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Reading Instructions Facilitate Signaling Effect on Science Text for Young Readers: an Eye-Movement Study

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Abstract Science texts often use visual representations (e.g. diagrams, graphs, photographs) to help readers learn science knowledge. Reading an illustrated text for learning is one type of multimedia learning. Empirical research has increasingly confirmed the signaling principle's effectiveness in multimedia learning. Highlighting correspondences between text and pictures benefits learning outcomes. However, the signaling effect's cognitive processes and its generalizability to young readers are unknown. This study clarified these aspects using eye-tracking technology and reading tests. Eighty-nine sixth-grade students read an illustrated science text in one of three conditions: reading material with signals, without signals (identical labels of Diagram 1 and Diagram 2 in text and illustration), and with signals combined with reading instructions. Findings revealed that the signaling principle alone cannot be generalized to young readers. Specifically, "Diagram 1" and "Diagram 2" in parentheses mixed with science text content had limited signaling effect for students and reading instructions are necessary. Eye movements reflected cognitive processes of science reading; students who received reading instructions employed greater cognitive effort and time in reading illustrations and tried to integrate textual and pictorial information using signals.

Keywords Diagrams · Eye tracking · Reading instruction · Science text · Signaling principle

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Introduction

Informational texts, such as science texts, often use visual representations (e.g. diagrams, graphs, photographs, tables) to help readers learn a specific topic. Reading an illustrated text is one type of multimedia learning. According to an influential theory (cognitive theory of multimedia learning, CTML; Mayer, 2014) of multimedia learning, readers need to select relevant textual and pictorial information, connect both representations, and integrate their prior knowledge to achieve reading comprehension.

An increasing number of empirical studies have confirmed the *signaling principle* (Van Gog, 2014) is effective in multimedia learning. That is, highlighting the corresponding elements of text and illustrations by providing signals or cues benefits readers' learning outcomes (Boucheix & Guignard, 2005; Jamet, 2014; Ozcelik, Arslan-Ari & Cagiltay, 2010; Scheiter & Eitel, 2015; Van Gog, 2014). Signals have many types, such as spotlights, color coding, and identical labels provided in the text and illustrations (Boucheix & Guignard, 2005; McTigue, 2009; Scheiter & Eitel, 2015). A recent meta-analysis (Richter, Scheiter & Eitel, 2016) has indicated that several studies have found the positive effects of signaling on learning outcomes, especially in low-prior knowledge university readers (i.e. Jamet, 2014; Ozcelik et al., 2010; Scheiter & Eitel, 2015); however, the reported effects of the signaling principle were inconsistent in primary or middle school students. Some studies reported positive effects (Boucheix & Guignard, 2005), while others reported null (i.e. Jeung, Chandler & Sweller, 1997) or negative (i.e. McTigue, 2009) effects, despite the fact that these young readers also had low or limited prior knowledge.

One possible source of inadequacy for the young readers may be linked to the fact that although readers' attention is guided by the signals (Mautone & Mayer, 2001), their eyes are fixated on the right place (e.g. relevant diagram of the corresponding sentences), so they know where to read, but they still do not know how and what to read. Indeed, previous researchers have confirmed that young children have a limited capacity for diagram literacy—i.e. they were poor at decoding diagram information (Jian, 2016; Jian & Ko, 2017; McTigue, 2009; Moore & Scevak, 1997). Therefore, the inclusion of reading strategy instructions might be necessary to encourage young readers to use signals while reading science articles.

Multimedia Learning Theories

Evidence strongly suggests that people learn better if they use multiple representations (e.g. text, pictures) to read rather than using a single representation; this phenomenon is called the *multimedia principle* (Butcher, 2014). In multimedia learning, two theories have been discussed extensively: the CTML (Mayer, 2014) and the integrated model of text and picture comprehension (ITPC; Schnotz, 2005). Both theories describe multimedia learning as a multistage cognitive process during mental model construction integrating textual and pictorial representations. Initially, output stimuli (word, picture) are represented in their surface features belonging to physical levels and then transformed into internal textual and pictorial representations belonging to psychological levels, and a mental model is created later in the process. Many of these ideas are clearly generated using Kintsch's construction-integration model of text comprehension. Kintsch (1988) proposed that reading comprehension processes include different representations in three levels. The first is the representation of linguistic surface structure: readers decode words' pronunciations, meanings, and syntax and store surface semantics of sentences while reading to the end of the sentences. The second is the representation of propositional text base: readers store the textual propositions and capture their semantics immediately during reading. The third is the representation of the situation model: textual propositions are integrated into readers' background knowledge and form a mental model with deep processing. These ideas are important foundations for the following theories of illustrated text reading, such as the CTML (Mayer, 2014) and the ITPC (Schnotz, 2005).

According to the CTML (Mayer, 2014), information from words and pictures is initially extracted and represented in separate sensory memory; after attentional selection, the selected words and pictures are transformed into textual and pictorial representations and integrated with each other in short-term memory, triggering readers' prior knowledge in long-term memory and finally integrating into a mental representation of the multimedia learning episode. According to the ITPC (Schnotz, 2005), there are two cognitive processes from reading an illustrated text to learning. Words and pictures correspond to descriptive and depictive representations, respectively. Readers first construct the surface representation of a text and produce a propositional semantic representation. This process of text-based comprehension relies on symbolic structure analysis. In another reading path for pictures, readers first perceive a picture's features and create a mental image of it. To comprehend pictures, readers not only perceive them but also execute semantic processing and finally construct a propositional representation and mental model of the image. This interplay and transformation of picture comprehension relies on analogical structure mapping, to which verbal (or textual) information can be added. To summarize the CTML and the ITPC, Eitel, Scheiter, Schüler, Nyström and Holmqvist (2013) explained that the interplay between processing of text and pictures may happen in the initial processing preserved in late processing during reading according to both theories.

