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Yu-Cin Jian

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Teaching Fourth-Grade Students of Different Reading Abilities to Read Biological Illustrations and Integrate In-Text Information: an Empirical Experiment

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Abstract
Scientific texts are often multimodal, consisting of both text and illustrations. However, previous research indicates that young readers are poor at using text-and-illustration integration strategies and at in-depth processing of scientific illustration information. This study used an experimental paradigm to teach strategies of illustration reading and text-and-illustration integration to fourth-grade students. The study manipulated reading ability (high vs. low level) and teaching strategy (presence vs. absence of reading strategies instruction) as between-subjects variables. Seventy-one participants completed a prior-knowledge test, read two illustrated biology texts, and answered comprehension questions. The results showed that the instructed groups outperformed the control groups on the overall reading test, and in the illustration memory and integration items. It was inspiring to discover that teaching fourth-grade students of both high and low reading ability levels to pay attention to scientific illustrations, process them in-depth, and consider the relationship between textual descriptions and detailed parts of illustrations benefited these young readers in reading comprehension and acquiring scientific knowledge.

Keywords Scientific illustrations · Reading strategies instruction · Reading ability · Text-and-illustration integration

Introduction

Reading is one of the critical components of scientific literacy. From the perspective of knowledge inheritance, readers can acquire understanding of scientists' findings from reading their written texts. Anderson (1999, p. 973) suggested that "reading and writing are the mechanisms through which scientists accomplish their tasks. Scientists create, share, and

✉ Yu-Cin Jian
jianyucin@ntnu.edu.tw

[1] Department of Educational Psychology and Counseling, National Taiwan Normal University, No.129, HePing East Road, Section 1, Taipei, Taiwan

negotiate the meanings of inscriptions—notes, reports, tables, graphs, drawings, diagrams." From the perspective of knowledge communication, newspapers, science magazines, and popular science books are primary sources of technical and scientific information for the general public (Jarman and McClune 2000). Therefore, science reading should play an important role in science education. However, traditionally, science teachers have had little concern for text, and reading has not been seen as an important part of science education (Wellington and Osborne 2001). Traditional science education does not cover literacy (that is, reading and writing), possibly at the risk that students will never fully grasp the point and significance of scientific knowledge (Norris and Phillips 2003).

Science education worldwide is currently progressively addressing the above situation. In addition to *hands-on* science, which remains highly valued in schools, science reading is gradually receiving greater emphasis (Cervetti et al. 2012; Norris and Phillips 2003; Ødegaard et al. 2014). The National Research Council (2014) in the USA is conscious of the importance of science literacy, and recognizes that language teachers and science teachers face unique challenges in developing the teaching skills required to support students in developing competence in reading and communicating about science. The Council regards elementary school students to be at a stage in which the *seeds of science* and *roots of reading* are developing. This line of thought is consistent with reading development theory (Chall 1983), which places fourth-grade elementary school students at the beginning of the *reading to learn* stage; prior to fourth grade, readers are at the stage of *learning to read*.

Biology is highly relevant to our daily lives, and biology texts are often multimodal, consisting of both text and illustrations. Illustrations may be of many types, such as photographs, realistic drawings, diagrams, maps, flow charts, and graphs (Kress and van Leeuwen 1996; Pozzer and Roth 2003). Readers need to understand these pictorial representations by decoding and extracting their meaning (Jewitt and Oyama 2001). However, the teaching of such *multiliteracies* has to date received little systematic attention in schools, with very little instruction on comprehension strategies occurring in elementary schools (Collins and Pressley 2002).

Before considering such instruction, it is important for teachers to better understand students' needs, to be aware of the reading strategies they use for sense making, and to be aware of the skills they lack. Previous research has indicated that elementary school students tend to be text-driven in their reading of illustrated biology texts (Jian 2016; Jian and Ko 2017; Hannus and Hyönä 1999)—they pay little attention to illustrations, cannot process illustration information in-depth, and cannot effectively integrate textual descriptions relevant to detailed illustrations (Jian 2016; Jian and Ko 2017; Hannus and Hyönä 1999; Moore and Scevak 1997). Therefore, the purpose of this study was to teach fourth-grade students strategies for reading illustrated biology texts, and to examine the effects of this reading strategy instruction on students with varying levels of reading ability.

