Improving children’s reading comprehension and use of strategies through computer-based strategy training

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Abstract

In this study, the attention–selection–organization–integration–monitoring (ASOIM) model, revised from Mayer’s [Mayer, R. E. (1996). Learning strategies for making sense out of expository text: The SOI model for guiding three cognitive processes in knowledge construction. Educational Psychology Review, 8, 357–371] SOI model of text comprehension, was used as a foundation to design a multi-strategy based system, which was named Computer Assisted Strategy Teaching and Learning Environment (CASTLE). CASTLE aims to enhance learners’ abilities of using reading strategies and text comprehension. The effects of CASTLE on students with different reading abilities were empirically evaluated. 130 sixth graders took part in an 11-week computer-based reading strategies course. The results show that CASTLE helps to enhance the students’ use of strategies and text comprehension at all ability levels.

Keywords: Computer assisted reading; Strategies; Comprehension

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1. Introduction

For enhancing reading ability, one of the methods most often recommended by researchers is reading strategy instruction. Reading strategy instruction is found to be effective. Through a deliberate design, it deals with problems on the vocabulary and sentence levels (Fischer, 2003; Sindelar, Monda, & O'Shea, 1990) as well as higher-level issues such as text comprehension (Alfassi, 2004; De Corte, Verschaffel, & De Ven, 2001; Johnson-Glenberg, 2000; van Keer, 2004). In recent years researchers have tried to deduce principles of reading strategies from empirical studies (Dole, Duffy, Roehler, & Pearson, 1991; Mastropieri & Scruggs, 1997). Some of the more widely recommended approaches are determining the main messages (e.g., summarization), using text enhancements (e.g., illustrations, text structure representations, and mental images), question and answer drills (e.g., self-questioning), meta-cognition (e.g., comprehension monitoring). Paris and Paris (2001) postulated that the using multiple strategies is one of the several important characteristics in successful reading strategy instruction.

In fact, considering the characteristics of successful strategy instructions described by Paris and Paris (2001), one can find that it is rather difficult for teachers to create those conditions in physical classroom environment. Take multiple-strategy instruction as an example. It takes a significant amount of training for most teachers to become familiar with using the strategies and being able to teach them to their students (Duffy, 1993a). In addition, preparing teaching materials for instruction simply takes too much time and energy (Pressley, Johnson, Symons, McGoldric, & Kurita, 1989). There are also complexities involved in providing students with opportunities to apply the strategies in daily life. Perhaps the difficulties mentioned above are the major reasons why strategy instruction is seldom implemented in classrooms (van Keer, 2004). Therefore, it is essential to create a proper environment for teaching assistance which can relieve teachers from their burden in implementing strategy instruction and help them to increases students’ opportunities and willingness to use reading strategies outside the classroom.

The difficulties of implementing reading strategy instruction in classrooms may be reduced with the assistance of information technology. Computer-assisted instruction has been very popular during the last two decades, and scholars agree on the feasibility of applying computers in reading instruction under appropriate designs (Labbo & Reinking, 1999; Leu et al., 1998; Lungberg, 1995). There are generally several advantages of incorporating computers in reading instruction (Lynch, Fawcett, & Nicolson, 2000; Mathes, Torgesen, & Allor, 2001). Firstly, computers can provide immediate individual feedback based on student’s learning condition. Secondly, learning with computers allows students to control the pace of learning by themselves. Thirdly, properly arranged courses may be operated independently with computers, thus relieving teachers from some of the burden and giving students more opportunities to learn independently. Finally, through presentations using different media, students’ motivation to read may be strengthened.

It is worth noting that, although the computer-assisted reading has had some impressive results (see Blok, Oostdamp, Otter, & Overmaat, 2002; MacArthur, Ferretti, Okolo, & Cavalier, 2001, for reviews), there are some limitations as well. Regarding levels of reading abilities, most studies on computer-assisted reading have dealt with reading issues on a more fundamental level, such as word recognition (e.g., Frederiksen, Warren, & Roseberry, 1985; Wise, 1992; van Daal & Reitsma, 2000) or phonological awareness (e.g., Farmer,
Klein, & Bryson, 1992; Mathes et al., 2001; van Aarle & van den Bercken, 1999). There are relatively few studies focusing on assisting higher-level text comprehension through computer technology. Currently, the majority of efforts on computer-assisted comprehension focus on the effects of text enhancement (such as indexes of difficult vocabularies or background information for texts, Chang, Sung, & Chen, 2001; Leong, 1995; MacArthur & Haynes, 1995; Reinking, 1988) or visual or auditory aids (such as illustrations, images or speech, Elkind, Cohen, & Murray, 1993; Montali & Lewandowski, 1996) on enhancing text comprehension. Those studies usually concerned with manipulating the assisting messages, and dealt with the improvement of learners’ reading capabilities to a very limited degree. Their practical implications are still in debate (MacArthur et al., 2001).

