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Influences of text difficulty and reading ability on learning illustrated science texts for children: An eye movement study

Yu-Cin Jian [a], Hwa-Wei Ko [b, *]

[a] Assistant Professor at the Department of Educational Psychology and Counseling, National Taiwan Normal University, No.129, HePing East Road, Section 1, Taipei, Taiwan
[b] Distinguished Professor at the Graduate Institute of Learning and Instruction, National Central University, No.300, Jhongda Rd., Jhongli City, Taoyuan County 32001, Taiwan

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ABSTRACT

In this study, eye movement recordings and comprehension tests were used to investigate children's cognitive processes and comprehension when reading illustrated science texts. Ten-year-old children (N = 42) who were beginning to read to learn, with high and low reading ability read two illustrated science texts in Chinese (one medium-difficult article, one difficult article), and then answered questions that measured comprehension of textual and pictorial information as well as text-and-picture integration. The high-ability group outperformed the low-ability group on all questions. Eye movement analyses showed that both group of students spent roughly the same amount of time reading both articles, but had different methods of reading them. The low-ability group was inclined to read what seemed easier to them and read the text more. The high-ability group attended more to the difficult article and made an effort to integrate the textual and pictorial information. During a first-pass reading of the difficult article, high- but not low-ability readers returned to the previous paragraph. The low-ability readers spent more time reading the less difficult article and not the difficult one that required teachers' attention. Suggestions for classroom instruction are proposed accordingly.

1. Introduction

Informational texts either in print or digital have one common characteristic, i.e., they usually have multiple representations (text, pictures, tables, etc.) in one article or in one web page. Theories of text and picture comprehension suggest that multiple representations facilitate reading comprehension if readers organize and integrate textual and pictorial information effectively according to their prior knowledge (Mayer, 2005; Schnotz & Bannert, 2003; Schnotz et al., 2014). However, multimedia presentations do not always improve comprehension or learning. Some researchers have shown that adding scientific illustrations to a text (McCabe & Castel, 2008) or mathematical illustrations to a problem-solving question (Berends & Van Lieshout, 2009; Ögren, Nyström, & Jarodzka, 2017) might have unfriendly effect.

Ten-year-old students in the fourth grade, who are at the beginning of the reading to learn stage (Chall, 1983), encounter academic requirements that include comprehension of increasingly complex texts (McMaster, Espin, & van den Broek, 2014;

* Corresponding author.
E-mail addresses: jianyucin@ntnu.edu.tw (Y.-C. Jian), hwawei@cc.ncu.edu.tw (H.-W. Ko).

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Sweet & Snow, 2003), for example, science texts. A science article is a typical formational text, and the picture–text ratio has expanded considerably from the past to the present in science textbooks (Pozzer & Roth, 2003; Slough, McTigue, Kim, & Jennings, 2010).

1.1. Background theories of text-and-picture reading

Various text and picture (including graphs & illustrations) reading theories explain the potentially beneficial effects of multimedia materials. Dual coding theory (Paivio, 1990) suggests that better memory for text accompanied by pictorial information can be attributed to a dual coding advantage: The activation of both verbal and visual representations in working memory makes it easier to connect the two codes, and consequently, to remember and retrieve information. Beneficial effects of multimedia materials on comprehension have been explained by the cognitive theory of multimedia learning (Mayer, 2005) and the integrated model of text and picture comprehension (Schnotz et al., 2014; Schnotz & Bannert, 2003).

The cognitive theory of multimedia learning proposed by Mayer (2005) suggests that text-and-picture reading involves three cognitive processes: 1) *selecting* relevant information, which occurs when readers devote attention to the text and relevant elements from the picture, and involves bringing external representations into working memory; 2) *organizing* selected information, in which verbal and pictorial models of selected textual and pictorial information are constructed separately in working memory; and 3) *integrating* the constructed verbal and pictorial models with existing prior knowledge to form a coherent mental model.

According to the integrated model of text and picture comprehension (Schnotz & Bannert, 2003; Schnotz et al., 2014), two different cognitive processes are involved in reading text-and-picture articles. One processing system is descriptive and involved in text reading, and the other is depictive and involved in picture reading. According to this model, text comprehension is a descriptive process that involves constructing surface textual knowledge, producing several propositional representations of the text content, and forming a mental model of the text theme. In contrast, picture comprehension is a depictive process that involves perceiving an external picture, creating a visual image, and constructing the picture's propositional representation and mental model. The information in the depictive process is based on structure mapping of analogy relations between depictive representations (Gentner, 1989). Readers deal with a picture's semantic components to comprehend rather than perceive it. The propositional representations and mental models in the two processing systems continuously interact. Both Mayer (2005) and (Schnotz et al., 2014; Schnotz & Bannert, 2003) theories of text and picture comprehension suggest that multiple representations facilitate reading comprehension. The premise is that the reader must encode both verbal and pictorial information presented in the article. However, the question of how young children with different reading abilities encode and connect the multiple representations (text and picture) while reading illustrated science texts, and whether text difficulty influences this process still demand further examination. The purpose of this study is to explore these questions by investigating how fourth graders with varying reading ability read science texts of varying difficulty.

1.2. Thinking-aloud protocols as a research tool in illustrated text reading research

Previous research has demonstrated that the multiple representation effect is inconsistent in children. Some studies have shown that illustrations inhibit reading comprehension (Harber, 1983), while others have demonstrated illustration facilitation of reading comprehension across different levels of reading ability (Small, Lovett, & Scher, 1993), or only for high-ability young readers (Hannus & Hyönä, 1999), only for low-ability young readers (Rusted & Coltheart, 1979). We speculated that young readers may have limited knowledge of the function of illustrations, and consequently do not pay enough attention to them. The process approach presented by thinking-aloud protocols and eye-tracking methodology offer an opportunity allowing for indirect (thinking-aloud) and direct (eye tracking) observations of reading behavior to test these assumptions.

Moore and Scevak (1997) used think-aloud protocols (i.e. report about one's mental processes) to investigate the reading strategies across different reading ability levels and ages. They asked students in grades five, seven, and nine to read a science article with illustrations (including tables and diagrams). Students were instructed to stop reading and report what they read and what they were thinking when they encountered red dots (inserted by the researchers) in the article. Coding the think-aloud data revealed that *without reference to illustrations* and *with reference to illustrations* were two major categories. Sub-categories for *without reference to illustrations* focused on text details, main text ideas, text themes, general strategies, artifact production, and artifact use. Sub-categories for *with reference to illustrations* focused on illustration details, main illustration ideas, illustration themes, and illustration use. This study found that the biggest differences in reading patterns between students in different grades were in the use of text themes and illustrations. Text themes were reported by 5%, 5%, and 52% of fifth, seventh, and ninth graders, respectively, and use of illustrations was reported in 8%, 13%, and 48% of fifth, seventh, and ninth graders, respectively. While reading science text, the fifth graders focused attention on text details, the seventh graders could hold the main idea of the text, and the ninth graders paid attention to the illustrations and connected text and illustration information. However, a cluster analysis showed that reading ability did not distinguish reading strategy use by students in any grade. These results are inconsistent with most other text reading research (Braten & Stromso, 2003; Dermitzaki, Andreou, & Paraskeva, 2008) that found that reading ability was tightly linked to reading strategy use, and reading strategy use was positively correlated with reading comprehension.

Norman (2012) used think-aloud protocols to investigate relationships between reading ability, reading processes, and reading comprehension in young readers. Second-grade students with high, medium, and low reading ability read informational texts with illustrations (including photographs, realistic drawings, maps, flow charts, and representation graphics), and shared their thinking as they were reading. They were prompted to think aloud whenever they studied an illustration. After reading each text, students summarized the text and answered reading comprehension questions. The verbal report data were analyzed by coding the reading strategies the participants used and the frequency of use. The reading strategies used included connection to prior knowledge, knowledge monitoring, making predictions, using illustrations, compare-contrast illustrations, repeated reading, and proposing speculation. A correlation analysis showed that the use of more reading strategies led to better summarizing performance in high-ability students. However, this facilitation effect was not found for medium- and low-ability students. Moreover, there was no significant correlation between the number of reading strategies used and reading comprehension performance. Overall, this study only found a relationship between reading strategy use and reading memory, not comprehension, and only for high-ability students. However, in Norman' s (2012) study, illustrations were not divided into different types for calculating analysis, such as decorative and organizational illustrations. Lenzner, Schnotz, and Muller (2013) have confirmed that decorative and organizational illustrations have different functions in diagram comprehension.

Taken together, using think-aloud protocols to investigate reading strategies has already provided some insight into how elementary school students read illustrated scientific texts. However, the think-aloud methodology may influence reading processes because young readers need to read and report what they are thinking simultaneously, and there may be competition for cognitive resources (Veenman, Van Hout-Wolters, & Afflerbach, 2006). Eye-tracking technology can record real-time reading behavior, and accordingly infer comprehension processes without adding cognitive load (Rayner, Chace, Slattery, & Ashby, 2006).