The Characteristics of Illustrated Biology Texts and Multiple Representations

Biology texts often consist of text and illustrations. In text sections, biological concepts may be used to introduce organism taxonomies. For example, one of the topics in the reading material used in this study focused on ants of different kinds (e.g., soldier ant, worker ant, queen ant). The verbal descriptions in this material use vocabulary like *kinds of*, *consist of*, etc. In illustration sections, one of the most common image types is one depicting a part-whole relationship, i.e., showing an object with its parts labeled; this type of illustration is a structured analytical image (Carney and Levin 2002; Kress and van Leeuwen 1996; Unsworth 2001).

Biology texts are typical of multiple representations. Multiple representations can provide benefits for learners' reading comprehension, according to some studies. Ainsworth (2006) proposed the DeFT (Design, Functions, Tasks) framework as a consideration for ensuring the effectiveness of multiple (external) representations (MERs). Ainsworth stresses the need to "design parameters that are unique to learning with more than one representation, the different pedagogical functions that MERs can play, and the cognitive tasks that must be undertaken by a leaner when interacting with MERs" (Ainsworth 2006, p. 184). Design parameters in MERs emphasize the design of the learning materials needed to consider the numerous representations, the way that information is distributed (e.g., whether the information represented in text is completely or partially redundant or entirely different from the picture), and the forms (e.g., whether the learning information is displayed in pictures, text, animations, sound, or graphs) for different learning contents, target readers, and teaching strategies. The function of MERs is that they emphasize that different representations have distinct advantages in conveying various pieces of information. For example, depictive representations are most useful in conveying concrete information, and descriptive representations more effectively express abstract information (Schnotz 2005). Cognitive tasks in MERs are built upon the idea that learners need to understand the form of representation and further select an appropriate representation, or construct one, in completing cognitive tasks. However, a number of studies have shown that children have difficulty applying and understanding the format and operators of graphs (e.g., Friel et al. 2001). In addition, novices have more difficulty in selecting appropriate representations than do experts, as they lack a deep understanding of the tasks they are trying to solve (Chi et al. 1981).

There are two approaches that have been identified as most common when explaining the effectiveness of multiple representations: the cognitive theory of multimedia learning (CTML) (Mayer 2005) and cognitive load theory (Sweller et al. 1998). Mayer's (2005) cognitive theory of multimedia learning has three assumptions. First, in the concept of dual channels, CTML assumes that humans have separate information-processing channels for verbal and pictorial representation, as proposed by Paivio's (1990) dual-coding theory. Second, the notion of limited capacity assumes that a human's working memory is formed of modality-specific limited capacity subsystems. That is to say, humans are limited in terms of the amount of information that they can process in each channel at one time, as suggested by Baddeley (1992) and Chandler and Sweller (1991). Third, the idea of active processing suggests that humans engage in active learning by attending to incoming information for reading comprehension. CTML proposed that learning a text with multiple representations involved three different cognitive processes. First, readers need to *select* certain information from text and picture from external representation into their working memory, due to the fact that a human's working memory is formed of modality-specific limited capacity subsystems. Second, to organize the information in working memory into a coherent mental structure, readers *organize* the selected information from text and picture into verbal and pictorial models that are constructed separately in their working memory. Finally, readers *integrate* the verbal and pictorial models constructed with prior knowledge then form a coherent mental model for reading comprehension. Therefore, if readers understand the forms of representations, encode the information of the representation, and further construct a representation in reading the illustrated texts, it is assumed they will have better learning outcomes than if they had used a single representation of either words or pictures.