Computer-assisted reading strategy training is a feasible approach to enhance students’ capabilities to deal with texts. Regarding the training of strategies for text comprehension, there have been some studies on using computer technology to conduct strategy instruction (Caverly, 1998; Chang, Sung, & Chen, 2002; Kaniel, Licht, & Bracha, 2000). But those strategies were chosen in a fragmented fashion, and were lack of integration. For example, Caverly (1998) used software for gathering strategies, arranging and presenting materials, while Chang et al. (2001) and Chang et al. (2002) used the concept mapping strategy. Because currently, much emphasis is placed on using multiple-strategy instruction in classroom situations (Paris & Paris, 2001; Pressley, Johnson, et al., 1989), we suggest it is important to find out how to design proper multiple strategies with computer technology to facilitate text comprehension abilities. Considering that there is a limited number of computer environments which are directly aimed at the learner’s reading abilities and are equipped with a set of comprehension strategies, the first purpose of this study is to design a reading instruction system with multiple strategies based on the components in the text comprehension process.

Another limitation of current available studies on computer-assisted reading is that most studies conducted on elementary school children focus on students with below-average learning ability (MacArthur et al., 2001). In contrast, there are fewer studies using students of average or above-average abilities as participants. Some studies on strategy instruction indicated that children of lower learning ability benefited less than those with average or above-average abilities (Garner, 1982). Nevertheless, some other researchers found that students with poorer abilities still managed to benefit from strategy instruction (Brown, Pressley, Van Meter, & Schuder, 1996; De Corte et al., 2001; Duffy, 1993b; Palincsar & Brown, 1984). There are few studies related to issues of whether strategy instruction in a computer environment produces different instructional effects on children with different abilities. Thus, the second purpose of this study is to compare the benefits for children with different abilities using computer-assisted reading strategies.

2. Method

2.1. Participants

The participants in this study were sixth-grade students from four classes in an elementary school of Taoyuan County, Taiwan. There were 65 students in the experimental group (35 males and 30 females) and 65 students in the control group (34 males and 31 females). The majority of the children were from middle-class families. The age of the students ranged from 12 to 13, with an average of 12 years 3 months.
2.2. Design

This study employed a quasi-experimental design. The independent variables in the experiment included group (experimental or control) and reading ability (high or low). Each class was randomly assigned into the experimental group or the control group. The students were given the Reading Comprehension Screening Test (Ko, 1999) prior the experiment. Students whose scores were higher than the average of all sixth-grade students were categorized to the high reading ability group, while those with scores lower than the average went into the low reading ability group. The experimental group had 31 high-ability and 34 low-ability students. The control group had 35 high-ability and 30 low-ability students. The dependent variables included a reading comprehension score of narratives, a reading comprehension score of exposition, and a score of using reading strategies, which was further divided into five categories, self-questioning, error detection, inference blank-filling, summarization, and prior-knowledge integration. The covariate was the students’ scores in their language arts course of the previous school year.

2.3. Experimental tool

This study developed a Computer Assisted Strategy Teaching and Learning Environment (CASTLE) as the major tool for implementing the strategy instruction. To find a sound base for designing strategies for CASTLE, the researchers of this study examined various models of reading comprehension (e.g., Just & Carpenter, 1987; Kintsch, 1998; Mayer, 1996). Finally, the Mayer’s (1996) Selection–Organization–Integration (SOI) model for text comprehension, which we believed was a suitable framework, was utilized in choosing and designing reading strategies. In Mayer’s model, selection means that in reading an article, one needs to know which parts of the content are more important and which ones are less important. Organization means that one has to re-organize the selected messages in the short-term memory, and then to form a coherent, interconnected overall concept. Integration represents linking the knowledge organized in short-term memory with former acquired knowledge into long-term memory. However, Dole et al. (1991) pointed out that the readers’ attention and whether they know how to monitor their own comprehension are important factors influencing comprehension. Although the SOI model has been validated by several studies about text-based reading (see examples in Mayer, 1996) and multimedia-based reading (Harp & Mayer, 1998), the SOI model does not sufficiently reflect the components of attention and monitoring in reading. So, this study expanded Mayer’s SOI model by adding the components of attention and monitoring. The attention–selection–organization–integration–monitoring (ASOIM) model (see Fig. 1) was constructed as the framework for selecting and designing comprehension strategies in this study. These strategies then formed the basis for designing a multiple-strategy reading assistance system, CASTLE. The examples, functions, and workflow of CASTLE are explained in details in the Procedure section. The following explains the detailed design of each strategy.

Strategies for attention. The strategies of self-questioning and error detection were used to help readers concentrate on reading texts. Self-questioning meant that learners asked themselves questions while reading an article. For example, after readers had read an article, they asked messages of the article regarding who (characters), what (events), where (settings), when (time) and why (reasons), and then they would answer to those questions. For expository texts, questions regarding what, how, why, or relationships were more
emphasized. Andr’ê and Anderson (1978–1979) and Anderson (1978) proposed that by using this strategy, students would have to constantly focus their attention on the material they were reading. A number of studies (Clark, Deshler, Schumaker, Alley, & Warner, 1984; King, 1989; Short & Ryan, 1984) also found that this strategy helped to enhance comprehension. Another aspect of strategies for attention was error detection which meant that readers should find explicitly or implicitly contradictory messages in the content of the article they were reading (Markman, 1979). In the process of error detection readers must concentrate to find any contradictions. This study incorporated it as one of the strategies for attention.