1.3. Eye-tracking technology as a research tool in multimedia learning research

The earliest research of young children's eye movement on reading science text illustrations was conducted by Hannus and Hyönä (1999). Their research involved fourth-grade students with high and low intellectual ability reading biology passages selected from fourth-year elementary school textbooks. Some illustrations (including color and black-and-white drawings and photographs) in the reading materials were more relevant to the text than others. For example, in the *Fly* passage, the illustration depicting the metamorphosis of a fly from an egg to an adult was the most relevant, and the photograph of a mosquito was the least relevant. After reading each passage, students reported the main points of the passages, and answered factual and comprehension questions based on the text and illustration content. The areas of interest (AOI) analyzed were text, illustrations, figure captions, and blank spaces in each passage. The results showed that high-ability students outperformed the low-ability students on all reading tests. The eye movement analyses showed that although total reading time was similar between groups, high-ability students read the text faster (105 words per minute) than low-ability students (77 words per minute), suggesting that the high-ability students spent more time rereading parts of the text. Total reading time for illustrations and figure captions did not differ between groups, but low-ability students spent more time on blank spaces. Further analyses showed that both groups spent significantly more reading time on more versus less relevant illustrations. However, high-ability students demonstrated more behaviors indicative of relating portions of text to relevant illustrations compared to low-ability students. This suggests that high-ability children use more mature reading strategies, concentrating on pertinent information and integrative processing. Another interesting finding was that only approximately 6% of total reading time was spent on illustrations across groups. This is much less than adults, who spend approximately 20–30% of their reading time on illustrations when reading science texts (Jian, 2016; Jian, Wu, & Su, 2014; Schmidt-Weigand, Kohnert, & Glowalla, 2010).

In Hannus and Hyönä (1999) study, they asked raters to estimate the amount of time spent on pertinent text and illustration areas (5-point scale, 5 = extensive eye movements back and forth, 1 = no interactive viewing). Thus, the number or times a reader moved their eye fixation back and forth (saccade) between the text and illustrations was not precisely calculated. "*Saccades are rapid eye movements used in repositioning the fovea to a new location in the visual environment. Saccadic movements are both voluntary and reflexive*" (Duchowski, 2007, p. 42). Readers' saccades between text and illustrations reflects connecting process of textual and pictorial representations (Jian, 2016; Mason, Tornatora, & Pluchino, 2015). Recent improvements in eye-tracking technology permit data collection on the number of saccades between text and illustration sections. In this study, we will use sequential analysis statistics (Bakeman & Gottman, 1997) to calculate readers' eye fixations, allowing for direct, objective observation of reading pathways (see Jian et al., 2014; Jian & Wu, 2015).

Recently, Mason et al. (2015) used eye-tracking technology to determine which eye movement indicators predict reading comprehension for illustrated text. Seventh-grade students read a science article (one text and one illustration) about the food chain, a topic that had not been previously presented in participants' science class. Then, participants completed reading tests that measured memory for textual and pictorial information, factual knowledge, and transfer knowledge. Hierarchical regression analyses showed that only the second-pass transitions (total number of transitions excluding first inspection), which indexes more purposeful processing and deeper reading between corresponding text and illustration segments uniquely predicted textual and pictorial memory and transfer knowledge test scores. This indicates that integrating text and illustration information via more purposeful allocation of visual attention is important for successful comprehension of illustrated texts. In this study, we adopted a test for the integration of textual and pictorial information to investigate fourth graders' deeper reading.

Earlier, Mason, Pluchino, and Tornatora (2013) investigated the effects of illustration labeling on science text processing and learning using eye-tracking methods. Sixth-grade students read a science passage on atmospheric pressure in one of three randomly assigned reading conditions: text with a labeled illustration, text with an unlabeled illustration, or text only. No differences were confirmed in factual knowledge. However, readers with the labeled illustration outperformed readers in the other two conditions on a knowledge transfer test. Furthermore, eye-fixation data showed that readers of text with the labeled illustration engaged in more fixation transfers between text and illustrations compared to the other two groups. This suggests that properly labeled illustrations promote integrative processing of reading material. Interestingly, a correlation analysis revealed that readers who spent more time reading relevant versus irrelevant information in text and illustration segments had higher reading comprehension scores. Thus, whether a reader can distinguish relevant from irrelevant information is an important factor for reading comprehension of an illustrated text.

Although Mason et al. (2013) found that labeled illustrations prompted sixth graders to read relevant illustration information, this was not observed in our previous study (Jian, 2016), in which a sequential analysis of eye fixations was conducted to investigate the cognitive processes and reading strategies are used by10-year-old students when reading illustrated texts. These results were compared to adult readers' performance. The target population included fourth-grade students with high reading ability, and the control group consisted of university students. All participants read an article titled *Morphologies and functions of flower, fruit, and seed*. The article was revised from an elementary school science textbook, and contained three paragraphs and two illustrations (one organizational and one decorative). The organizational illustration depicted a detailed, labeled illustration of a flower's structure as described in the text. The organizational illustration is regarded as an instructional picture, in contrast, decorative illustration seems to initiate better mood, but neither harmful nor beneficial for learning (Lenzner et al., 2013). After reading the article, participants answered questions on textual and illustration items. As expected, university students outperformed the younger students on all tests; more interestingly, eye movement patterns revealed that adult readers had bidirectional reading pathways for relevant text and illustration information. High-frequency transitions occurred not only reading the organizational illustration and its corresponding text description, but also while reading the decorative illustration and its corresponding text. Although fourth graders' eye fixations went back and forth within text paragraphs and between illustrations, they made fewer eye movements across text and illustration for mutual references, even though the organizational illustration included labels for several different flower features. Is this a general phenomenon in fourth graders? We examined it by grouping students by their reading abilities and manipulating text difficulty (see Methods section).

1.4. The present study and research questions

The present study investigated how fourth grade 10-year-old students, who were at the read to learn stage of reading development (Chall, 1983), with different levels of reading comprehension ability read Chinese illustrated science texts of varying difficulty. Text difficulty has a great influence on reading comprehension (McNamara, Graesser, & Louwerse, 2012). However, the studies reviewed above (Jian, 2016; Hannus & Hyönä, 1999; Mason et al., 2015, 2013; Moore & Scevak, 1997; Norman, 2012) did not take text difficulty into consideration, which we will examine in this study.

Moreover, we were specifically concerned with how students learned by means of reading; therefore, unfamiliar science articles modified from a fifth-grade textbook were used as reading materials rather than familiar (or taught) ones that might measure readers' prior knowledge. The reading materials had different types of illustrations (See Materials section) that had high ecological validity in science textbooks. The topics were not presented to fourth-grade readers in science class, and were new to our participants. Using unfamiliar reading materials allowed us to explore the reading processes and strategies involved in learning new information from illustrated texts.

We recruited students with both low and high reading ability to participate. Several eye movement indicators used in previous research (Jian, 2016; Hannus & Hyönä, 1999; Mason et al., 2013; 2015) were included in this study, and we added a new eye movement indicator, mean fixation duration, to reflect word decoding for text sections and decoding depth for illustration sections. We also analyzed saccades by performing sequential analyses to compare cognitive processes and reading patterns for articles of varying difficulty between high- and low-ability students. We were interested in (a) the effect of reading ability level on learning science by reading illustrated science texts, and (b) reading processes in high- and low-ability fourth-grade children for articles of varying difficulty.

2. Methods

2.1. Participants

Initially, 112 fourth-grade students (58 girls and 54 boys, mean age = 10.1 years) were recruited from five classes at an elementary school. We selected high- and low-ability participants for the eye movement experiment using a standardized reading comprehension screening test (Ko, 1999). The standard test comprised 20 multiple-choice questions, and each correct answer was awarded 1 point. Based on these reading test results, students with reading test accuracy higher than 80% met the national norms of Taiwan for the high-ability group (N = 25, 14 girls and 11 boys) with an average age of 10.4 years (range = 9.2–10.7 years, *SD* = 3.6 months). Students with reading test accuracy of 30–60% met the national norms for the low-ability group (N = 23, 10 girls and 13 boys) with an average age of 10.2 years (range = 9.3–10.4 years, *SD* = 3.2 months). We excluded students with accuracy below 30%, as they may have reading difficulties. In total 48 participants completed the eye movement experiment after obtaining parental consent. The experiment was safe, and the participants were rewarded for their participation with stationery. All participants had normal or corrected-to-normal vision.