Theoretical Basis of Reading Strategy Instruction

In teaching the fourth-grade students in this study to read biology texts, the participants received the instruction of the three reading strategies. These were based on several theoretical considerations, including the cognitive theory of multimedia learning (Mayer 2005), DeFT framework (Ainsworth 2006), and functional descriptions of visual grammar (Kress and van Leeuwen 1996; Unsworth 2001).

The first strategy instruction of text-and-illustration integration (detailed information appears in the "Method" section) in this study was informed by the cognitive theory of multimedia learning (Mayer 2005) and the DeFT framework (Ainsworth 2006). The cognitive theory of multimedia learning (Mayer 2005) proposes that illustrated text reading mainly involves three cognitive processes, as mentioned above. The first process is selection of relevant textual information and illustrations. This occurs when a reader pays attention to the indicated words and illustrations, bringing an external representation into the working memory of the cognitive system. The second process is organization of the selected information. This involves organizing several pieces of textual representation into a larger unit of textual representation, the same as the pictorial representation. Third, the textual information and illustrations are integrated into the reader's prior knowledge, which is extracted from long-term memory. According to Mayer's CTML theory (2005) and Ainsworth's DeFT framework (2006), the integration of both textual and pictorial information, in the form of multiple representations, provides the advantage of using the function of words (descriptive representation) for conveying abstract concepts and of using diagrams (depictive representation) for displaying concrete concepts, transforming the two representations into each other in order to construct a mental model for reading comprehension. This benefits readers by helping them store information more deeply, giving them a greater chance of extracting it from long-term memory than if they had only used a single representation.

The second and third types of strategy instruction in this study emphasized reading and decoding scientific illustrations based on statements of functional descriptions of visual grammar (Halliday 1994; Kress and van Leeuwen 1996; Unsworth 2001). Extrapolating from systemic functional linguistic descriptions of language (Halliday 1994), Kress and van Leeuwen (1996) developed corresponding functional descriptions of visual grammar, as explained and integrated by Unsworth (2001). Using functional semiotic accounts of images, Unsworth (2001) proposed three meaning-making resources. First, for representational meaning, the nature of events is constructed visually. Analytical images usually represent spatial relations and relative locations. Second, for interactive meaning, visual resources are used to construct certain relationships between the reader and what is viewed. This emphasizes readers' initiative and their interaction with images. Third, in terms of compositional meaning, the layout of each image in the article text is purposeful. Some elements in an image may have particular salience, and influencing factors include the elements' relative size, color, sharpness, and location.

Therefore, the second and third strategies of the instructions in this study were designed to emphasize the decoding and comprehension of the science illustrations. For example, students were expected to determine what the important characteristics were in the science illustrations, such as part-and-whole relationship of an organism, its shape, size, and so on, and how these were related to the illustration tiles. Detailed information appears in the "Method" section.

Empirical Research

Science Literacy Instruction

Cervetti et al. (2012) investigated the efficacy of integrated science and literacy instruction in fourth-grade classes. Half of the participating teachers taught their classes integrated science and literacy in lessons on light and energy, using an instruction model that required the students to read text, write notes, and investigate and discuss learning science concepts. The remaining teachers taught their classes content-comparable science and literacy, separately. The results showed that the students who received the integrative science and literacy instruction outperformed those who had received separate content-comparable science and literacy instruction, on a test of their science knowledge. However, Cervetti et al.'s (2012) research reported only one reading strategy, namely, making predictions; other reading strategies, such as illustration reading and connecting textual science information to illustrations, were not mentioned.

Ødegaard et al. (2014) also investigated the effect of integrating inquiry-based science and literacy. Their research comprised a small-scale qualitative study. Six teachers attended a professional development course on an instruction model for integrated inquiry-based science and literacy, and volunteered for the study. Students from grades 1 to 5 participated; all the teachers' teaching behaviors were video recorded. Analysis of the video recordings revealed that the students subjected to an integrated instructional approach used multiple learning modalities, namely, reading, writing, doing, and talking. The researchers also found that most of the students' reading activities were intertwined with oral activities. Ødegaard et al. (2014) reported on the percentage of students engaged in reading activities as opposed to the remaining classroom activities, but did not mention what reading strategies the teachers had taught their students or whether the students used these spontaneously.