**Strategies for selection.** This study used strategies of concept map blank-filling and highlighting to train the participants to select important messages. Novak and Gowin (1984) argued that when teaching materials were presented through concept maps, students could easily find the interrelation of the concepts. To avoid the difficulty of producing concept maps from scratch, this study applied the concept map blank-filling strategy by Chang et al. (2001), asking students to select corresponding important messages to supplement the missing parts of the concept maps. The highlighting strategy was implemented by researchers to confirm key concepts and to enhance reading comprehension (Shaughnessy & Baker, 1988; Wade & Trathen, 1989).

**Strategies for organization.** This study also adopted the strategies of concept map correction and inference blank-filling to train readers how to organize the messages in an article. The concept map correction method worked as follows. After the students had finished reading an article, they would be given a complete concept map in which some concepts were wrong. The students needed to select the correct concepts from a list of concepts provided by the system and then fill them in. Because the students must understand the organization and relationship of the main concepts in the entire concept map before they could judge which concept nodes were correct or incorrect, the student had to organize and link the concepts in the entire article. This process might help students to organize the ideas in the text (Chang et al., 2002). Inference blank-filling requires the
readers to resort their own abilities in order to supply the missing important messages in the context of the article. The system left out some blanks in an article. The readers needed to make judgments according to the context of the article, chose the correct words or phrases from a pull-down menu provided by the system, and then filled them in the blanks.

Strategies for integration. This study used proposition-combining and summarization strategies to train the readers to integrate knowledge. Proposition combining was derived from the sentence-combining strategy (Fusaro, 1992; Neville & Searls, 1991). The difference between proposition combining and sentence combining is that combining sentences formed paragraphs, while combining propositions used concepts (arguments) as units and combined them into propositions. In the strategy of proposition combining, important concepts were picked out from an article, and then mixed with new concepts related or unrelated to the old propositions that were not found in the present article (the concepts were chosen from textbooks previously used by the readers). Then, the system provided relation links (predicates) for the readers to integrate the concepts. Summarization was a strategy preferred by many researchers. Anderson and Hidi (1989) pointed out that a summary was a brief narrative of condensed information to represent the original article, which could help students comprehend the reading material and organize the article they were reading. In fact, it is not easy to re-organize the important concepts in an article without a fair amount of prior knowledge as foundation. Therefore, summary to a certain degree should involve integrating new and old knowledge (Palincsar & Brown, 1984). This study adopted a method based on Brown and Day (1983) and Dole et al. (1991), which asked readers to select important content from an article, to delete the trivial and redundant details, and to combine the remaining important sentences.

Strategies for monitoring. The purpose of the monitoring strategy in this study was to train students to understand how well they are executing the strategies in the four processes described above. By doing this, we tried to foster the reader’s awareness in their own comprehension and employment of strategies. The method used in this study was based on the informed strategies for learning by Paris, Gross, and Lipson (1984), which asks readers to remind themselves and to evaluate their state of learning after completing each strategy learning session through the verification of sentences related to the use of strategies.

After the selected strategies were implemented in CASTLE system, this study invited 52 fifth graders to participate a 20-h pilot study. And the opinions from these students and their teachers were integrated for the revision of the interface and the procedure of CASTLE system. Through the current version of CASTLE, teachers might replace the texts used in CASTLE with any texts they think are suitable for their classes. More functions for teachers’ selection and design of other types of reading strategies fitting their needs are under implementation.

Teaching materials. The teaching materials were 62 articles which were selected and modified jointly by the researchers and an elementary school teacher. Of these, 33 were narratives and 32 were expository texts. For the experiment group, these articles were incorporated into CASTLE, and each reading strategy instruction unit contained about eight articles for practice.

2.4. Measures

Reading comprehension tests. The Expository Text Comprehension Test (ETCT) and the Narrative Text Comprehension Test (NTCT, Lin & Su, 1991) were adopted as post-
test tools to evaluate the students’ comprehension abilities. The ETCT included five pieces of expository writings from both scientific and social science domains. Each article had about 200–400 Chinese characters. The NTCT contained five stories, each story included about 200–350 Chinese characters. Both tests had 25 multiple-choice questions constructed from those articles or stories. The students scored 1 point for each correct answer. A pilot test on 196 fifth and sixth graders had Cronbach \( \alpha \) coefficients of 0.69 and 0.71 for NTCT and ETCT, respectively. The criterion-related validities using the scores of language arts courses in the previous school year as the criterion were 0.50 and 0.49 for NTCT and ETCT, respectively.

Use-of-strategy test. The use-of-strategy test was developed for understanding the students’ abilities of using strategies after the strategy instruction. The strategy-use test left out strategies that needed operations requiring long practice sessions, such as concept mapping. There were five subtests. In each strategy subtest, one narrative and one expository article were given. The articles, titles, word count, guiding remarks, and score ranges of the strategies are shown in the appendix. The format and rationale for the construction are as following:

For the self-questioning, the students were required to write down five questions and answers to those questions after reading each article. The standards for scoring were based on the self-questioning strategy instruction by Clark et al. (1984) and the story grammar strategy proposed by Short and Ryan (1984). If the questions posed by the students were related with the characters, setting, events, time, reasons, how, or relationships in the article, then they earned 1 point. If students’ answer for the posed question was correct then they got one more point.