The Signaling Principle in Multimedia Learning

The signaling principle (Richter et al., 2016; Van Gog, 2014) means highlighting the correspondences between verbal and pictorial information through signals or cues to improve learning in reading a multimedia message (e.g. illustrated text). Three types of signals that highlight specific correspondences between text and diagrammatic elements have usually been used in empirical research (Scheiter & Eitel, 2015): color coding, labels in text and diagrams, and deictic expressions. Color coding uses identical colors to print words and their corresponding diagram elements (Kalyuga, Chandler & Sweller, 1999; Ozcelik, Karakus, Kursun & Cagiltay, 2009). Labels can serve as signals, where words from the text are printed again in a diagram that acts as a pointer to identify the corresponding element between the text and the diagram (Jian, & Wu, 2015; Mason, Pluchino & Tornatora, 2013; Mayer & Johnson, 2008). Deictic expressions use short phrases in the text, such as "this can be seen in the middle part of the diagram," to point out corresponding elements (Scheiter & Eitel, 2015).

Why are signals beneficial to multimedia learning? The guiding-attention hypothesis (De Koning, Tabbers, Rikers & Paas, 2009; Ozcelik et al., 2010) and visual-search hypothesis (Jamet, 2014; Ozcelik et al., 2010) are possible explanations. These two hypotheses are supported by several empirical studies using eye-tracking technology. The use of eye-tracking technology in multimedia learning research has become very popular recently. This method is based on the eye-mind assumption (Just & Carpenter, 1980) that the direction of a person's gaze indicates the location of the information (e.g. words, picture, symbols) they are processing at a cognitive level. According to the guiding-attention hypothesis, the signaling effect may stem from guiding readers' attention to relevant information (Ozcelik et al., 2010); thus, readers are expected to spend considerable time and have many eye fixations when reading the signals and their corresponding areas. On the other hand, according to the visual-search hypothesis, the underlying reason for the signaling effect is to reduce unnecessary visual search processes (Jamet, 2014; Tabbers, Martens & Merriënboer, 2004); thus, readers are expected to attend more easily and quickly to the relevant areas where signals are located or indicated.

Scheiter and Eitel (2015) investigated effects of signaling on visual attention using eye-tracking technology. They asked undergraduate students to read an illustrated text consisting of 16 pages about the human circulatory system, either with or without corresponding signals. The signals simultaneously used deictic references, labels, and color coding as previously mentioned. The results showed that signaled elements were inspected more frequently in the condition with corresponding signals than in the condition without signals, supporting the guiding-attention hypothesis. Additionally, students in the signal condition tended to attend more rapidly to signaled elements to which the text referred than did students in the no-signal condition, supporting the visual-search hypothesis. Jamet (2014) investigated the effects of attention guiding in multimedia learning of static diagrams and spoken explanations by recording participants' eye movements. Undergraduate students were asked to learn the cognitive theory of multimedia learning (Mayer, 2005) on the monitor with a theory figure. In the signaling condition, items on the screen turned red when they were mentioned in spoken sounds; in the no-signaling condition, no color changed. The results showed students in the signals group spent more total reading time on the relevant information than students in the no-signals group, supporting the guiding-attention hypothesis. Furthermore, a relationship between visual searching and shortened processing time was also found. Students in the signals group developed anticipatory strategies, fixations on the right areas prior to signals occurring, supporting the visual-search hypothesis. Ozcelik et al. (2010) also used eye-tracking technology to investigate the influence of signals on adult readers. They asked undergraduate students to read about a turbofan jet engine and hear a narration about how the engine works. The illustration of the engine either was or was not in a signaled format. In the signaled format, each corresponding terminological label in the illustration was presented in red while the item was mentioned in the narration of the sentence. The results showed that signals guided readers' attention to the relevant information, and they had a higher number of fixations and a longer total reading time for the relevant information including labels and related parts in the illustration.

The above research reports all recruited undergraduate students as participants to investigate the signaling effect in science multimedia learning. According to the meta-analysis of Richter et al. (2016), research has seldom used elementary school students as participants to investigate the reading process and the effectiveness of the signaling principle in young readers. Only one study (Mason et al., 2013) also used eye-tracking technology to examine the reading process of multimedia learning, and only two studies (Jeung, Chandler & Sweller, 1997; McTigue, 2009) used reading tests to verify the signaling effect in young readers.

Mason et al. (2013) investigated the signaling effect for young readers while reading an illustrated science text about atmospheric pressure and a related phenomenon. Sixth-grade students were assigned to one of three reading conditions: text only, text with an unlabeled illustration, and text with a labeled illustration. Results showed that readers of the labeled illustrated text significantly outperformed both readers of text only and readers of unlabeled illustrated text in the test of knowledge transfer, but the three groups showed no differences in a factual knowledge test. Eye-movement data also showed that readers of the labeled illustrated text spent more time rereading text segments while re-inspecting the illustration. This indicated that the labeled illustration promoted more integrative processing of the reading material. Consistent with adult research (Ozcelik et al., 2010; Scheiter & Eitel, 2015), this study confirmed that visual signaling was effective in improving reading comprehension and integrating information from the text and illustrations.