Although science reading is gradually enjoying more emphasis in current science education, and despite some research focusing specifically on science reading (Cervetti et al. 2012; Ødegaard et al. 2014), information on the reading strategies young readers use or lack, and the effect of reading strategies instruction on science comprehension, remains limited. This was the main rationale motivating the present study.

Illustrated Science Text Reading Strategies for Young Readers

In the research field of science education, think-aloud protocols are often used to investigate science article reading strategies. Moore and Scevak (1997) used think-aloud protocols to investigate readers' strategies at different grade levels. They asked fifth-, seventh-, and ninth-grade students to read historical and scientific articles containing several illustrations. Participants were instructed to pause reading, explain the content that they had just read, and explain what they thought about that content, when they encountered red dots that the researchers had placed at various points throughout the articles. The results showed that students of different grade levels used different reading strategies in reading science articles. Readers incorporated information from illustrations 8%, 13%, and 48% of the time if they were in fifth-, seventh-, and ninth-grade, respectively. In reading science articles, fifth-grade students focused on detailed text information, seventh-grade students were capable of extracting the main ideas of the article, and ninth-grade students focused on illustration processing, as well as connecting text and illustration information. These differences in reading strategies by grade level were not observed for history articles.

Norman (2012) also used a think-aloud protocol to investigate relationships between reading ability, reading processes, and reading comprehension in the reading of illustrated science texts. Researchers asked high-, medium-, and low-ability second graders to read two science articles: one was about dinosaur fossils, and the other was about weather. All participants needed to talk about what they were thinking while reading, retell the text content in their own words, and complete reading comprehension tests. The results showed that readers' retelling performance, as well as the number of times that readers used reading strategies (e.g., using title information, using illustration information, repeated reading, inferences, and comprehension monitoring), differed significantly (from the performance and reading strategy use of readers of all other levels and texts) only for the high-ability students reading the dinosaur fossil article. Another interesting finding was that reading strategy use had inconsistent effects on reading performance. Using the title and illustrations positively correlated with retelling-story scores, but the number of emotional responses did not.

The above literature review indicates that elementary school students, particularly those at lower reading levels, have limited ability to use illustration information, and connect text and illustration information. Some scholars believe that visual literacy in science may develop gradually following increases in science knowledge, since it seems that visual literacy in science as a cognitive behavior seems to develop slowly (Kress and van Leeuwen 1996; Moore and Scevak 1997). Some scholars also believe that young readers prefer to view single components of illustrations rather than whole structures, and regard illustrations as independent from text in articles (Gerber et al. 1995). On the contrary, adult readers regard illustration information as part of articles (Jian 2016; Jian and Wu 2015; Hegarty 1992), especially for the *visualizers* (Koć-Januchta et al. 2017). According to the differences in cognitive style, visualizers are learners who think more in pictures, whereas those who think more in words are called verbalizers (Koć-Januchta et al. 2017). Koć-Januchta et al. (2017) found that, during the illustrated text reading in science and psychology classes, undergraduate students belonging to the visualizer group spent more time inspecting pictures, entered into relevant areas of pictures sooner, and had a better reading comprehension test score than the students belonging to the verbalizer group.

These previous studies have implications for the reading strategies that I have developed and taught to young learners in this study. Here, I examine whether young readers can learn science-reading strategies well or not, and whether their reading performance changes after receiving science-reading instruction. Positive findings will add to the current body of research on science literacy.

The Present Study and Research Questions

This experimental study investigates the effects of reading strategy instruction on fourth-grade students' reading of illustrated biology texts. I am interested in (a) the effect of reading strategy instruction on fourth-grade students' science reading, (b) the effects of reading instruction on readers of different reading ability levels, and (c) the components of reading (text/illustration recognition, text/illustration comprehension, or text-and-illustration integration) that might be improved by the use of reading strategies.