For error detection, students had to detect the explicit and implicit contradictions, based on Markman (1979), in the article. Each article contained six errors, and each error detected could score 1 point.

For inference blank-filling, the content was designed according to the cloze test by Schmitt (1987). Each article contained 10 blanks related to the context. The students could earn one point for each correct blanks.

For text summarization, one narrative and one expository articles were provided. The students were required to summarize each article in about 250 words. According to Garner (1982), summarizing efficiency represented students’ summarizing abilities. Summarization efficiency scores ranged from 0 to 1, the fewer words used to represent the main ideas of an article, the higher the summarization efficiency. The idea units, which corresponded roughly to the major clauses of the sentences (Lorch & Lorch, 1996), in the summary were labeled level 1, 2 or 3 according to their importance. 1 represented the main concepts that should be appeared in the summary, while 2 and 3 meant those secondary and unimportant concepts that should not be appeared in the summary. The number of main concept units was divided by the total number of characters in the summary to get an indicator of summary efficiency. There were 13 and 14 idea units in the narrative and expository articles, respectively. If students’ summaries had any level 1 idea units which were as same as the idea units in the articles, then they earned one point.

For prior-knowledge integration, this test was designed according to the elaboration questions proposed by Gagne, Yekovich, and Yekovich (1993). It asked the readers to elaborate their ideas on the article after completing the reading, such as giving more detailed description of the situations in the text, citing examples, telling the possible following scenarios, or making analogies. If the students’ elaborations were belong to any
of the four categories mentioned above and were related to the text, then one point was assigned. Each correct cited example and analogy could score one point (maximum 3).

Ninety-nine sixth and fifth graders were sampled to get the reliability coefficients for the subtests. For the narrative article, the Kuder–Richardson reliabilities were .68 and .64 for the error detection and inference subtests, respectively. The inter-rater reliability from two graduate students scoring the self-questioning, summarization, and prior-knowledge integration were .83, .84, and .82, respectively. For the expository article, the Kuder–Richardson reliabilities were .65 and .63 for the error detection and inference subtests, respectively. The inter-rater reliability from two graduate students scoring the self-questioning, summarization, and prior-knowledge integration were .80, .78, and .79, respectively. In the post-test of this study, any inconsistency in scoring self-questioning, summarization, and prior-knowledge integration subtests was solved by further negotiation by two raters.

2.5. Procedure

Both of the experimental and control groups took the screening test in a 20-min session one week before the formal experiment began. This study utilized the Reading Comprehension Screening Test (Ko, 1999) to distinguish the students of high reading ability from those of low reading ability. The content of the test included one short article and 20 multiple-choice questions with four choices each. Each correct answer was scored one point. A pilot test administered on 175 sixth-grade students had a Cronbach $\alpha$ coefficient of 0.80. Its criterion related validity with the revised Peabody graphic vocabulary test (Lu & Liu, 1994) was 0.61 ($p < .001$). In the formal experiment, the experimental group was administered instructions on using CASTLE. The 50-min instructions were given twice a week during the 11-week instruction experiment, so there were 22 sessions in total. For session 1 to session 12, one strategy was instructed and completed in each session. Further, when two strategy-training sessions are completed, the following session was used for review (using new articles). For session 13 to session 22, each strategy was reviewed in one or two sessions.

In each session, the students of the experimental group logged on to CASTLE system through a browser on a local computer, and retrieved data of the teaching materials from a database on the remote server. CASTLE used an agent to guide the users. The agent gave voice instructions to provide guidance on three major procedures: the work procedure, the user’s interface, and feedback. The guidance on the work procedure was presented to the users on the system startup. For guidance on the user’s interface, instructions were given to the users regarding the operations of the system interface. For guidance on feedback, users were given proper feedback according to the results after any strategies were completed. Fig. 2 shows how the agent and the toolbox worked.

In CASTLE, the workflow for reading strategy instructions was designed according to the steps of reading strategy instruction recommended by Taylor, Harris, and Pearson (1995). First of all, what was in the strategy (what) and why the strategy was important (why) were explained. The next step was to demonstrate how to use the strategy (how). After that, in what situation this strategy may be used (when) should be explained to readers. And then, an opportunity should be provided to guide the readers to practice using actual articles. Finally, the readers would be asked to practice independently through reading articles.

Incorporating the steps mentioned above, the procedures CASTLE executed were as follows. On startup, CASTLE communicated with the users through text and voice
instruction by the agent to inform the users about the meaning of the selected reading strategy. Then, the system provided an example, in which the agent operated and demonstrated the instruction procedures of the reading strategy. To help the users to get familiar with that reading strategy, they were asked to choose another article to read, and actually used the strategy. After the operation had completed, CASTLE provided the users with feedback, and then the users verified the processes of using the strategy. The four processes described above formed a complete cycle. After reading one article, the readers needed to go through all the processes before he could go to the next article.