2.2. Materials

The experimental materials were two illustrated science texts from a fifth-grade science textbook (Huang, 2013). An article was about plants and consisted of 400 Chinese characters and two illustrations (see Fig. 1), including a title, text section, and illustration section. The text section had three paragraphs: the first briefly explained flower reproduction through blossoming and seeding, the second described the parts of a flower (e.g., stamen, pistil, anther, thrum, and ovary) and their functions, and the third described pollination by bees. The illustration section included two types of illustrations: the illustration at the top of the page depicted the detailed flower structure with labels (organizational illustration) which was in correspondence to the text, and the illustration below it depicted a bee gathering flower nectar (decorative illustration).

The other article was about insects (ants) and consisted of 414 Chinese words and two illustrations with explanations (see Fig. 2). The text section had three paragraphs. The first paragraph briefly explained that there are different kinds of ants (e.g., soldier ant, worker ant, queen ant) and the definition of social insect, the second paragraph described the characteristics and functions of different kinds of ants, and the third paragraph described how ants secrete pheromones. The illustration section included two illustrations with explanations. The top illustration depicted ant holes with an explanation of ants' responsibilities, and the bottom illustration depicted belly characteristics of an ant while releasing pheromones, normal walking, or finding food, with written explanations. The bottom illustration was partly corresponded to the third paragraph, with new information such as an ant downloaded belly to release pheromones. Three experts (a professor in reading psychology, a Ph.D. candidate in science education who taught science courses in elementary schools for several years, and a science teacher at an elementary school with a master's degree in science education) assessed difficulty and readability of the illustrated science texts and comprehension tests, and their suitability for fourth-grade students. To rate text difficulty, the experts were invited to complete a questionnaire with the following options: “This article is very easy, a little easy, medium, a little difficult, or very difficult for fourth-grade students.” The two elementary school science teachers agreed that the plant article was more difficult, and the insect article was of medium difficulty, for fourth graders. After difficulty rating, we modified both articles following their suggestions to improve text readability. Participants also rated subjective difficulty on a 5-point scale after reading each article (see Procedure section), and the results were identical to the teachers' ratings.

Reading comprehension tests had yes-or-no and essay questions (see Appendix). Yes-or-no *questions* measured reading comprehension with five for text, illustration, and integration items respectively for each article. Text items assessed how well participants understood the textual information (e.g., functions of a flower's parts). Illustration items assessed how well participants extracted information from illustrations (e.g., number or relative position of a flower's parts) when the information was not further described in the text; integration items required readers to integrate textual and pictorial information. Essay questions, which were more difficult for the younger participants, included six “what” questions (e.g., “Which components of a flower compose the stamen?”), one “why” question (“Why do flowers attract insects and birds to distribute pollen?”), and one “how” question (“Please explain how a bee pollinates”). Each reading material was displayed on a single screen, and there was no scroll bar or additional pages.

2.3. Apparatus

Eye movements were recorded using an Eyelink 1000 at a sampling rate of 1000 Hz. A chin bar was used to minimize head movement. Viewing was binocular and eye movements were recorded from the right eye only. The reading material was presented on a 24-inch LCD monitor with a resolution of 1920 × 1200 pixels. Each Chinese character in the text section of the reading material was 28 × 28 pixels, and the distance between the monitor and participants was 65 cm. Thus, each Chinese character covered approximately 1° of visual angle on the screen. The illustration section was approximately 557 × 971 pixels. The whole reading material covered 46° (horizontal) × 30° (vertical) of visual angle on the screen.

2.4. Procedure

Data were collected in two sessions. In the first session, participants collectively completed the standard reading-comprehension screening test (Ko, 1999) in the classroom. This session lasted about 30 min.

In the second session two weeks later, participants were individually tested in a quiet room in the elementary school, and were instructed to read two articles for comprehension and press the space bar on the keyboard when they finished reading to initiate the reading tests. There was no time limit for reading to provide natural reading conditions. Therefore, participants read at their own pace. They read a practice article on the screen and answered two comprehension questions. This was followed by the formal experiment. A 13-point calibration and validation of eye movements was conducted for each participant. Participants were instructed to keep their head still while reading. To avoid order effects, half the participants in each ability group read the plant article first and then the insect article, and the other half of participants read the articles in

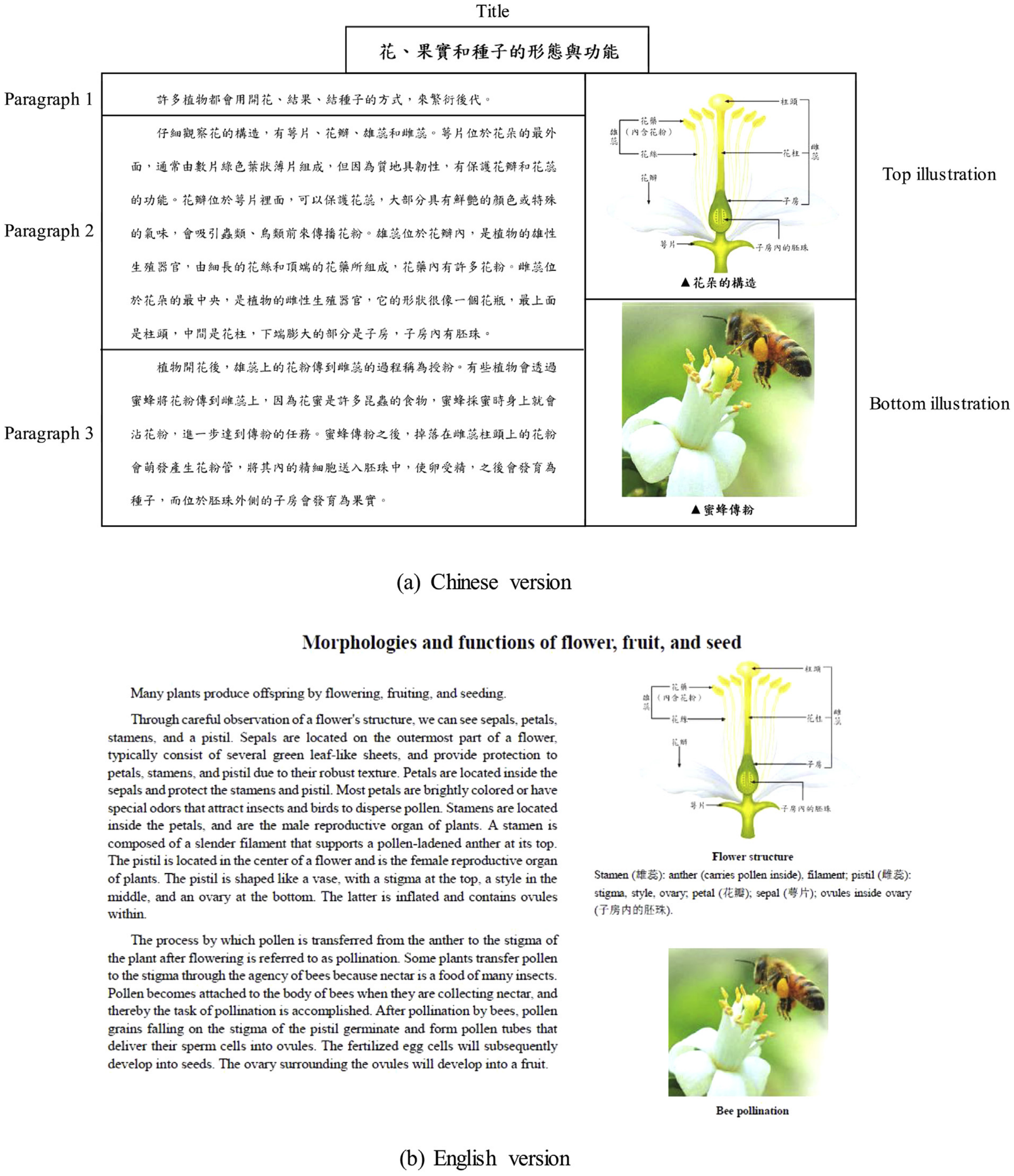


Fig. 1. Six AOIs (title, paragraph 1, paragraph 2, paragraph 3, topillustration, and bottom illustration) of the reading material(plant article). The participants did not see the black frames.

the reverse order. Participants completed reading tests immediately after reading each article to measure how well they remembered and understood the reading materials. Finally, they rated article difficulty on a 5-point scale (1 = very easy, 5 = very difficult). This session was approximately 30–40 min.