Method

Participants and Design

After obtaining parental consent, 80 fourth-grade students were recruited from four classes at three elementary schools. A standard reading comprehension screening test (Ko 2006) was used to measure their reading ability. Based on the standard test scores, nine students were excluded because of suspected reading difficulties. Seventy-one participants therefore participated in this experiment. The Z scores of the 71 participants ranged from − 0.68 to 2.0. The Z score is the number of standard deviations from the mean. To be close to equal numbers of participants for high- and low-reading ability groups, the participants with Z scores exceeding 0.8 (the percentile in the standard normal curve is 79%) were classified as high-ability readers (34 participants in total). Those participants with a Z score between − 0.68 and 0.5 (the percentile is 25 to 69%) were classified as low-ability readers (37 participants in total). No participants' Z scores fell between 0.5 and 0.8.

The study used a 2 × 2 between-subjects design; the two between-subjects variables were reading ability (high vs. low) and teaching strategy (presence vs. absence of instruction). The instructed group, comprising 35 participants (16 with high and 19 with low reading ability), received individual reading strategy instruction by a research assistant, and 36 participants (18 with high and 18 with low reading ability) were assigned to the control group, receiving no instruction. The average Z scores of the standard reading comprehension screening test between the instructed group ($M = 0.63$, SD = 0.67) and the control group ($M = 0.65$, SD = 0.69) had no significant difference, $t(69) = -0.125$, $p > .05$.

Materials

The experimental materials comprised a prior-knowledge test, two illustrated biology texts, and a reading test. The prior-knowledge test comprised 12 yes-or-no questions, half of which measured plant knowledge (e.g., "Is an ovule a flower's female organ?") and the other half of which measured knowledge of ants (e.g., "Is a young ant very capable of adapting to temperature change?").

The two illustrated biology texts were modified from a fifth-grade science textbook (Huang 2013). One text, the same as that used in my previous research (Jian and Ko 2017), was about plants and consisted of 400 words and two illustrations. This text was titled "Morphologies and functions of flower, fruit, and seed," and contained three paragraphs of text and two illustrations. The first paragraph briefly explained flower reproduction through blossoming and seeding, the second described the parts of a flower (e.g., stamen, digynia, anther, thrum, and ovary) and their functions, and the third described pollination by bees. The top illustration depicted a detailed flower structure with labels, and the bottom illustration depicted a bee collecting nectar from a flower. The second illustrated text, comprising 414 words and two illustrations with explanations, was about ants. It was entitled "Social insect—Ant," and contained three paragraphs. The first paragraph briefly explained that there are different kinds of ants (e.g., soldier ant, worker ant, queen ant) and gave the definition of a social insect. The second paragraph described the characteristics and functions of different kinds of ants, and the third described how ants secrete pheromones. The top illustration depicted an ant hole with an explanation of ants' responsibilities, and the bottom illustration, which was accompanied by written explanations, depicted the belly characteristics of an ant while it released pheromones, walked normally and found food.

To assess participants' memory and comprehension after reading the two illustrated biology texts, I created a reading test for each. The reading tests contained recognition questions and comprehension questions for textual and pictorial information, respectively. The multiple-choice recognition questions assessed memorization by means of seven text recognition items (e.g., "Which of these appeared in the article that you read?" "Petals are *above* the sepal"; "Petals are *inside* the sepal"), and seven illustration recognition items evaluating participants' memory for flower structure (e.g., Given the flower picture, participants were asked "Which of the following three flower components is indicated by the arrow?"). Yes-or-no comprehension questions measured reading comprehension and included five items each for text, illustration, and integration, respectively. Text comprehension items required participants to understand biological knowledge from having read the text, rather than recalling surface-level words. Illustration comprehension items assessed how well participants extracted information from the illustrations (e.g., the characteristics or relative position of a flower's parts) that were not further described in the text. Finally, integration items required participants to integrate textual and pictorial information. Both texts had the same types of questions, except that only the plant article had illustration recognition items, which measured participants' memory of a flower's components. The insect article did not design illustration recognition items due to its two illustrations had no components of an insect that needed to be remembered. Thus, there were 29 items for the plant text and 22 items for the ant text, with the overall test consisting of 14 text recognition items, 7 illustration recognition items, 10 text comprehension items, 10 illustration comprehension items, and 10 text-and-illustration integration items. Each correct answer was awarded one point, and correct scores were transformed to percentage scores.