Regarding the explanation of a reading strategy and practice it on an example, CASTLE informed the users about the meaning of the reading strategy through text and voice narration by the agent, and asked the users to practice it on an example. The users needed to practice successfully on the example before they were allowed to choose an article to read (see Fig. 3a).

For reading an article and using a strategy, after the readers had read the article, they could use the mouse to highlight the sentences in the article, and then pressed the “underscore” button to transform the highlighted sentences into blue characters to signify the semantic contradictions. The readers could also use the mouse to highlight the words or sentences he did not know and then pressed the “voice” button to ask the agent to pronounce or read aloud (see Fig. 3b).
In the third step of giving feedback according to the reader’s operations, CASTLE provided voice and text feedback according to the reader’s results of using the strategy (Fig. 3c).

The final step was verification of the reading process. When the readers had completed the strategy training on one article, the system provided the readers with a six-question reading process verification checklist to fill out. For example, the questions may include: I have used the detection strategy in reading the article (1, not at all; 4, very frequently); For the error detection strategy, I am: (1, not familiar with; 4, quite familiar with); What is the meaning of error detection: (four answers to choose from) (see Fig. 3d).

The researchers and the monitoring teachers of the classes answered the students’ questions regarding the operation of computers. All of the students’ operations and the time they took were recorded by the computer, which also monitored the progress.

![Fig. 3a. An example of the interface for reading strategy instruction and example practice (using error detection).](image)

![Fig. 3b. An example of interface for reading the article and operating the strategy.](image)

![Fig. 3c. An example of the interface for feedback according to the operation process.](image)
The control group used the self-study approach to learn the strategies. In each session, students were given the same reading materials to read. They were also given the paper-based workflow of the CASTLE. The main differences between the two groups were that students in the control group could not see the demonstration of using the strategies by the agent. They could not get feedback when they were practicing paper-based exercises, and their progresses of learning were not monitored and used as a basis for feedback.

The post-tests were administered one week after the instruction experiment ended. The tests came in three parts at different times. The first part was the ETCT and the summarization test of expository text in the use-of-strategy test, each of which lasted 20 min. The second part was the NTCT and the summarization test of narrative text in the strategy-use test, each of which lasted 20 min. The third part was a 35-min session for the self-questioning, error detection, inference, and prior-knowledge integration subtests from the use-of-strategy test.

3. Results

This study collected the students’ scores of reading comprehension and strategy-use tests (shown in Tables 1 and 2). We conducted two two-way multivariate analyses of covariance (MANCOVA) to study how the students in different groups with different abilities differ in the various dependent variables.

3.1. Comparison of reading comprehension and strategy-use scores in the narrative text

The students’ scores of the Narrative Text Comprehension Test (NTCT) and scores of using strategies with narrative text, such as self-questioning, error detection, inference, summarization efficiency, and prior-knowledge integration, were submitted to a 2 (experimental or control groups) by 2 (high and low abilities) multivariate analyses of covariance (MANCOVA), in which the six scores mentioned above were used as dependent variables and the language arts score from the students’ previous semester was used as the covariate. Prior to the MANCOVA analysis, we tested the assumption of the homogeneity of regression coefficients of the covariate for different levels of groups and abilities, and the result was not significant, the Wilk’s Lambda statistic = .04, $S = 3$, $M = 1$, $N = 57 \frac{1}{2}$, $p > .05$. 

Fig. 3d. An example of the interface of the reading process checklist.
This suggested a common regression coefficient was appropriate for the covariance portion of analysis.

The results from the MANCOVA revealed a significant multivariate test of the group factor, Wilk’s Lambda statistic = .87, $S = 1$, $M = 2$, $N = 57 1/2$, $p < .05$. The univariate test indicated that students in the experimental group scored higher in NTCT, adjusted $M = 14.92$ ($F(1,122) = 4.38$, $\eta^2 = .04$, $p < .05$, MSe = 6.82); self-questioning, adjusted
$M = 4.48$ ($F(1,122) = 60.01$, $\eta^2 = .34$, $p < .01$, MSe = 1.86); error detection, adjusted $M = 4.72$ ($F(1,122) = 21.33$, $\eta^2 = .19$, $p < .01$, MSe = 2.97), summarization, adjusted $M = 0.036$ ($F(1,122) = 83.44$, $\eta^2 = .41$, $p < .01$, MSe = 0.02), and prior-knowledge integration, adjusted $M = 2.01$ ($F(1,122) = 11.45$, $\eta^2 = .11$, $p < .01$, MSe = 3.46) than students in the control group, in which the adjusted Ms of the NTCT, self-questioning, error detection, summarization, and knowledge integration were 13.11, 2.22, 3.31, 0.022, 1.38, respectively. The difference of the inference subtest between the two groups was not significant ($F(1,122) = 2.88$, $\eta^2 = .03$, $p > .05$, MSe = 5.27).