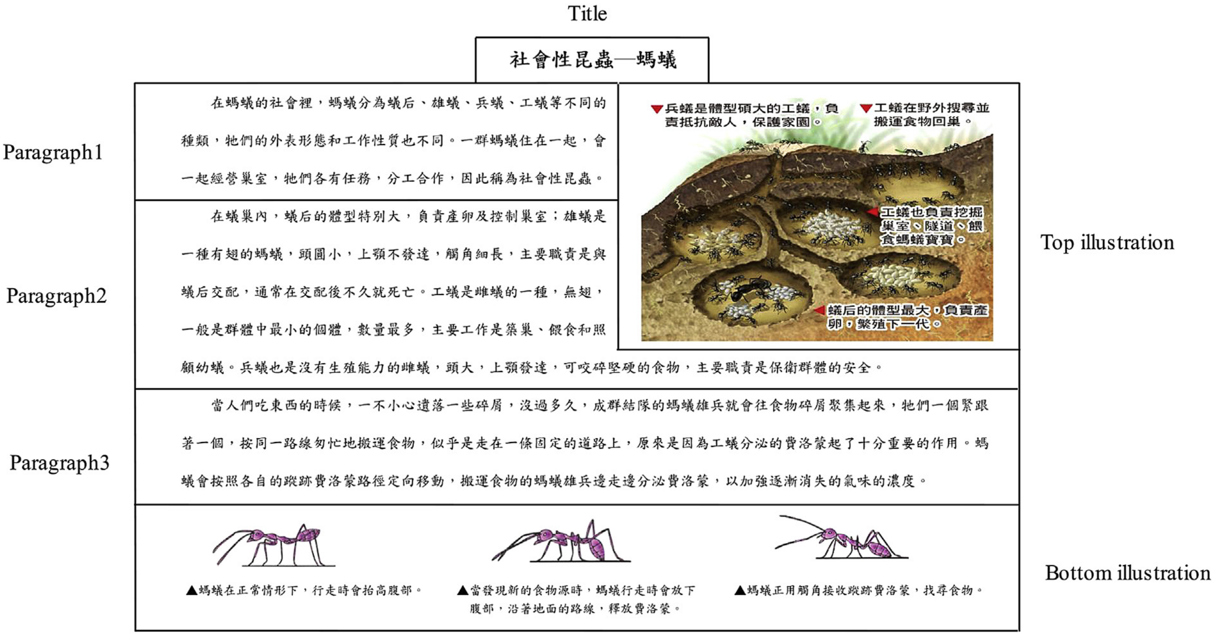


Fig. 2. Six AOIs (title, paragraph 1, paragraph 2, paragraph 3, topillustration, and bottom illustration) of the reading material(insectarticle). The participants did not see the black frames.

2.5. Data selection and scoring

2.5.1. Eye movements

Eye movement data from six participants were discarded due to unsuccessful eye-tracker recordings (two participants) or apparent drift (four participants). Unsuccessful recording occurred due to data transmission failure, and apparent drift occurred when fixations were almost entirely in the blank space, not on the text or illustrations. A crucial first step in eye-tracking experiments is to confirm that eye fixations were not subject to apparent drift to ensure that fixation locations were recorded correctly. Therefore, data from 42 participants (22 high-ability readers and 20 low-ability readers) were included in the analyses.

Before analyzing eye-movement data, the experimenters needed to define areas of interest (AOIs. We included AOIs of specific features such as paragraph, text, and picture on the reading materials as suggested by Duchowski (2007). Several eye movement indicators were included in the analyses: 1) total reading time (the sum of all fixation durations in AOI), which provides an indicator of the overall difficulty and degree of cognitive effort required to process reading materials; 2) mean fixation duration (average duration of all fixations in AOIs), which reflects how much time readers required to process words or illustrations (longer mean fixation durations on a word generally indicate word-decoding difficulty, and longer mean fixation durations on illustrations reflect deeper processing); 3) the number of fixations (the sum of all fixations in an AOI), which reflects how much attention and cognitive investment the readers devoted to the reading material; and 4) proportion of total reading time (fixation duration in specific AOIs divided by total fixation duration during the reading episode), which reflects selective attention to specific target regions during reading.

In addition to these four eye movement indicators, we analyzed the sequence of eye fixations to investigate reading strategies adopted by high- and low-ability participants. A series of matrix calculations (Bakeman & Gottman, 1997) was conducted to analyze the sequence of eye fixations, including first-pass sequences and total-pass sequences. First-pass reading (first reading of a target region) reflects early processing, including word decoding and derivation of initial meaning (Jian, Chen, & Ko, 2013; Jian & Ko, 2014; Mason et al., 2015), and is calculated the first time participants move from a target region to the next region. For example, 22 high-ability readers first read A-AOI, 11 of them made their next fixations to B-AOI, and so the transition percentage of first-pass sequences from A-AOI to B-AOI is 0.50. Total-pass sequences included first- and second-pass sequences (returning to a target region after first-pass reading that reflects higher order cognitive and more purposeful processing) (Hyönä, Lorch, & Kaakinen, 2002; Hyönä & Nurminen, 2006; Mason et al., 2013, 2015). Total-pass sequences were calculated based on all transition fixations from target regions to the next region. For example, A-AOI was read a total of 80 times by 22 high-ability readers, and there were 20 total transfers to B-AOI, so the transition percentage of total-pass sequences from A-AOI to B-AOI is 0.25.

2.5.2. Comprehension test

The comprehension tests included yes/no, multiple-choice, and essay questions. For the first two tests, correct answers were awarded one point; these were converted to percentage scores. For essay questions, answers were scored by two independent raters who were blind to the study purpose. Inter-rater reliability (Cohen's kappa) for each essay question ranged from 0.92 to 1.00. Any disagreement was carefully examined and discussed by the two raters until consensus was reached.

3. Results

To compare how the high- and low-ability groups read the insect (medium-difficulty) and plant (difficult) articles, several two-way mixed-design analyses of variance (ANOVAs) were conducted on measures of article difficulty ratings, all reading tests, and eye movement indicators. Reading ability (high, low) was a between-subjects variable, and article difficulty (medium-difficult and difficult) was a within-subjects variable.

3.1. Article difficulty ratings

Means and *SD*s for article difficulty ratings are presented in Table 1. There was a main effect of article difficulty, such that participants rated the plant article as significantly more difficult than the insect article, $F(1, 40) = 13.88$, $p < 0.01$, $\eta^2 = 0.26$, but the main effect of reading ability and the interaction between reading ability and article difficulty were not significant, $ps > 0.05$.

3.2. Learning outcomes

The first research question was whether high- and low-ability readers have different learning outcomes after reading illustrated science texts that varied in difficulty. The results are shown in Table 2.

For textual comprehension items, there was a main effect of article difficulty, $F(1, 40) = 4.67$, $p < 0.05$, $\eta^2 = 0.11$, but no main effect of reading ability, $p > 0.05$. The interaction between reading ability and article difficulty was also significant, $F(1, 40) = 10.13$, $p < 0.01$, $\eta^2 = 0.20$. Simple effects tests showed that accuracy was significantly higher for the high-versus low-ability group for the insect article, $F(1, 40) = 7.62$, $p < 0.01$, $\eta^2 = 0.16$, but not the plant article, $p > 0.05$. Accuracy was significantly higher for the insect versus plant article in the high-ability group, $F(1, 21) = 17.44$, $p < 0.001$, $\eta^2 = 0.45$, but accuracy did not differ between articles in the low-ability group, $p > 0.05$.

For the illustration comprehension items, there were main effects of reading ability, $F(1, 40) = 207.16$, $p < 0.001$, $\eta^2 = 0.85$, and article difficulty, $F(1, 40) = 31.62$, $p < 0.001$, $\eta^2 = 0.47$, but the interaction between reading ability and article difficulty was not significant, $p > 0.05$. The high-ability group outperformed the low-ability group, and both groups performed significantly better on the insect versus plant article.

For integral comprehension items, there were main effects of reading ability, $F(1, 40) = 5.14$, $p < 0.05$, $\eta^2 = 0.11$, and article difficulty, $F(1, 40) = 54.33$, $p < 0.001$, $\eta^2 = 0.58$. The interaction between reading ability and article difficulty was also significant, $F(1, 40) = 5.62$, $p < 0.05$, $\eta^2 = 0.12$. Simple effects tests showed that accuracy was significantly higher for the high-versus low-ability group for the insect article, $F(1, 40) = 14.24$, $p < 0.01$, $\eta^2 = 0.26$, but not for the plant article, $p > 0.05$.

Table 1
Means and Standard Deviations for 5-point rating of the article difficulty for high-ability and low-ability groups (1 indicates very easy and 5 indicates very difficult).

	High-ability group		Low-ability group	
	M	(SD)	M	(SD)
Plant article	3.41	(1.22)	3.50	(0.89)
Insect article	2.86	(1.08)	2.70	(1.03)

Table 2
Accuracy on the Reading Tests for both Articles for High- (N = 22) and Low-Ability (N = 20) Groups.

	Plant article		Insect article	
	High-ability group	Low-ability group	High-ability group	Low-ability group
	M (SD)	M (SD)	M (SD)	M (SD)
Yes-or-no questions (%)				
Textual items (5)	59 (19)	60 (21)	80 (28)	56 (29)
Diagram items (5)	67 (28)	56 (24)	90 (10)	72 (18)
Integration items (5)	49 (26)	48 (20)	90 (10)	69 (24)
Essay questions (correct answers)	6.45 (3.54)	2.85 (0.99)	8.86 (2.40)	6.25 (2.31)

Accuracy was significantly higher for the insect versus plant article in both the high-ability, $F(1, 21) = 47.20$, $p < 0.001$, $\eta^2 = 0.69$, and low-ability, $F(1, 19) = 12.72$, $p < 0.01$, $\eta^2 = 0.40$, groups.