On the contrary, McTigue (2009) did not find a signaling effect for young readers. McTigue asked sixth-grade students to read a life science and a physical science text. The students were randomly assigned to one of four groups: (1) science texts with illustrations (i.e. the control group), (2) science texts with labeled illustrations of each part of the human body cycle and the machine cycle (i.e. the parts group), (3) science texts with labeled illustrations of the cycles for each major process (i.e. the steps group), and lastly, (4) science texts with labeled illustrations for each part and each major process (i.e. the parts and steps groups). The results found no significant difference between the four groups on the reading comprehension test of the physical science text. This implied that signaling important and relevant information of the text on the diagram did not improve young readers' reading comprehension of the science article.

Pictorial Representations in Science and the Benefit of Strategic Instruction

Pictorial representation has an important function in a scientific text. For example, figures often depict the physical appearance and spatial structure of a phenomenon (Hegarty & Just, 1993; Johnson-Laird, 1980) and allow an otherwise imperceptible structure described in the text to become discernable. In an illustrated text reading, when readers first view a figure, they could represent it as a single chunk (Miller, 1956) and a holistic unit in working memory. A figure requires few cognitive resources and releases considerable amounts of resources for processing of text propositions, as well as connecting textual and pictorial representations and, in turn, facilitating text comprehension (Eitel et al., 2013; Scheiter & Eitel, 2015). In sum, including figures provides a scaffolding effect (Johnson-Laird, 1980; Larkin & Simon, 1987) in science reading.

However, previous research has revealed that young readers were poor at using scientific figures or diagrams (Jian, 2016; Jian & Ko, 2017; McTigue, 2009; Moore & Scevak, 1997) and even ignore them (Jian, 2016, 2017; Hannus & Hyönä, 1999) during science reading. As pictorial representations are important in conveying scientific concepts, it is necessary to teach young readers how to interpret scientific illustrations. Besides, young readers often have other reading difficulties in science reading. Scheiter et al. (2015) indicated that young or middle school students often encounter difficulties in interpreting verbal or pictorial representations, understanding the relationship between the textual and pictorial representations, and transforming one representation into others (Ainsworth, 2006) when reading science texts. Therefore, helping young readers to learn how to interpret diagram information and integrate it with textual information is very important. The majority of strategic instructions or prompts targeted in educational multimedia materials emphasized the following two reading strategies: that is, to prompt readers to select, organize, and integrate relevant information of the text and pictures by identifying the corresponding picture elements described in the text, and taking a close look at the picture, by comparing the selected textual and pictorial information to create an integrated mental model for reading comprehension (Bartholomé & Bromme, 2009; Larson et al., 1986; Scheiter, Schubert, Gerjets & Stalbovs, 2015).

Previous research have designed some studies to investigate the effects of reading strategy interventions on multimedia learning for adult readers (Bartholomé & Bromme, 2009; Kombartzky, Ploetzner, Schlag & Metz, 2010; Larson et al., 1986), but only scarce studies on young readers (Schlag & Plötzner, 2011) or middle school students (Scheiter et al., 2015). Schlag and Plötzner (2011) developed a reading strategy for sixth-grade students to investigate its effect on comprehension of an illustrated biology text. The reading strategy trained the students to acquire a general overview of the article, underline relevant terms in the text, mark relevant elements in the picture, use the underlined terms to label elements in picture, and finally, summarize the text in their own words, as well as draw a summative sketch. The cognitive process of performing this learning strategy corresponds to the selection, organization, and integration of the CTML (Mayer, 2005). The results showed that the students that received the reading strategy training had better reading comprehension performance than the students who did not receive the strategy training.

On the contrary, Scheiter et al. (2015) did not find that a reading strategy intervention had an effect on the multimedia learning of middle school students. They followed the reading strategies by Schlag and Plötzner (2011) who used the CTML (Mayer, 2005) as a framework. Scheiter et al. developed a multimedia strategy training for ninth-grade students. The strategy training included nine learning strategies: initial global inspection of the picture, identification of textual units, selection of relevant words and pictures, organization of relevant words and pictures, integration of verbal and pictorial information, final inspection of the picture, and responding to comprehension problems. An instructor first provided a demonstration for the participations, then the participants practiced the learning strategies in a small group, and the instructor provided feedback to them. The results showed although the participants learned the learning strategies content, their reading comprehension tests were not influenced by the training condition. Scheiter et al. proposed two possible explanations why the ninth-grade students had failed to apply the strategies taught to them when reading the material. The first explanation posited that preexisting strategies may have influenced the extent which the new strategies were acquired (Hasselhorn & Körkel, 1986). These ninth-grade students may have favored strategies in reading illustrated text. Another possible explanation was that the reading strategies were not sufficiently internalized by the students, such that they could not apply them to new learning material. Beyond the two explanations, another possible explanation is that the nine reading strategies may have been too much to remember. Therefore, the kinds of reading strategies in this study were taken into consideration.

The reading strategy instructions in this study followed the literature review that emphasized text-and-picture references. Also, due to the fact that pictorial representation plays an important role in science reading, the strategies of reading a diagram were combined with the general reading instructions of this study. For example, to speculate what the diagram means, read the title and think about the relation between the title and content. Based on a different point of view from previous research (Scheiter et al., 2015; Schlag & Plötzner, 2011), this study did not emphasize the sequences of reading strategies. As readers have their own approaches to reading sequences, for example, some read the text first then read the picture, some sequences were in reverse, and yet their reading comprehension test did not differ if they made references to the text and picture in the reading processes (Jian, 2016).