There was also a significant multivariate test of the ability factor, Wilk’s Lambda statistic = .89, $S = 1$, $M = 2$, $N = 57 1/2$, $p < .05$. The univariate test indicated that students with higher reading ability performed better in NTCT, adjusted $M = 15.89$ ($F(1,122) = 12.78$, $\eta^2 = .11$, $p < .01$, MSe = 2.82); self-questioning, adjusted $M = 4.01$ ($F(1,122) = 3.86$, $\eta^2 = .02$, $p < .05$, MSe = 3.37), error detection, adjusted $M = 4.20$ ($F(1,122) = 7.54$, $\eta^2 = .06$, $p < .01$, MSe = 2.24), and the prior-knowledge integration, adjusted $M = 2.21$ ($F(1,122) = 4.92$, $\eta^2 = .05$, $p < .05$, MSe = 2.11) than the lower ability group, in which the means of NTCT, self-questioning, error detection, and knowledge integration are 12.25, 3.11, 3.21, 1.12, respectively. The two groups were not different in the subtests of inference, adjusted Ms = 6.89 and 6.01 in high- and low-ability groups ($F(1,122) = .71$, $\eta^2 = .00$, $p > .05$, MSe = 3.98) and summarization efficiency, adjusted Ms = 0.026 and 0.020 in high-and low-ability groups ($F(1,122) = .02$, $\eta^2 = .00$, $p > .05$, MSe = 0.20).

Regarding the interaction of group and ability, the multivariate test indicated that the Wilk’s Lambda statistic = .92, $S = 1$, $M = 2$, $N = 57 1/2$, $p < .05$. The univariate test indicated that the interaction between group and ability was significant in the error detection ($F(1,122) = 5.21$, $\eta^2 = .04$, $p < .05$, MSe = 2.20) and summarization ($F(1,122) = 7.83$, $\eta^2 = .06$, $p < .01$, MSe = 0.09) subtests, but not in the subtests of self-questioning ($F(1,122) = .13$, $\eta^2 = .00$, $p > .05$, MSe = 4.43), inference ($F(1,122) = .12$, $\eta^2 = .01$, $p > .05$, MSe = 3.78), and prior-knowledge integration ($F(1,122) = .17$, $\eta^2 = .00$, $p > .05$, MSe = 4.42). A simple main effect test for the error detection subtest showed that group (experiment or control) had significant effects in both the high- and low-ability readers, and the treatment effect in low-ability readers ($F(1,122) = 28.02$, $p < .01$, MSe = 1.13) was more significant than that in high-ability readers ($F(1,122) = 4.32$, $p < .05$, MSe = 2.01). A simple main effect test for summarization indicated that the effect of ability in the experiment group was not significant ($F(1,122) = 2.43$, $p > .05$, MSe = 0.12). However, it was significant in the control group ($F(1,122) = 6.01$, $p < .05$, MSe = 0.06), where students with low reading ability got higher scores in the summarization subtest than those with high reading ability.

### 3.2. Comparison of reading comprehension and strategy-use scores in the expository text

The students’ scores of the Expository Text Comprehension Test (ETCT) and scores of using strategies with expository text, such as self-questioning, error detection, inference, summarization efficiency, and prior-knowledge integration, were submitted to a two-way MANCOVA, in which the design was the same as above section. Prior to the MANCOVA analysis, we tested the assumption of the homogeneity of regression coefficients of the covariate for different levels of groups and abilities, and the result was not significant, the Wilk’s Lambda statistic = .10, $S = 3$, $M = 1$, $N = 57 1/2$, $p > .05$. This suggested a common regression coefficient was appropriate for the covariance portion of analysis.
The results from the MANCOVA revealed a significant multivariate test of the group factor, the Wilk’s Lambda statistic = 1.2, S = 1, M = 2, N = 57 1/2, p < .05. The univariate test indicated that students in the experimental group scored higher in ETCT, adjusted M = 14.22 (F(1,122) = 5.32, η² = .06, p < .05, MSe = 5.81); self-questioning, adjusted M = 3.66 (F(1,122) = 20.99, η² = .14, p < .01, MSe = 2.83), error detection, adjusted M = 3.20 (F(1,122) = 21.78, η² = .15, p < .01, MSe = 2.21), inference, adjusted M = 7.26 (F(1,122) = 16.82, η² = .12, p < .01, MSe = 4.80), and summarization, adjusted M = 0.036 (F(1,122) = 44.19, η² = .25, p < .01, MSe = 0.02). The difference of the prior-knowledge integration subtest in the experimental group, adjusted M = 1.33, was not significantly higher than the control group (F(1,122) = 1.22, η² = .01, p > .05, MSe = 6.82). The adjusted means of the ETCT, self-questioning, error detection, inference, summarization, and knowledge integration of control groups were 12.66, 2.12, 1.99, 6.02, 0.022, and 1.11, respectively.

There was also a significant multivariate test of the ability factor, the Wilk’s Lambda statistic = 1.23, S = 1, M = 2, N = 57 1/2, p < .01. The univariate test indicated that students with higher reading ability performed better in ETCT, adjusted M = 15.71 (F(1,122) = 10.68, η² = .09, p < .05, MSe = 3.83) and inference subtests, adjusted M = 7.30 (F(1,122) = 3.56, η² = .03, p = .052, MSe = 5.01), but not in the subtests of self-questioning, adjusted M = 3.60 (F(1,122) = 2.11, η² = .02, p > .05, MSe = 7.22), error correction, adjusted M = 2.90 (F(1,122) = 2.60, η² = .02, p > .05, MSe = 6.77), summarization, adjusted M = 0.031 (F(1,122) = 0.94, η² = .00, p > .01, MSe = 0.15), and prior-knowledge integration, adjusted M = 1.40 (F(1,122) = 1.57, η² = .00, p > .05, MSe = 7.83). The adjusted means of the ETCT, self-questioning, error detection, inference, summarization, and knowledge integration of control groups were 12.35, 2.69, 2.21, 6.18, 0.030, and 1.12, respectively.

