achieve with the appropriate scaffolding.

Moreover, the results suggest that the impact of iSTART may be improved by adapting training to the needs of the learner. Specifically, these results indicate that less strategic students should be provided with more training overall. First, they should be provided with more basic-level training to monitor their comprehension and paraphrase the text. Once mastered, they should be provided with more training to help them move toward deeper levels of comprehension. This training would involve extended practice on the more difficult strategies such as making bridging or elaborative inferences. In contrast, more strategic students may gain from receiving less basic-level training, and concentrating more on the higher-level strategies. While our current version of iSTART successfully adapts to the students' performance levels as they proceed through the program, future versions will also adapt to the student based on prior aptitude assessments. In this way, students will be provided with the type and depth of strategy training that addresses their needs.

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