Present Research and Questions

The purpose of this study was to investigate the effectiveness and reading processes of the signaling principle with or without reading strategy instruction in multimedia learning. Signals were designed in the text (the words "Diagram 1" and "Diagram 2" written in parentheses mixed with text content) and in corresponding illustrations' titles in the learning material (an illustrated biological text). These types of signals have high ecological validity and are commonly seen in science articles and textbooks. Sixth-grade students were randomly assigned to one of three reading conditions: reading material with or without signals (no-labels group, labels group) and with signals as well as reading instructions (teaching group). Students in the three groups had equal reading ability, prior knowledge of the learning material, and reading self-efficacy (see the "Methods" section). The two research questions are as follows.

First, do signals promote reading performance for young readers, or are signals alone insufficient to show signaling effects and must be combined with reading instructions?

Second, are there differences in the reading processes of illustrated text reading in three reading conditions (no-labels, labels, and teaching)?

Methods

Participants and Design

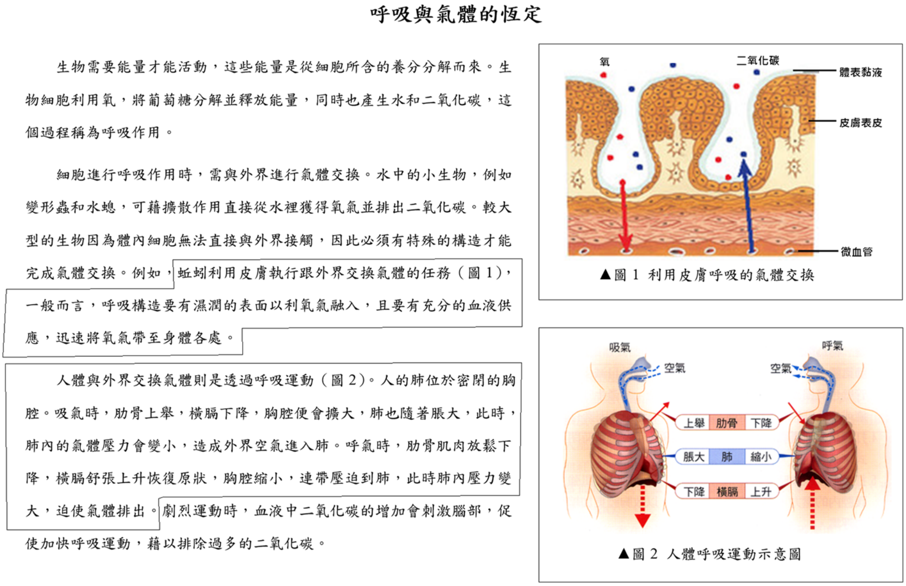
Initially, 148 sixth-grade students who were Chinese native speakers from seven classes at two elementary schools in Taiwan completed a standard reading comprehension screening test (Ko, 2006). Because readers need to possess a certain degree of reading ability to "read to learn," only students whose standard reading test Z-scores were above 0 (medium degree in the national norm) were chosen to participate in the following reading experiment. There were 102 participants (48 girls, 44 boys, $M_{age} = 12.32$ years) in total. Parental consent was obtained, and students were rewarded for their participation with stationery. Participants were randomly assigned to one of three reading conditions: no-labels (the words "Diagram 1" and "Diagram 2" did not appear in the text), labels (the words "Diagram 1" and "Diagram 2" were mixed with the text), and teaching (the words "Diagram 1" and "Diagram 2" were mixed with the text, and reading strategy instruction was provided) groups. Consequently, each group had 34 participants. Reading ability did not differ between groups ($p > .05$; see Table 1).

Materials

The learning materials consisted of a practice article and formal article (also used in our previous research, Jian, 2017). The practice article was a biological text with illustrations designed to familiarize participants with the article form they would read in the formal article, and was also used as an example of reading strategy instruction for the teaching group. The formal article was an illustrated biological text rewritten from a seventh-year science textbook used in Taiwan (Lin et al., 2008). It introduced gas exchange of cells in the human respiratory system and consisted of 425 Chinese characters in the text with a title and two diagrams (see Fig. 1). The text introduced the definition of respiration (paragraph 1), gas exchange of small and large living creatures (paragraph 2), and respiratory movement of humans (paragraph 3). The illustration section included two diagrams. The upper diagram depicted the method of gas exchange using skin breathing; for example, the skin surface of an earthworm is moist allowing oxygen to dissolve in it. The bottom diagram (obtained from http://www.phyworld.idv.tw) depicted the status of inhalation and exhalation in human respiratory movement; for example, while humans inhale, the ribs upthrow, the diaphragm descends, the thoracic cavity enlarges, and the lungs become swollen. Some important components' names (e.g. capillary, skin epidermis, ribs, diaphragm, thoracic cavity, lung) and status (e.g. upthrow, descend, enlarge, reduce) were labeled with words in the diagrams. Arrows in the diagrams also indicated direction and motion (e.g. an arrow in the upper diagram indicated oxygen from the outside of the skin moving into the blood capillaries). Each of the learning materials was displayed on a single screen without the next page or a scroll bar. The text was on the left and illustration on the right, similar to previous research on multimedia learning (Jian, 2016; Jian, & Wu, 2015; Mason et al., 2013; Mason, Tornatora, & Pluchino, 2015; Scheiter & Eitel, 2015).