For the essay questions, there were main effects of reading ability, $F(1, 40) = 28.70$, $p < 0.001$, $\eta^2 = 0.42$, and article difficulty, $F(1, 40) = 31.84$, $p < 0.001$, $\eta^2 = 0.44$, but the interaction between reading ability and article difficulty was not significant, $p > 0.05$. The high-ability group outperformed the low-ability group, and both groups performed significantly better on the insect versus plant article.

3.3. Eye movement analysis

The second research question was whether there are processing differences between high- and low-ability fourth-grade students, including cognitive investment, visual attention distribution between text and illustrations, and reading path, when reading illustrated science texts with varied article difficulty. Means and *SD*s for eye movement indices are presented in Table 3.

3.3.1. Analysis of the whole article

The upper section of Table 3 shows that for total reading time, there were no main effects of reading ability or article difficulty, $ps > 0.05$, but the interaction between reading ability and article difficulty was significant, $F(1, 40) = 12.74$, $p < 0.001$, $\eta^2 = 0.24$. Simple effects tests showed that the high-ability group spent significantly more total reading time on the plant versus insect article, $F(1, 21) = 9.00$, $p < 0.01$, $\eta^2 = 0.30$. In contrast, the low-ability group spent significantly more total reading time on the insect versus plant article, $F(1, 19) = 5.50$, $p < 0.05$, $\eta^2 = 0.22$.

For mean fixation durations for whole articles, there were main effects of reading ability, $F(1, 40) = 12.99$, $p < 0.01$, $\eta^2 = 0.25$, and article difficulty, $F(1, 40) = 6.33$, $p < 0.05$, $\eta^2 = 0.14$, and the interaction between reading ability and article difficulty was marginally significant, $F(1, 40) = 3.20$, $p = 0.08$, $\eta^2 = 0.07$. Simple effects tests showed that mean fixation durations were significantly shorter in the high-versus low-ability group for both the plant, $F(1, 40) = 7.43$, $p < 0.01$, $\eta^2 = 0.16$, and insect, $F(1, 40) = 16.27$, $p < 0.001$, $\eta^2 = 0.29$, articles. The high-ability group had significantly shorter mean fixation durations for the insect versus plant article, $F(1, 21) = 17.93$, $p < 0.001$, $\eta^2 = 0.46$. However, mean fixation durations did not differ between articles for the low-ability group, $p > 0.50$.

3.3.2. Analyses of text and illustration sections

Total reading time, number of fixations, proportion of total reading time, and mean fixation durations were dependent variables in these analyses. Means and *SD*s for these measures are also presented in Table 3.

3.3.2.1. Text sections. For total reading time, there were no significant main effects of reading ability or article difficulty, $ps > 0.05$, but the interaction between reading ability and article difficulty was significant, $F(1, 40) = 14.14$, $p < 0.01$, $\eta^2 = 0.26$. Simple effects tests showed that the high-ability group spent significantly more total reading time on the plant versus insect article, $F(1, 21) = 14.55$, $p < 0.01$, $\eta^2 = 0.41$. In contrast, total reading time did not differ between articles for the low-ability group, $p > 0.05$. Total reading time was significantly shorter for the high-versus low-ability group for the insect article, $F(1, 40) = 4.90$, $p < 0.05$, $\eta^2 = 0.11$, but not the plant article, $p > 0.05$.

For number of fixations, there were no significant main effects of reading ability or article difficulty, $ps > 0.05$, but the interaction between reading ability and article difficulty was significant, $F(1, 40) = 16.87$, $p < 0.001$, $\eta^2 = 0.30$. Simple effects tests showed that the high-ability group made significantly more fixations on the plant versus insect article, $F(1, 21) = 12.72$, $p < 0.01$, $\eta^2 = 0.38$. In contrast, the low-ability group made significantly more fixations on the insect versus plant article, F(1,

Table 3
Means and Standard Deviations for Eye-Movement Measures for High- (N = 22) and Low-Ability (N = 20) Groups on both articles.

	Plant article		Insect article	
	High-ability group	Low-ability group	High-ability group	Low-ability group
	M (SD)	M (SD)	M (SD)	M (SD)
Whole article				
Total reading time (sec)	147.89 (56.01)	121.42 (60.42)	123.99 (49.47)	156.53 (75.13)
Mean fixation duration (millisecond)	272.86 (36.02)	303.94 (37.89)	255.74 (31.34)	301.04 (41.20)
Text section				
Total reading time (sec)	121.11 (53.46)	102.48 (50.23)	88.86 (31.03)	118.83 (54.62)
The number of fixations	447.55 (184.29)	330.75 (154.52)	339.68 (111.83)	390.40 (179.40)
Proportion of total reading time (%)	81 (11)	85 (13)	73 (13)	79 (16)
Mean fixation duration (millisecond)	270.18 (40.70)	307.86 (41.04)	260.72 (34.71)	303.51 (42.78)
Diagram section				
Total reading time (sec)	25.12 (15.17)	14.74 (16.42)	32.30 (24.09)	31.36 (32.26)
The number of fixations	90.09 (54.39)	50.60 (50.27)	124.77 (99.07)	96.35 (82.88)
Proportion of total reading (%)	18 (11)	11 (12)	24 (12)	17 (13)
Mean fixation duration (millisecond)	280.40 (37.27)	265.49 (48.77)	248.80 (53.87)	283.90 (78.69)

19) = 4.93, $p < 0.05$, $\eta^2 = 0.21$. The high-ability group made significantly more fixations than the low-ability group for the plant article, $F(1, 40) = 4.90$, $p < 0.05$, $\eta^2 = 0.11$, but not the insect article, $p > 0.05$.

For proportion of total reading time, there was a significant main effect of article difficulty, such that readers spent a larger proportion of total reading time on the plant versus insect article, $F(1, 40) = 13.17$, $p < 0.01$, $\eta^2 = 0.25$. There was no significant main effect of reading ability nor a significant interaction between reading ability and article difficulty, *ps* > 0.05.

For mean fixation duration, there was a significant main effect of reading ability, such that mean fixation duration was significantly shorter for the high-versus low-ability group for both articles, $F(1, 40) = 12.03$, $p < 0.01$, $\eta^2 = 0.23$. There was no significant main effect of article difficulty nor a significant interaction between reading ability and article difficulty, *ps* > 0.05.

3.3.2.2. Illustration sections. For total reading time, there was a significant main effect of article difficulty, such that readers spent more total reading time on the insect than plant illustration section, $F(1, 40) = 9.47$, $p < 0.01$, $\eta^2 = 0.19$. There was no significant main effect of reading ability nor a significant interaction between reading ability and article difficulty, *ps* > 0.05.

For number of fixations, there was a significant main effect of article difficulty, such that readers made more fixations on the insect versus plant illustration section, $F(1, 40) = 11.95$, $p < 0.01$, $\eta^2 = 0.23$. There was no significant main effect of reading ability nor a significant interaction between reading ability and article difficulty, *ps* > 0.05.

For proportion of total reading time, there were significant main effects of reading ability, $F(1, 40) = 4.20$, $p < 0.05$, $\eta^2 = 0.10$, and article difficulty, $F(1, 40) = 12.71$, $p < 0.01$, $\eta^2 = 0.24$. The proportion of total reading time was significantly larger for the high-versus low-ability group, and readers spent a larger proportion of total reading time on insect versus plant illustrations.

For mean fixation duration, there were no significant main effects of reading ability or article difficulty, *ps* > 0.05, but the interaction between reading ability and article difficulty was significant, $F(1, 40) = 9.17$, $p < 0.01$, $\eta^2 = 0.19$. Simple effects tests showed that mean fixation durations were significantly longer for plant than insect illustrations in the high-ability group, $F(1, 21) = 11.19$, $p < 0.01$, $\eta^2 = 0.35$. Mean fixation durations did not differ between diagrams for the low-ability group, $p > 0.05$.

3.4. Analyses of proportions of total reading time on detailed AOIs

We divided each article of the reading materials into six AOIs: the title, paragraph 1, paragraph 2, paragraph 3, top illustration, and bottom illustration (see Figs. 1 and 2), and calculated the proportion of reading time for each AOI. Means and *SDs* for the proportion of reading time are presented in Fig. 3.