All of the reading materials and tests were assessed in terms of difficulty (suitability for fourth-grade students) and readability by a panel of three experts—a professor in reading psychology, a Ph.D. candidate in science education who had taught science courses in elementary schools for several years, and an elementary school science teacher with a Master's degree in science education.

Procedure

All procedures were conducted individually with each participant at their respective elementary schools, to ensure that all instructed participants mastered the reading strategies and all control participants received no instruction but followed the same testing procedure.

Participants first completed the prior-knowledge biology test at their own pace, then received reading strategy instruction (or not, as in the case of both high and low reading ability control groups). Instructed participants were told to learn the three reading strategies and use these strategies to read the experimental texts by themselves. The three reading strategies were modified from my previous research (Jian 2018). The instruction for the first strategy read: "Pay attention to the sentences that are relevant to the illustrations. Read these sentences carefully and observe whether the characteristics on the illustration are identical to those in the descriptive sentences." The instruction for the second strategy read: "Read every label on the illustrations and carefully study the characteristics of all objects indicated by the labels, for example, shapes, sizes, relative positions, and relationships between components." The instruction for the third strategy read: "Read the illustration titles, and the worded explanations of the illustrations, and observe whether the illustration characteristics are consistent with the information provided in the words on the illustrations." A research assistant used a practice illustrated biology text to teach the participants individually. She explained each reading strategy in combination with an example to model how to use it. She then asked the participants to repeat the three strategies, and the participants used the same practice text to explain to the research assistant how they read the text. If a participant had failed to report on or use any reading strategy appropriately, the research assistant instructed them further, until they had mastered all three strategies.

After ensuring such reading strategy mastery, participants were instructed to read the two illustrated biology texts by themselves using these strategies. They were also informed that there would be some questions to be answered after they completed each reading. The participants completed the reading tests immediately after reading each text. Except the reading instructions, the control group followed the same procedure as the experimental group, such as being informed of the reading tests after reading each text. There were no time limits set for any of the reading or testing activities, and each participant took approximately 30 to 40 min to complete the experimental procedures.

Data Analysis

To test the effects of teaching science-reading strategies to both high- and low-ability readers, I conducted several two-way ANOVAs on prior-knowledge test scores and various reading test item scores (overall reading test, text recognition items, illustration recognition items, text comprehension items, illustration comprehension items, and text-and-illustration integration items).

Results

The Prior-Knowledge Test

Means and SDs for performance in the prior-knowledge test are presented in Table 1. The results of the homology analysis of variation between the four groups did not show a significant

Table 1 Accuracy on the prior-knowledge test for the four groups

	Good readers *M* (SD)	Poor readers *M* (SD)
Teaching group	.51 (.14)	.47 (.16)
Control group	.53 (.12)	.50 (.12)

difference in the prior-knowledge test, $p > .05$. There were no main effects of reading ability or teaching strategy, nor any interaction between reading ability and teaching strategy, p's > .05. The results showed that the four groups had similar prior knowledge about plant and ant concepts.