Table 1 Basic characteristics for the no-labels, labels, and teaching groups

	No-labels (N = 29)	Labels (N = 30)	Teaching (N = 30)
Standard reading comprehension test (Z-score)	1.04 (0.49)	1.03 (0.48)	1.03 (0.46)
Prior-knowledge test (6 items)	2.48 (1.24)	2.70 (1.32)	2.47 (1.04)
Reading self-efficacy questionnaire (5-point scale)	14.03 (3.34)	13.60 (2.59)	14.27 (3.75)



呼吸與氣體的恆定

生物需要能量才能活動，這些能量是從細胞所含的養分分解而來。生物細胞利用氧，將葡萄糖分解並釋放能量，同時也產生水和二氧化碳，這個過程稱為呼吸作用。

細胞進行呼吸作用時，需與外界進行氣體交換。水中的小生物，例如變形蟲和水螅，可藉擴散作用直接從水裡獲得氧氣並排出二氧化碳。較大型的生物因為體內細胞無法直接與外界接觸，因此必須有特殊的構造才能完成氣體交換。例如，蚯蚓利用皮膚執行跟外界交換氣體的任務（圖 1），一般而言，呼吸構造要有濕潤的表面以利氧氣融入，且要有充分的血液供應，迅速將氧氣帶至身體各處。

人體與外界交換氣體則是透過呼吸運動（圖 2）。人的肺位於密閉的胸腔。吸氣時，肋骨上舉，橫膈下降，胸腔便會擴大，肺也隨著脹大，此時，肺內的氣體壓力會變小，造成外界空氣進入肺。呼氣時，肋骨肌肉放鬆下降，橫膈舒張上升恢復原狀，胸腔縮小，連帶壓迫到肺，此時肺內壓力變大，迫使氣體排出。劇烈運動時，血液中二氧化碳的增加會刺激腦部，促使加快呼吸運動，藉以排除過多的二氧化碳。

Fig. 1 The reading material (the black frames were analysis areas of semantically relevant sentences and illustrations, and the participants did not see them)

Measures

Measurements were taken in three parts. The first part included a reading efficacy questionnaire and prior-knowledge test to ensure the three groups were equivalent on basic characteristics for reading. The reading self-efficacy questionnaire was selected from the Progress in International Reading Literacy Study (PIRLS, 2011) and consisted of seven items, such as "Reading is easy for me," "Compared to my classmates, my reading ability is better," etc. Students were instructed to use a 4-point scale (1 = strongly agree, 4 = strongly disagree) to rate each item. The lower the sum score of the seven items, the higher the individual's self-efficacy for reading. The prior-knowledge test contained six yes-or-no questions about respiratory systems of organisms, so this topic was highly relevant to the formal reading material. Each correct answer was awarded one point; a perfect score was six.

The second part was a reading comprehension test to measure participants' learning outcomes from reading the formal article. It included three textual items, three pictorial items, and four integration items for the text and illustrations. All items were yes/no questions. Each correct answer was awarded one point. Three experts (one reading psychology professor, one science education Ph.D. candidate, and one elementary school teacher with a master's degree who taught science courses) revised and assessed the readability and difficulty of the reading materials and test.

The third part consisted of eye-movement measures. Several eye-movement indicators were selected in this study to measure readers' cognitive processes during multimedia learning (Jian, 2016; Jian, Wu, & Su, 2014; Jian, & Wu, 2015; Eitel, 2016; Hannus & Hyönä, 1999; Kriz & Hegarty, 2007; Mason et al., 2013, 2015). The degree of cognitive effort and conscious processing was measured using *total reading time* and the *number of fixations* on the areas of interest (AOIs). The eye-mind assumption (Just & Carpenter,

1980) proposes that one's eye fixates on specific objects (e.g. words, diagram), indicating that one is processing information about the objects. Thus, people look longer and have more eye fixations on words and diagrams when they are thinking about the objects more (Miller, 2015). The attention distribution of a learning episode was measured using the *proportion of total reading time* on the AOIs. Previous research showed that the majority of readers spend a significantly higher proportion of total reading time on text rather than on illustration sections during illustrated text reading (Jian, 2016; Jian, & Wu, 2015; Hannus & Hyönä, 1999; Hegarty & Just, 1993). This phenomenon is called text-driven reading (Hegarty & Just, 1993). The degree of (attempted) integration between text and illustration was measured using the *number of saccades between text and illustration*. Previous research showed that the numbers of saccades between text and illustration positively correlate with learning outcomes (Mason et al., 2013), and high-ability readers perform this saccade behavior more than low-ability readers (Hannus & Hyönä, 1999).

Apparatus

Eye movements during reading of the learning materials were recorded by an eye-movement device, the EyeLink 1000, at a sampling rate of 1000 Hz. Stimuli (the reading material) were presented on a 24-in. LCD monitor with a resolution of 1920 × 1200 pixels and a visual angle of 46° (horizontal) × 30° (vertical). A chin bar was used to minimize head movement. The distance between the monitor and participants was 65 cm.