Regarding the interaction of group and ability, the multivariate test indicated that the Wilk’s Lambda statistic = .11, S = 1, M = 2, N = 57 1/2, p > .05. The univariate test indicated that there was no significant interaction between group and ability in all the dependent variables with the expository text.

4. Discussion

It is widely agreed by many researchers that comprehension strategies enhance comprehension ability. However, the practical application of comprehension strategies in reading instruction leaves much to be investigated (Alfassi, 2004; De Corte et al., 2001; Pressley, Johnson, et al., 1989). Based on considerations for improving the accessibility of comprehension strategies, increasing the opportunities for students to practice these strategies (Paris & Paris, 2001), and relieving teachers’ burdens of designing strategy instruction (Pressley, Johnson, et al., 1989), this study selected comprehension strategies that have more potential to produce benefits. According to the ASOIM model of text comprehension and recommendations from scholars in past studies (Mastropieri & Scruggs, 1997; Pressley, Johnson, et al., 1989), strategies with both verbal and visual features, such as self-questioning, error detection, inference, summarization, and concept mapping are implemented on the Internet based CASTLE system.

We found that this type of design can effectively enhance students’ abilities to apply strategies. In this study, the participants in the experimental group performed better than
the control group in applying the majority of strategies corresponding to the text comprehension process. This finding conforms with the discovery by researchers conducting single-strategy instruction in classroom situations, such as error detection training by Paris and Jacobs (1984) and Paris and Oka (1986), inference blank-filling training by Schmitt (1987) and Tregaskes (1987), and summarization training by Chang et al. (2002) and Jitendra et al. (2000). It is also consistent with the findings of researchers conducting studies on multiple-strategy instruction, such as De Corte et al. (2001). The positive results of applying the CASTLE system support the argument that strategy instruction should be reasonably feasible in a computerized environment.

But this study also finds that the advantages of strategy training as described above are not unconditional, and the performance varies with the style of articles being used. For example, in applying the inference blank-filling strategy, the students in the experimental group only outperform those in the control group in expository articles, but not in the narrative articles. One of the reasons for this may be that in narrative articles, it is easier to find relevant clues (such as the story grammar) through prior knowledge about the story. As a result, it is easier to complete the story and the difference between groups is less distinguished. On the other hand, expository articles have a much more complex structure and contain far more related messages. Therefore, it takes more inference to find connections between the concepts, and the scoring is more difficult. At this time the benefits of strategy training become more apparent.

In addition, in applying prior-knowledge integration strategy, the students in the experimental group only outperform the control group in narrative, but not in expository articles. Several possible reasons emerge after analysis. First, the prior-knowledge integration test for expository article is more difficult to answer. Since the article used in this study is mainly scientific in nature (“How Animals Breathe”), the students may have difficulty in elaborating related concepts by describing the details, citing examples and continuing the article without prior knowledge or exposure to related articles. As a result, even if the students have the intention and ability to use the strategy of integrating prior knowledge with new concepts, they may not be able to put this strategy into practice. On the contrary, the content of the narrative (“the Brave Eskimo Child”) may provide messages that are more concrete and closer to living and to give the readers more room for imagination, so that the integration with prior knowledge and the elaboration of the concepts in the text may be easier.

Another noteworthy finding of this study is that in the control group, students of low reading ability performed better than those with high reading ability in summarizing narrative articles. While investigating the reason, we find that if we use the summarizing efficiency formula by Garner (1982), in which summarizing efficiency equals to the number of main concepts in the summary divided by the total word count in the summary content, the summary word count may lead to lower summarizing efficiency if students write down lots of words in their summary or higher efficiency if students write down very few words in their summary, in case they have the same number of correct idea units. In this study, the control group students with low reading ability tend to use less words (202 on average) in writing the summary, while the control group students with high reading ability use more words (227 on average). Further, there are more students (12) who used less than 60 words in the lower ability group than those (four) in the higher ability group. This is a possible cause for lower ability students got higher summarizing efficiency scores.
Many previous studies used reading strategy instruction programs to help students enhance their reading comprehension abilities, and had satisfactory application results (Brown et al., 1996; De Corte et al., 2001; Palincsar & Brown, 1984). This study also found that after the students’ reading strategies improved, their reading comprehension was also improved. Past studies related to computer-assisted reading comprehension did not reach decisive conclusions regarding its effect on improving reading comprehension (MacArthur et al., 2001). The positive effects produced by our computer-based strategy instruction may be due to several reasons. First, the mechanisms for computer-assisted reading comprehension in the past mostly focused on providing assistance for contents of articles themselves, like synthesized speech (Elkind et al., 1993; Farmer et al., 1992) or related text enhancements such as background knowledge, indexes for difficult vocabularies, summaries, etc. (Leong, 1995; Reinking, 1988; MacArthur, Graham, Schwartz, & Schafer, 1995). These mechanisms do not intervene with a learner’s own ability, so in the testing stage when there was no assisting message given, improvement in a reader’s achievement may not be easy to continue. Compared to the weaker approaches mentioned above, this study trained the readers in the comprehension strategies that are directly related to their comprehension abilities. This involves a more robust intervention. Moreover, since the duration of strategy training in this study was 11 weeks long with 22 sessions, which was much longer than the average computer-assisted reading programs, the effects may be more pronounced.