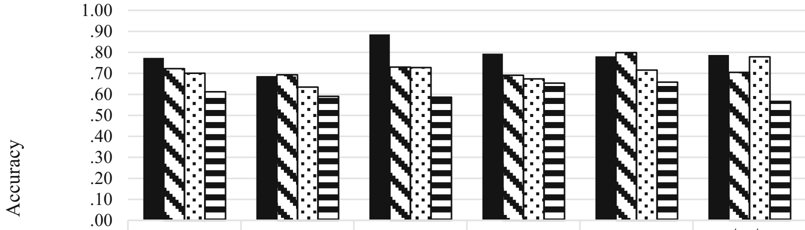
The Reading Tests

Figure 1 displays the performance of all participants on all the reading test items for the plant and ant texts. The results of the homology analysis of variation between the four groups did not show significant differences in any of the reading test items, p's > .05.

Overall Reading Test Main effects of reading ability, $F_{(3,67)} = 20.85$, $p < .001$, $\eta^2 = .24$, and teaching strategy, $F_{(3,67)} = 11.97$, $p < .01$, $\eta^2 = .15$, were found, but the interaction between reading ability and teaching strategy was not significant, $p > .05$. The high-ability group outperformed the low-ability group, and the groups that received instruction outperformed those that did not, in the overall reading tests.

Recognition Questions Examination of just the text recognition questions revealed a main effect of reading ability, $F_{(3,67)} = 7.90$, $p < .01$, $\eta^2 = .11$, with the high-ability groups outperforming the low-ability groups in both the instructed and the not-instructed conditions; however, there was no main effect of teaching strategy, and no interaction between reading ability and teaching strategy, p's > .05. For the illustration recognition items, there were main effects of reading ability, $F_{(3,67)} = 13.71$, $p < .001$, $\eta^2 = .17$, and teaching strategy, $F_{(3,67)} = 13.33$, $p < .01$, $\eta^2 = .17$, but the interaction between reading ability and teaching strategy was not significant, $p > .05$. The high-ability groups outperformed the low-ability groups, and the instructed groups outperformed the not-instructed groups in the illustration recognition items.

Comprehension Questions Figure 1 shows that there were main effects of reading ability for the text comprehension items, $F_{(3,67)} = 4.22$, $p < .05$, $\eta^2 = .06$, and for the illustration comprehension items, $F_{(3,67)} = 8.78$, $p < .01$, $\eta^2 = .12$, but there were no main effects of teaching strategy for text comprehension or illustration comprehension items, and no interaction between reading ability and teaching strategy for both comprehension item types, p's > .05.



	total items	text recognition items	illustration recognition items	text comprehension items	illustration comprehension items	text-illustration integration items
good reader- instruction group	.77	.69	.89	.79	.78	.79
good reader- control group	.72	.69	.73	.69	.80	.71
poor reader- instruction group	.70	.64	.73	.67	.72	.78
poor reader- control group	.61	.59	.59	.65	.66	.57

Mean accuracies of each type of the reading test

Fig. 1 Accuracies of the reading tests for the four groups in this study

The high-ability groups outperformed the low-ability groups on both the text comprehension items and the illustration comprehension items.

Text-and-Illustration Integration Questions Figure 1 shows that there were main effects of reading ability, $F_{(3,67)} = 4.09$, $p < .05$, $\eta^2 = .06$, and teaching strategy, $F_{(3,67)} = 16.43$, $p < .001$, $\eta^2 = .20$, but no significant interaction between reading ability and teaching strategy, $p > .05$. The high-ability group outperformed the low-ability group, and the instructed groups outperformed the not-instructed groups in the integration items.

Discussion

Science reading is gradually being emphasized in science education (Cervetti et al. 2012; Norris and Phillips 2003; Ødegaard et al. 2014), but research investigating the effects of reading strategies instruction on science reading remains rare. The present study is an experiment in which fourth-grade students with high and low reading abilities were taught illustration reading and text-and-illustration integration strategies, in order to read illustrated biology texts. The four experimental groups (high- and low-ability readers with or without reading instruction) did not differ in their performance on a prior-knowledge test; thus, the findings may be attributed with some confidence to the reading strategy instruction and reading abilities, rather than to the participants' background knowledge. Additionally, the accuracies of the prior-knowledge test scores of the four groups were approximately .05—near guessing rate—suggesting that the reading materials were unfamiliar to all readers, and indicating that the texts were suitable for this study.