Procedure

The students participated in the reading experiment individually. They were first asked to complete the reading self-efficacy questionnaire and prior-knowledge test on the monitor, followed by the eye-movement experiment. Before executing the formal experiment, the eye-tracking device had to be calibrated to the participants' gaze. The criterion of successful calibration and validation of the eye tracker was a deviation of 0.5° of the visual angle between the predictive values and observed values of eye fixation positions. In the eye-movement experiment, participants in the three groups (no-labels, labels, teaching) were instructed to read for comprehension, and that they would be tested after reading was completed. They were also told there was no time limit to read the article, the time they spent was up to them, but they could not return to see the article once they pressed the space keyboard to finish reading. All participants first read a practice article and completed two reading questions to familiarize them with the reading and testing forms; this was followed with the formal article reading, and finally, they completed a reading test on the monitor. All experimental procedures were identical for the three groups, except that the teaching group received the reading strategy instruction.

The reading strategy instruction was revised from my previous research (Jian, 2017), but this study focused more on the experimental manipulation (see Diagram 1 and Diagram 2 in the text to read their corresponding diagrams) and encouraged students to think deeply about what the diagrams conveyed. The instructions were as follows: "I will teach you three reading strategies to help you read better. The first strategy is to pay attention to the sentences that are relevant to the illustrations. For example, when you read the words “Diagram 1” and “Diagram 2” in the text, please carefully read the sentence containing these words, and observe if the characteristics of their corresponding diagrams are the same as the sentence’s description. The second strategy is to speculate about what the diagrams mean, and read all the labels of the components in the diagrams as well as observing their structure (e.g., shapes, relative positions, relations of components) carefully. The third strategy is to think about what relationship the diagram title has with its content.” A research assistant first taught the participants individually using the practice article (in paper form) as an example to demonstrate how to use the reading strategies. Then, participants were told to recall all the reading strategies they had been taught. If students were unclear or forgot, the researcher taught them again until they could repeat aloud the three reading strategies and use them in text reading correctly. Finally, participants read the same practice article on the eye-tracking device to confirm they had learned the three reading strategies, and the formal article reading began. The experimental procedure lasted approximately 20–30 min.

Results

Results were analyzed in three stages. First, scores for the standard reading comprehension, prior-knowledge test, and reading self-efficacy questionnaire were analyzed to determine whether the three groups of no-labels, labels, and teaching were comparable regarding these basic demographic characteristics. Second, students’ learning outcomes from reading the illustrated text were analyzed to determine the signaling effect with or without reading instructions, and on which comprehension levels (e.g. textual, pictorial, or integrational) this effect occurred. Third, participants’ eye movements were analyzed to compare the reading processes of illustrated text reading in the three reading conditions. One-way ANOVAs were conducted to analyze the main effect of groups, and if the groups’ differences reached statistical significance, the Bonferroni post hoc tests were conducted. The Bonferroni correction was used to adjust probability values because of the increased risk of a type I error when conducting multiple statistical tests. It can be used to correct experiment-wise error rates in multiple comparisons and reduce the chance of a type I error (Armstrong, 2014).

Thirteen participants’ eye-movement data were discarded due to calibration failure, data transmission failure, or apparent drift, so only 89 participants’ data were analyzed.

Basic Characteristics

Means and SDs for standard reading comprehension test scores, prior-knowledge test scores, and reading self-efficacy ratings are shown in Table 1. One-way ANOVAs revealed that students in the three groups did not differ on any of the three tests and questionnaire (ps > .05). Therefore, groups were comparable regarding their basic characteristics in this study.

Learning Outcomes

Research question 1 asked whether signals (words for Diagrams 1 and 2 written in parentheses mixed with science text content and in the diagrams) promoted reading performance for young readers or if the signals alone were insufficient to show a signaling effect and had to be combined with reading instructions. This question was answered by comparing the scores of reading tests for the three groups. The results of independent samples one-way ANOVAs are shown in Table 2.

One-way ANOVA for the reading test score revealed a main effect of groups ($F(2, 86) = 9.35$, $p < .001$, $\eta^2 = .18$). Bonferroni post hoc comparisons showed no significant difference in reading test scores for the no-labels versus labels group ($p > .05$). However, the reading test score was significantly higher for the teaching group versus the no-labels group ($p < .05$, $d = .67$) and versus the labels group ($p < .001$, $d = 1.11$). In further analyses of different types of items, there were no significant differences between the three groups for the textual items ($p > .05$), but significant main effects of groups in the pictorial and integration items ($F(2, 86) = 8.81$, $p < .001$, $\eta^2 = .17$; $F(2, 86) = 3.32$, $p < .05$, $\eta^2 = .07$). Post hoc comparisons showed no significant differences in pictorial item scores nor in the integration items for the no-labels versus labels group (ps > .05). However, the teaching group had significantly higher pictorial and integration item scores than the labels group ($p < .001$, $d = 1.01$; $p < .05$, $d = .71$). The teaching group also had a significantly higher pictorial item score than the no-labels group ($p < .01$, $d = .85$).

Eye-Movement Analysis

Research question 2 asked if there were differences in the reading processes of the illustrated text reading in the three reading conditions (no-labels, labels, and teaching). This question was answered by analyzing several eye-movement indicators in the three groups. One-way ANOVAs were conducted on the eye-movement indicators as below. The illustrated text was first divided into two interest areas of text and illustration to preliminarily understand how readers allocated their visual attention and cognitive resources on the different representations. Then, further detailed analyses (e.g. adding title analysis area, semantically relevant areas of sentences and individual diagrams, areas of words—Diagrams 1 and 2 in the text section) were conducted to investigate the reading processes of signals only versus signals with reading instructions.