3.4.1. Plant article

The results showed that the high-ability group spent a significantly greater proportion of reading time on the top illustration compared to the low-ability group, $t(40) = 2.26$, $p < 0.05$, $d = 0.70$, while the low-ability group spent a significantly greater proportion of reading time on the title and paragraph 1 compared to the high-ability group, $t(40) = -2.45$, $p < 0.05$, $d = -0.76$; $t(40) = -3.45$, $p < 0.01$, $d = -1.06$. Groups did not differ in proportion of total reading time for paragraph 2, paragraph 3, or the bottom illustration, *ps* > 0.05.

3.4.2. Insect article

The high-ability group spent a significantly greater proportion of reading time on the bottom illustration compared to the low-ability group, $t(40) = 2.29$, $p < 0.05$, $d = 0.71$, while the low-ability group spent a significantly greater proportion of reading time on paragraph 3 compared to the high-ability group, $t(40) = -2.08$, $p < 0.05$, $d = -0.63$. Groups did not differ in proportion of total reading time for the title, paragraph 1, paragraph 2, or the top illustration, *ps* > 0.05.

3.5. Analyses of eye-fixation sequences

To examine cognitive processes and reading strategies used, we conducted a series of sequential analysis matrix calculations (Bakeman & Gottman, 1997) to analyze the sequence of eye fixations. Using the same procedure as our previous study (Jian, 2016), we divided each illustrated text into six AOIs (see above), and calculated the saccades from each of the six AOIs to the other AOIs. The results for first-pass and total pathways are reported below.

3.5.1. First-pass fixation sequences

3.5.1.1. Plant article. Fig. 4 provides first-pass transition illustrations of reading the plant article for the high- and low-ability groups. Fig. 4(a) indicates the high-ability group tended to localize their fixations on each text paragraph and then regress to the previous paragraph (e.g., paragraph 2 to paragraph 1, paragraph 3 to paragraph 2) after leaving the target area. The transfer probabilities for *paragraph 1* to *title*, *paragraph 2* to *paragraph 1*, and *paragraph 3* to *paragraph 2* were significantly higher than the expected values, $Z = 4.28$, $p < 0.001$, $Z = 3.41$, $p < 0.001$, and $Z = 2.66$, $p < 0.01$, respectively. Furthermore, the high-ability group tended to refer from *paragraph 3* to the *bottom illustration*, $Z = 3.57$, $p < 0.001$. Moreover, after the first scan, the high-ability group tended to transfer fixations back and forth between the two illustrations. Thus, the transfer

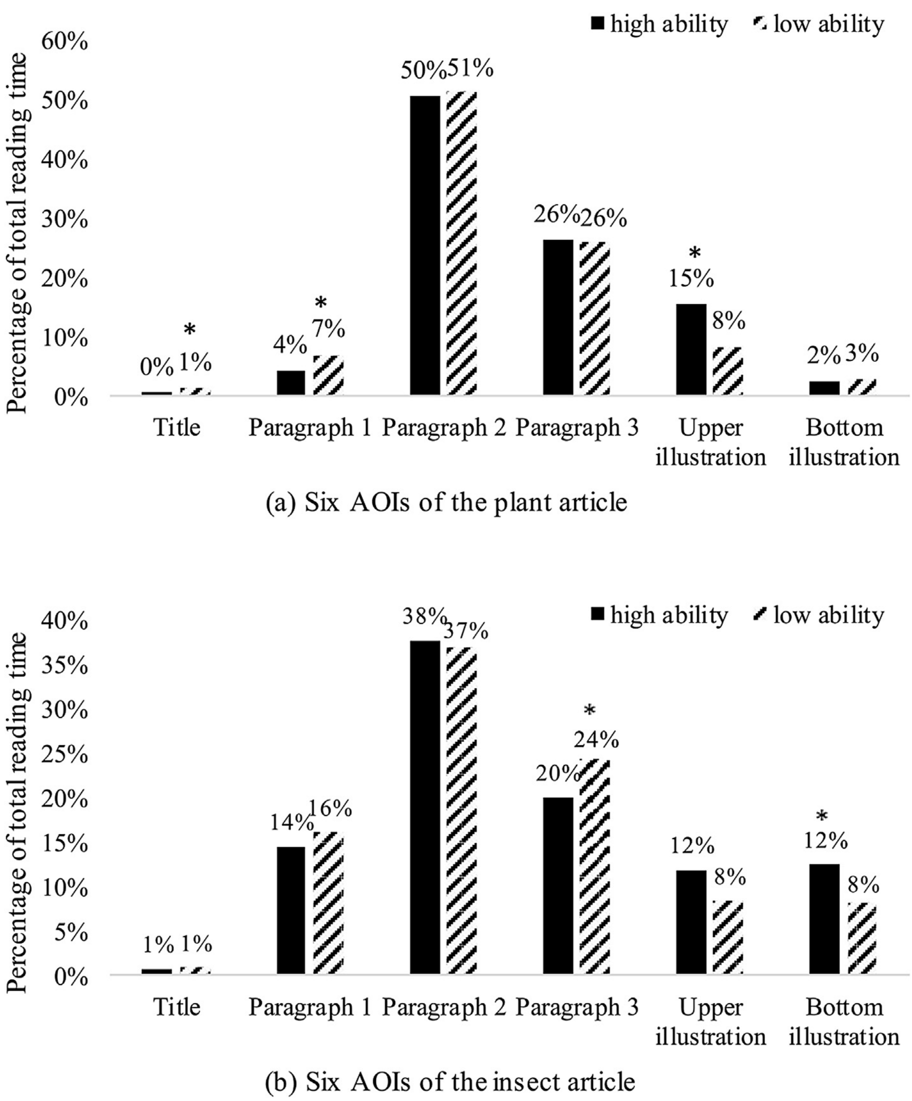


Fig. 3. Proportions of total reading time on AOIs (title, paragraph 1, paragraph 2, paragraph 3, topillustration, and bottom illustration) of the reading materials for high-ability and low-ability groups. (*$p < 0.05$).

probabilities for *top illustration* to *bottom illustration* and *bottom illustration* to *top illustration* were significantly higher than the expected values, $Z = 2.82$, $p < 0.01$, and $Z = 4.54$, $p < 0.001$, respectively. However, Fig. 4(b) indicates that the low-ability group did not regress to the previous paragraph as often as the high-ability group; instead, they tended to localize their next fixations on the following paragraphs. The low-ability group had a higher transfer probability for *title* to *paragraph 1*, $Z = 4.46$, $p < 0.001$, *paragraph 1* to *paragraph 2*, $Z = 2.20$, $p < 0.05$, and *paragraph 2* to *paragraph 3*, $Z = 3.22$, $p < 0.01$, compared to expected values.

3.5.1.2. Insect article. Fig. 5 provides first-pass transition illustrations for the insect article for the high- and low-ability groups. Fig. 5(a) shows that the high-ability group tended to transfer fixations from the title to paragraph 1, from paragraph 2 to the top illustration, and from paragraph 3 to paragraph 2; the transfer probabilities for these AOIs were significantly higher than the expected values, $Z = 3.28$, $p < 0.01$, $Z = 2.02$, $p < 0.05$, and $Z = 2.78$, $p < 0.01$, respectively. Furthermore, the high-ability group tended to transfer fixations back and forth between paragraph 3 and the bottom illustration, as shown by significantly higher transfer probabilities compared to expected values for paragraph 3 to the bottom illustration, $Z = 5.27$, $p < 0.001$, and the bottom illustration to paragraph 3, $Z = 2.00$, $p < 0.05$. Fig. 5(b) indicates that the low-ability group tended to transfer fixations from the title to the top illustration, from the top illustration to paragraph 1, from paragraph 1 to the title, and from paragraph 2 to the top illustration; the transfer probabilities for these AOIs were significantly higher than the expected values, $Z = 2.00$, $p < 0.05$, $Z = 2.85$, $p < 0.01$, $Z = 4.02$, $p < 0.001$, and $Z = 3.14$, $p < 0.01$, respectively. Furthermore, the low-ability group

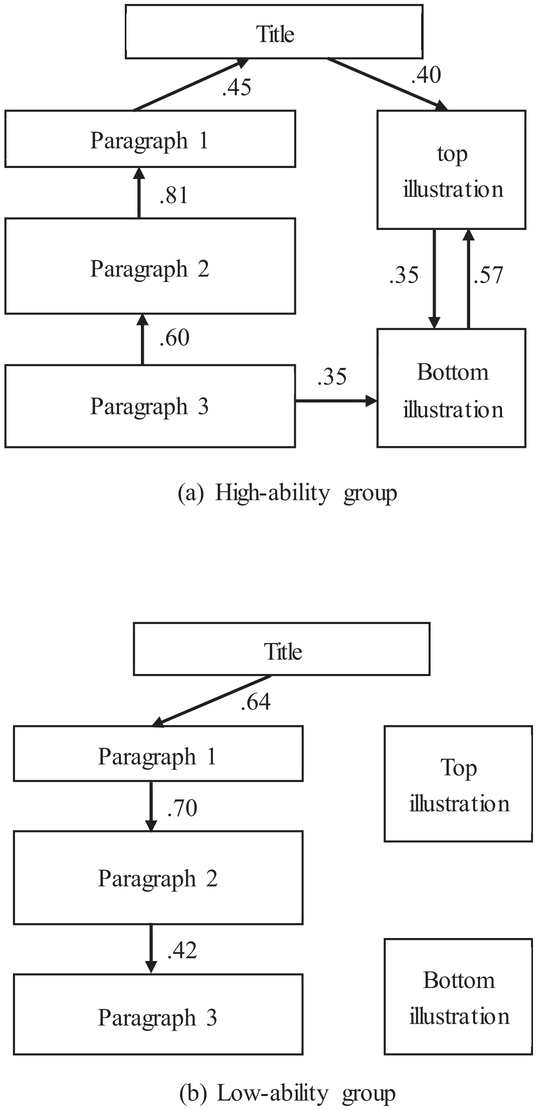


Fig. 4. *First-pass* transition diagrams of reading the *plant article* for the high-and low-ability groups. The numbers beside the arrow show the transition probabilities.