It was inspiring to discover that teaching fourth-grade students to pay attention to illustrations, to process them in-depth, and to think about the relationship between textual descriptions and detailed parts of illustrations benefited these young readers in acquiring scientific knowledge; in particular, observing the scientific illustrations and remembering the important characteristics and labels, as well as integrating multiple representations from the science article, was effective for the students, regardless of their reading ability levels. It was also surprising to discover that the low-ability readers who received reading strategy instruction performed similarly in the overall reading test (the accuracy was 70%) to the high-ability control group (the accuracy was 72%), even slightly surpassing them in the text-and-illustration integration items. The accuracies of the text-and-illustration questions were 78% for the low-ability readers who received instruction versus 71% for the high-ability readers who had received no instruction; however, the differences were not statistically significant. In comparison to the majority of adult readers, who regard illustration information as an integral part of articles (Jian 2016; Jian and Wu 2015; Hegarty 1992; Koć-Januchta et al. 2017), young readers pay little attention to illustrations, cannot process their information in-depth, and cannot effectively integrate textual descriptions relevant to detailed sections of illustrations (Jian 2016; Hannus and Hyönä 1999; Moore and Scevak 1997). According to the results of this study, some of these skills may be learned by means of reading strategy instruction.

However, the tested reading strategy instruction was not found to benefit students' text recognition or text comprehension abilities. Performance on the reading test items measuring understanding of textual information fell below .70 for all groups. This may be because the reading strategies taught in this study focused on illustration reading rather than text reading.

There remain several directions for further research. First, whether reading strategy instruction changes learners' reading processes or not. Eye-tracking technology is an ideal research tool to answer this question. Second, to develop and test more reading strategies that may improve scientific text comprehension is an important issue, such as making predictions and inferring from the text context. Third, whether the reading strategies apparently acquired in this study last over a longer time, and whether they can be transferred to other scientific topics, such as physics, chemistry, and astronomy. Fourth, further research might investigate the effects of combining multiple explicit reading strategy instructional techniques in science courses, to increase scientific literacy (Cervetti et al. 2012; Ødegaard et al. 2014). Fifth, it would be interesting to determine whether the benefits of individual reading strategy instruction might also be gained through group or classroom instruction.

Contribution, Implications, and Limitations

The most important contribution of this study was the development of three instructional strategies for reading, on the basis of the cognitive theory of multimedia learning (Mayer 2005) and functional descriptions of visual grammar (Kress and van Leeuwen 1996; Unsworth 2001). The researcher in this study systematically taught fourth-grade students how to use these three reading strategies, and confirmed their beneficial effects on learning science knowledge (including memorizing scientific illustration information and integrating text-and-illustration information into a better mental model) for readers of varying ability levels. The findings of this study have several implications for science instruction. First, our standpoint is consistent with that of the National Research Council (2014), which proposed that language teachers and science teachers should jointly devote efforts to science reading. This study clearly indicated that fourth-grade students, who are at the reading development stage of *reading to learn* (Chall 1983) with the *seeds of science* and *roots of reading* being sown and developed (National Research Council 2014), could master reading strategies and apply them to science reading. Second, teachers may need to have more confidence in students with lower reading ability. If such elementary school students are offered appropriate reading strategy instruction combined with textual examples, teaching models, and practice in strategy use, even those with lower reading ability levels might master the skills necessary for reading science articles.

One research limitation of this study is this study cannot determine if the facilitation of text-and-illustration integration arising from the three-strategy intervention in this study (one-by-one teaching) appears in the whole-class teaching. In this study, the fourth-grade students were taught individually to ensure that all instructed participants mastered the reading strategies (pay attention to illustrations, to process them in-depth, and to think about the relationship between textual descriptions and detailed parts of illustrations), and found the instructions benefited these young readers in learning scientific knowledge from reading, irrespective of their level of reading ability. Further research will confirm its validity effect in classroom.

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