Table 2 Accuracy and deviation of the reading test for the no-labels, labels, and teaching groups

	No-labels (N = 29)	Labels (N = 30)	Teaching (N = 30)
Textual items (3)	1.76 (0.87)	1.47 (0.90)	1.90 (0.85)
Pictorial items (3)	1.66 (0.81)	1.47 (0.94)	2.33 (0.76)
Integration items (4)	2.03 (1.01)	1.80 (0.76)	2.40 (0.93)
Entire reading test (10)	5.45 (1.74)	4.73 (1.64)	6.63 (1.77)

AOIs for Text and Illustrations Proportion of total reading time, number of saccades from text to illustrations, and number of saccades from the two sentences (see Fig. 1, sentences 1 and 2) to the semantically relevant illustrations were dependent variables in these analyses. Means and SDs for these measures are presented in Table 3.

One-way ANOVA for the proportion of total reading time on text revealed a marginally significant main effect of groups ($F(2, 86) = 3.05$, $p = .053$, $\eta^2 = .07$). Post hoc comparisons showed no significant difference in the proportion of total reading time on text for the no-labels versus labels group ($p > .05$). However, the proportion of total reading time on text was marginally lower for the teaching group versus the no-labels group ($p = .092$, $d = -.63$). One-way ANOVA for the proportion of total reading time on illustrations revealed a main effect of groups ($F(2, 86) = 3.18$, $p < .05$, $\eta^2 = .07$). Post hoc comparisons showed no significant difference in the proportion of total reading time on illustrations for the no-labels group versus labels group ($p > .05$). The proportion of total reading time on illustrations was marginally higher for the teaching group versus no-labels group ($p = .064$, $d = .67$). As for the number of saccades from text to illustrations, one-way ANOVA analysis revealed a main effect of groups ($F(2, 86) = 6.61$, $p < .01$, $\eta^2 = .14$). Post hoc comparisons showed no significant difference in the number of saccades from text to illustrations for the no-labels group versus labels group ($p > .05$). The number of saccades from text to illustrations was significantly higher for the teaching group versus the no-labels group ($p < .01$, $d = .74$) and versus the labels group ($p < .05$, $d = .79$). Additionally, one-way ANOVA for the number of saccades from two sentences (see the black frame in Fig. 1) in paragraphs 2 and 3 to the relevant illustrations revealed a main effect of groups ($F(2, 86) = 8.27$, $p < .01$, $\eta^2 = .16$). Post hoc comparisons showed no significant difference in the number of saccades from the two sentences to the relevant illustrations for the no-labels versus labels group ($p > .05$). However, the number of saccades from the two sentences to the relevant illustrations was significantly higher for the teaching group versus the no-labels group ($p < .001$, $d = .98$) and versus the labels group ($p < .05$, $d = .67$).

AOIs for Title, Text, and Illustrations To understand the degree of cognitive engagement with all objects (title, text, illustration) of the reading material for the three groups (labels, no-labels, and teaching), the total reading time and the number of fixations for each object were calculated. Means and SDs for the two eye-movement indicators are presented in Fig. 2.

Table 3 Eye-movement indicators for the no-labels, labels, and teaching groups

	No-labels ($N = 29$)	Labels ($N = 30$)	Teaching ($N = 30$)
Proportion of total reading time on text	.81 (.14)	.80 (.12)	.74 (.07)
Proportion of total reading time on illustrations	.17 (.13)	.18 (.12)	.24 (.07)
Number of saccades from text to illustrations	5.25 (5.55)	5.90 (3.61)	9.63 (5.61)
Number of saccades from two sentences AOIs to the relevant illustrations	3.10 (3.70)	4.47 (3.13)	6.97 (4.21)

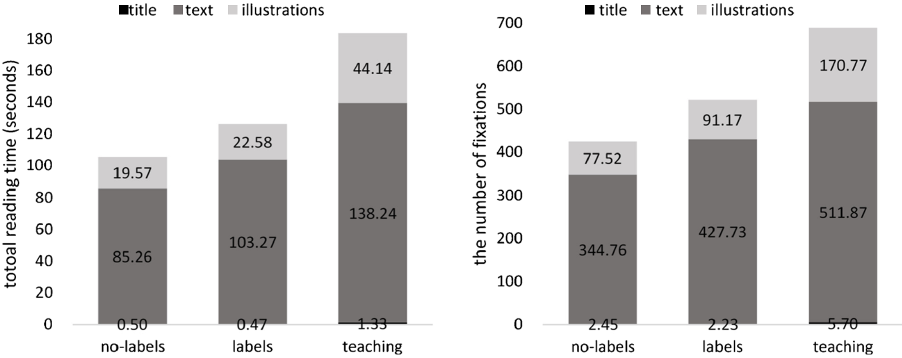


Fig. 2 Total reading time and number of fixations on the title, text, and illustrations for the no-labels, labels, and teaching groups