During the past two decades, more emphasis has been placed on cognitive process-oriented strategy instruction, and the arrangement and selection of strategy instruction have been growing in diversity (Dole et al., 1991). Process oriented and multi-strategy based instruction may be an important factor in making strategy instruction beneficial to learners with poorer learning abilities (Brown et al., 1996; De Corte et al., 2001; Klinger & Vaughn, 1996; Palincsar & Brown, 1984), rather than limited to just those with high learning abilities. Our results indicate that the CASTLE system, which is also a process oriented and multi-strategy based teaching environment, again supports the finding that the multiple-strategy instruction can benefit students with low reading ability. Another possible reason for this benefit might be attributed to the characteristics of computer-based instruction, such as individual instruction, monitoring and immediate feedback. CASTLE allows personalized progress by placing a learner in an independent and threat-free situation in which enhances the effects of practice. This study finds that these characteristics may also have a high potential for helping learners with lower abilities in their acquisition of higher-level skills, and not only for lower-level reading skills such as word-recognition and phonological awareness.

This study found that while integrating computer technology with strategy instruction has a potential for reading instruction design, there are some points worthy of investigation. To elaborate the design of systems like CASTLE, researchers may consider providing a wider variety of appropriate reading strategies for learners or teachers to choose from, or arrange strategies according to their own needs or preferences.

Acknowledgements

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Appendix. The articles, score range, word count and instruction used in the strategy-use tests

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Article title</th>
<th>Word count</th>
<th>Guiding remarks and examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-questioning</td>
<td>1. b Smart Farragut</td>
<td>472</td>
<td>Guidance: This is a self-questioning test. After reading the articles presented, please write as many questions in the article as you think are important as possible in the limited time, then write down the right answer. Example: Yue-fei lived in the Sung Dynasty. He fought wars with the Jing troops and avenged the shame of our country. He won people’s respect. Question: Who is this article mainly about? Answer: Yue-fei</td>
</tr>
<tr>
<td></td>
<td>2. Penguin</td>
<td>365</td>
<td></td>
</tr>
<tr>
<td>Error detection</td>
<td>1. Brave Jackson</td>
<td>260</td>
<td>Guidance: There are two articles in this test. Both of the articles contain some statements that are not consistent with the context. Please read the two articles carefully, and put circles around the statements that you think are wrong. Example: Tom forgot to bring his homework to school this morning and was punished by the teacher. He was very [happy]. What should we change [happy] into?</td>
</tr>
<tr>
<td>(0–6)</td>
<td>2. Why are flowers fragrant?</td>
<td>333</td>
<td></td>
</tr>
<tr>
<td>Inference blank-filling</td>
<td>1. A white dog that appreciates paintings</td>
<td>280</td>
<td>Guidance: There are two articles in this test. There are some blanks in the articles. Please fill in the blanks with one or two appropriate words according to the title and the context. Example: The ingredients of air include at least oxygen and carbon dioxide. Plants often release ... the morning to make the morning air especially fresh. The blank ... should be filled with “oxygen”</td>
</tr>
<tr>
<td>(0–10)</td>
<td>2. How demoisturizers work</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Summarization</td>
<td>1. b The legend of Lantern Festival</td>
<td>798</td>
<td>Guidance: This is a summarizing ability test. Please use 20 min to carefully read the article presented; and when you have finished, find out the content you think is important and write a summary of no more than 250 words. You may also cross out the unimportant content in the article and then use the remaining content</td>
</tr>
<tr>
<td>(0–1)</td>
<td>2. Koala</td>
<td>760</td>
<td></td>
</tr>
</tbody>
</table>
### References


### Appendix (continued)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Article title</th>
<th>Word count</th>
<th>Guiding remarks and examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior-knowledge integration (0–5)</td>
<td>1. The Eskimo Hunter</td>
<td>230</td>
<td>Guidance: There are two articles in this test. Each one is followed by several questions related to the article. After you have finished reading each of the articles, please answer the following essay questions.</td>
</tr>
<tr>
<td></td>
<td>2. How animals breathe</td>
<td>221</td>
<td>Example: Taking the Eskimo Hunter as example, the questions are:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1. The story mentions that Kish’s father is a great hunter. He brings home lots of meat and distributes the meat fairly. Besides that, try to write a more detailed description of Kish’s father.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. The story mentions that the chief held a village council with the hunters. Now cite some examples of when we need to hold meetings.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3. If the story continues developing, what do you think will happen next?</td>
</tr>
</tbody>
</table>

a Score range.

b 1: Narrative style; 2: expository style.