also tended to transfer fixations back and forth between paragraph 3 and the bottom illustration, as shown by significantly higher transfer probabilities compared to expected values for paragraph 3 to the bottom illustration, $Z = 5.58$, $p < 0.001$, and from the bottom illustration to paragraph 3, $Z = 2.99$, $p < 0.01$.

3.5.2. Total-pass fixation sequences

3.5.2.1. Plant article. Fig. 6 shows total-pass transitions of reading the plant article for high- and low-ability groups. Overall, patterns of total-pass transitions indicate greater interaction within the text and between illustrations for both groups. We found that transfer probabilities for *title* to *paragraph 1* were significantly higher than the expected value for high-ability, $Z = 3.36$, $p < 0.01$, and low-ability, $Z = 4.72$, $p < 0.001$, readers. A similar result was found for the reverse transfer, *paragraph 1* to *title*, $Z = 9.06$, $p < 0.001$, and $Z = 7.70$, $p < 0.001$, respectively. High- and low-ability readers had higher transfer probabilities for *paragraph 1* to *paragraph 2* than the expected values, $Z = 4.49$, $p < 0.001$, and $Z = 2.26$, $p < 0.05$, respectively. A similar result was found for the reverse transfer, *paragraph 2* to *paragraph 1*, for the high-ability, $Z = 3.69$, $p < 0.001$, and low-ability, $Z = 2.56$, $p < 0.05$, readers. Furthermore, both the high- and low-ability groups tended to transfer fixations back and

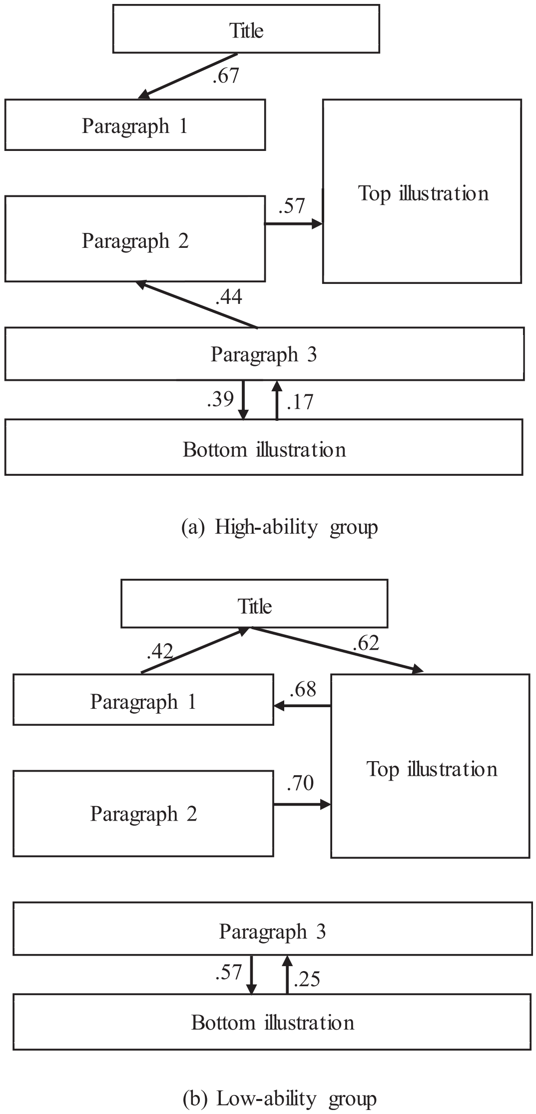
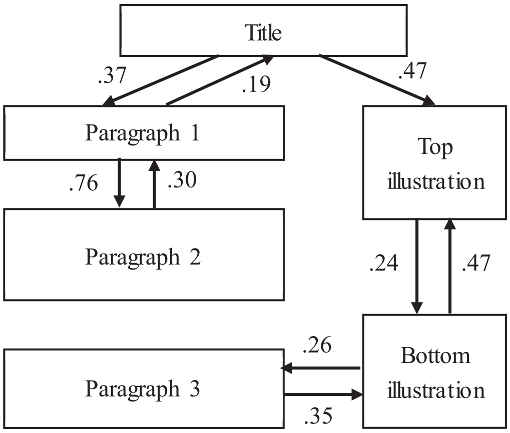


Fig. 5. *First-pass* transition diagrams of reading the *insect article* for the high-and low-ability groups. The numbers beside the arrow show the transition probabilities.

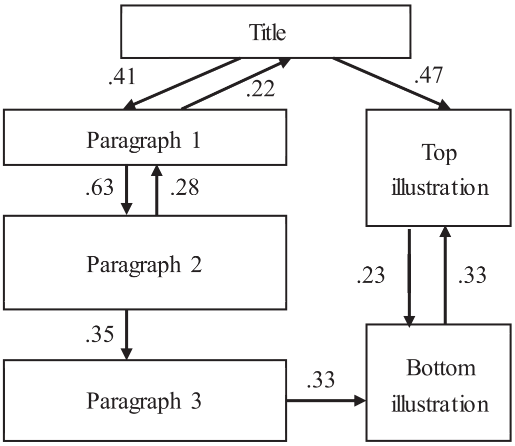
forth between the two illustrations, as shown by significantly higher transfer probabilities for *top illustration* to *bottom illustration*, $Z = 4.69$, $p < 0.001$, and $Z = 2.55$, $p < 0.05$, respectively, and *bottom illustration* to *top illustration*, $Z = 6.02$, $p < 0.001$, and $Z = 5.06$, $p < 0.001$, respectively, compared to expected values.

Total-pass transition fixations for *paragraph 3 to bottom illustration* differed between groups. Fig. 3(a) shows the total-pass fixation sequences for the high-ability group, who performed bidirectional reading transitions between *paragraph 3* and *bottom illustration*, $Z = 5.28$, $p < 0.001$, and $Z = 3.02$, $p < 0.01$, respectively. In contrast, as indicated in Fig. 3(b), the low-ability group performed unidirectional transitions, such that only the transfer probability of *paragraph 3* to *bottom illustration* was significantly higher than the expected value, $Z = 5.39$, $p < 0.001$.

3.5.2.2. Insect article. Fig. 7 shows total-pass transitions for the insect article for the high- and low-ability groups. Overall, patterns of total-pass transitions were very similar for both groups. We found that transfer probabilities for the title to paragraph 1 were significantly higher than the expected value for high-ability, $Z = 4.01$, $p < 0.001$, and low-ability, $Z = 4.05$, $p < 0.001$, readers. A similar result was found for the reverse transfer, paragraph 1 to the title, $Z = 4.59$, $p < 0.001$, and $Z = 6.09$, $p < 0.001$, for high- and low-ability readers, respectively. Transfer probabilities for the title to the top illustration were significantly higher than the expected value for high-ability, $Z = 2.66$, $p < 0.01$, and low-ability, $Z = 3.48$, $p < 0.001$, readers. A similar result was found for the reverse transfer, the top illustration to the title, $Z = 3.95$, $p < 0.001$, and $Z = 3.56$, $p < 0.001$, for high- and low-ability readers, respectively. Moreover, both groups tended to localize their next fixation on the subsequent



(a) High-ability group



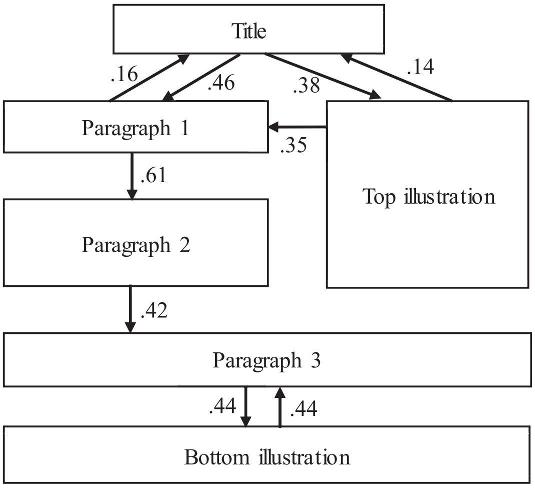
(b) Low-ability group

Fig. 6. *Total-pass* transition diagrams of reading the *plant article* for the high-and low-ability groups. The numbers beside the arrow show the transition probabilities.

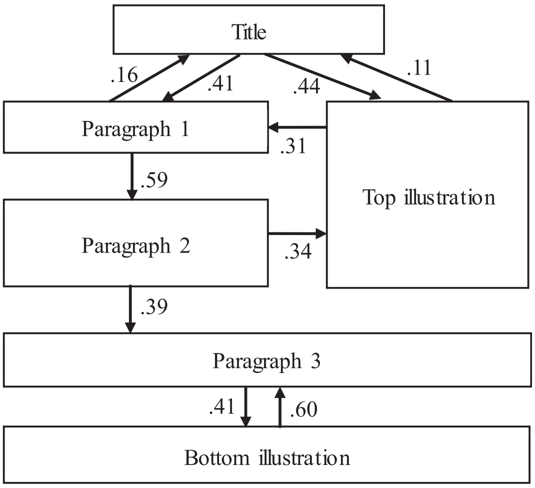
paragraph. The high-ability group had a higher transfer probabilities compared to expected values for paragraph 1 to paragraph 2, $Z = 4.54$, $p < 0.001$, and paragraph 2 to paragraph 3, $Z = 3.22$, $p < 0.01$. The low-ability group had higher transfer probabilities compared to expected values for paragraph 1 to paragraph 2, $Z = 4.56$, $p < 0.001$, and paragraph 2 to paragraph 3, $Z = 2.36$, $p < 0.05$. High- and low-ability readers also had higher transfer probabilities compared to expected values for bottom illustration to paragraph 3 and top illustration to paragraph 1, $Z = 3.69$, $p < 0.001$, and $Z = 7.42$, $p < 0.001$, $Z = 4.03$, $p < 0.001$, and $Z = 4.20$, $p < 0.001$, respectively.

4. Discussion

This study investigated how 10-year-old students in fourth grade, who were beginning to read to learn, with different reading abilities read illustrated science articles of varying difficulty. Articles were selected from a fifth-grade science textbook and the topics of the article would not be taught in fourth grade. Article difficulty was rated by elementary school science teachers and the students themselves. The article about plants was rated more difficult than the article about insects. Effects for both article and ability were observed. In general, all students had better comprehension performance for the easier insect article, and high-ability students outperformed low-ability students on all measurements. The differences indicated that the low-ability students not only had trouble reading text, but also had difficulties with reading illustrations and higher-order integration of textual and pictorial information. This phenomenon is supported by eye-tracking data, which will be discussed below.



(c) High-ability group



(d) Low-ability group

Fig. 7. *Total-pass* transition diagrams of reading the *insect article* for the high-and low-ability groups. The numbers beside the arrow show the transition probabilities.

The eye movement data for entire articles showed that the two groups of students had roughly similar reading time in both articles. In any case, a 2×2 ANOVA on mean fixation duration revealed that the high-ability group made longer fixations on the difficult plant versus easier insect article. The high-ability readers' data was consistent with that of a previous study (Hannus & Hyönä, 1999). They spent more time and had longer fixation duration on the more difficult text, but low-ability students showed no difference in fixation duration between the two articles. However, a different picture emerged when we examined the data by analyzing text, illustrations, and text and illustrations individually. In total reading time for text alone, there was no difference between the two groups, but high-ability students had more attention (number of fixations) and selective attention (proportion of total reading time) on the difficult plant article. On the contrary, low-ability students had their attention and selective attention on the easier insect article.

For illustration reading, both groups fixated more on insect illustrations. Yet, for deeper processing measured by mean fixation duration, the high-ability group showed longer duration for plant illustrations. For text and illustrations that were analyzed by AOIs, low-ability students spent more time on the plant article's title and first paragraph, and the third paragraph of the insect article. The high-ability students spent more time on the top illustration of the plant article, and the bottom illustration of the insect article. Both illustrations contained new information that were exclusive to them and otherwise mostly corresponded to the texts. This might indicate that in order to have better performance on integration comprehension items, the high-ability group tried to integrate the textual and pictorial information to form a coherent mental model as

Mayer (2005) suggested for multimedia learning. In general, our high-ability students read like adult readers, who monitored the reading process and allocated the resources required for text and illustrations to enhance comprehension, as a previous study has already shown (Jian, 2016).

Supplementary evidence was obtained from eye-fixation sequence analysis. A major difference was observed for initial reading processes, including word decoding and derivation of initial meaning. When reading the difficult plant article, the high-ability group tended to locate their fixations on each paragraph of the text and then regress to the previous paragraph, and transfer fixations back and forth between illustrations. The low-ability group did not regress to previous paragraphs as often as the high-ability group during initial reading. However, for advanced, purposeful processing, represented by total-pass transitions, high- and low-ability readers had higher transfer probabilities for transferring from paragraph 1 to paragraph 2, and for transferring fixations back and forth between the illustrations. The look-back and regress reading behavior is supposed to represent monitoring behavior and metacognitive ability (Rayner et al., 2006). The data seemed to contradict the above-mentioned observation. The low-ability students did not regress to previous paragraphs as often as the high-ability group during initial reading and tended to focus on the easier text than the difficult text. In sum, although both groups of students spent roughly the same amount of time reading both articles, the low-ability students spent more time on the easier insect illustrations and had a similar total-pass fixation sequence, i.e., they had a different way of reading them. The low-ability group was inclined to read what seemed easier to them and to read the text more. When we took the text and illustration data together, it was clear that the low-ability students had higher reading time for text than illustrations.

Our participants were10-year-old students who were supposed to be able to read to learn, and their reading behavior showed that they all performed like capable readers. For example, both groups spent only 1% of total reading time on the title, and 2–3% on the bottom decorative illustration for the plant article, which depicted a bee gathering nectar. For the easier insect article, first-pass and total-pass transitions were similar between the two groups, and they made similar transitions from text to corresponding illustrations, as Mason et al. (2015) found with seventh graders. However, the low-ability students' reading in the initial stage seemed to be a problem for them, especially with the difficult article. It might explain why their effort of devoting more reading time to the text did not result in a better comprehension performance. Nevertheless, comprehension performance for the insect illustration of low-ability students is encouraging. Their performance was a little better than chance for questions about the text (0.56), but was 0.72 for questions about the insect illustrations (compared to 0.56 for the plant illustrations). This indicated that low-ability readers did learn from the illustrations of easier text but not from higher reading time for the text.

5. Conclusion

In this study, we provided different types of questions to assess comprehension for text and pictures individually as well as integration items that required readers to integrate textual and pictorial information. The results showed that in addition to an effect of reading ability, there was also an effect of the type of article. For example, the high-ability students, who showed relatively mature reading behavior, did not do well in comprehending the difficult article either. Their performance for the plant article's text ($M = 0.59$), illustration ($M = 0.67$), or integrated questions ($M = 0.49$) was not satisfactory. The eye movement data is noteworthy for researchers and teachers because similar reading time and reading behavior between the two groups of students did not result in similar reading achievement. What concerns us was the low-ability students who devoted time and cognitive resources to the easier text, which did not help them read better. Our data indicated that their reading problems might occur during the initial reading stage. It definitely deserves more attention from science teachers. Nevertheless, an illustration may boost their reading comprehension if it is easy for them to read. Using illustrations to promote initial reading might help low-ability students read to learn.

This study thus has two pedagogical implications. First, young readers, even those with high reading abilities, still require assistance while reading more difficult science articles. Although our high-ability students monitored their reading processes by rereading the previous paragraph as the adult readers did, their reference behavior across text and illustrations was apparently employed less than by adult readers (Jian, 2016). Therefore, helping students to connect relevant textual and pictorial information, as suggested by Mayer (2005), might be an ideal way to overcome this difficulty. Second, this study demonstrated that the easier article seemed to raise the low-ability students' interests, and they were willing to devote their efforts to reading. Therefore, to increase the fitness degree of reader and text, a teacher should modify a difficult text into an easier one. Adding friendly illustration explanations might be a feasible method.

Despite this study's research and practical contributions, there are limitations to be considered. We only used biological articles as reading materials; other science topics, such as physics, chemistry, and earth science, were not studied. Science illustrations are multivariate, such as diagrams, photographs, or flow charts, and they have different visual forms, functions, and degrees of difficulty. Therefore, the results of this study might be limited in generalizability to other science topics. Another limitation was that eye-tracking studies directly measure attention but not cognition. Readers' cognitive processes were indirectly inferred from eye-movement patterns, and interpretation should be cautious.

Acknowledgement

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