One-way ANOVAs for total reading time revealed main effects of groups for title ($F(2, 86) = 5.33$, $p < .01$, $\eta^2 = .11$), text ($F(2, 86) = 4.70$, $p < .05$, $\eta^2 = .10$), and illustrations ($F(2, 86) = 12.31$, $p < .001$, $\eta^2 = .22$). Post hoc comparisons showed no significant differences in total reading times for title, text, or illustrations for the no-labels versus labels group ($ps > .05$). The teaching group spent a significantly longer total reading time on the title, text, and illustrations compared to the no-labels group ($p < .01$, $d = .62$; $p < .01$, $d = .82$; $p < .001$, $d = 1.16$). The teaching group also spent a significantly longer total reading time on the title and illustrations compared to the labels group ($p < .05$, $d = .63$; $p < .001$, $d = .94$). One-way ANOVAs for the number of fixations revealed main effects of groups for title ($F(2, 86) = 5.22$, $p < .01$, $\eta^2 = .11$), text ($F(2, 86) = 3.41$, $p < .05$, $\eta^2 = .07$), and illustrations ($F(2, 86) = 11.67$, $p < .001$, $\eta^2 = .21$). Post hoc comparisons showed no significant differences in the number of fixations on title, text, or illustrations for the no-labels versus labels group ($ps > .05$). The teaching group had a significantly larger number of fixations on the title, text, and illustrations compared to the no-labels group ($p < .05$, $d = .61$; $p < .05$, $d = .76$; $p < .001$, $d = 1.14$). The teaching group also had a significantly larger number of fixations on the title and illustrations compared to the labels group ($p < .05$, $d = .64$; $p < .021$, $d = .90$).

Analysis of "Diagrams 1 and 2" in the Text To investigate whether the words "Diagram 1" and "Diagram 2" in the text triggered the readers to look at their corresponding illustrations, a chi-square test of homogeneity was performed. The proportions were distributed identically across the different groups (labels vs. teaching). Figure 3 shows that the proportion of readers in the teaching group who read the word "Diagram 1" and immediately transferred their eye fixations to look at Diagram 1 in the illustration was significantly higher than that in the labels group ($\chi^2_{(1,\ N = 60)} = 7.50$, $p < .01$); the result was the same for Diagram 2 ($\chi^2_{(1,\ N = 60)} = 14.07$, $p < .001$).

Detailed Analysis of the Illustrations To further investigate what the influence of reading instruction may have on the signals indication on the attentional allocation to the illustrations' labels, the labels group and teaching group were compared using *t*-tests to determine whether both groups had different total reading times and numbers of fixations on the diagram titles, words, and graphs in the illustrations. The AOIs of titles

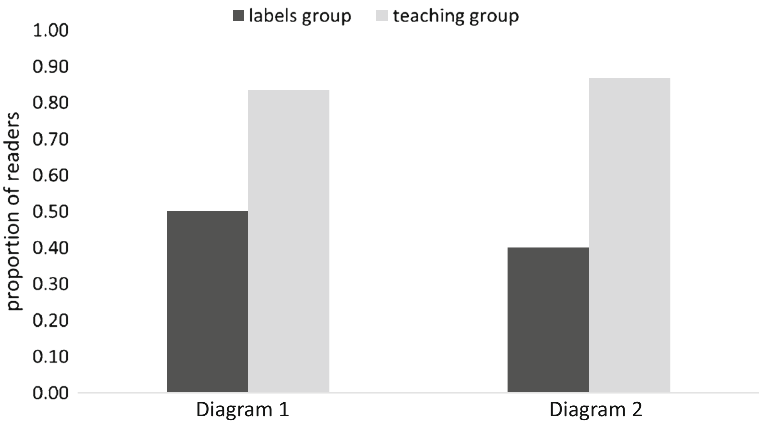


Fig. 3 Proportion of readers in the labels and teaching groups who immediately read "Diagram 1" and "Diagram 2" in the illustration section after first looking at "Diagram 1" and "Diagram 2" in the text section

included two rectangle areas in Fig. 1 and its title words as well as Fig. 2 and its title words. The AOIs of words combined several rectangle areas including five label words in the upper diagram, four breathing status words, and nine words in the middle of the bottom diagram. Among them, the nine words in the middle of the bottom diagram were drawn as a large AOI because they were close to each other. In addition, the AOI boundaries around the words were drawn in a 1° visual angle horizontally and vertically if there were no graphs beside them. The AOIs of graphs included the areas of shapes and arrows. The boundaries of AOIs between different representations of titles, words, and graphs were drawn in half of the space. For example, the bottom boundaries of the graphs were drawn in the space separate from the titles.

The results in Fig. 4 revealed the teaching group spent a significantly longer total reading time on the title, text, and illustrations compared to the labels group ($t(58) = 2.55$, $p < .05$, $d = .66$; $t(58) = 3.05$, $p < .01$, $d = .79$; $t(58) = 2.75$, $p < .01$, $d = .71$). The same results were shown in the number of eye fixations for the three areas ($t(58) = 3.60$, $p < .01$, $d = .93$; $t(58) = 3.00$, $p < .01$, $d = .77$; $t(58) = 2.63$, $p < .05$, $d = .68$).

Discussion and Conclusion

This study investigated the effectiveness and reading processes of the signaling principle with or without reading strategy instruction in multimedia learning. Unlike in previous studies in which adult participants showed stable signaling principle effects (Boucheix & Guignard, 2005; Jamet, 2014; Ozcelik et al., 2010; Scheiter & Eitel, 2015), this was not shown in young readers in this study. The labels group in this study did not outperform the no-labels group in the reading test. However, this study found that when reading strategy instruction to read labeled learning material was added for young readers, the signaling principle in multimedia learning appeared. Supporting evidence was that the teaching group outperformed both the no-labels and labels groups

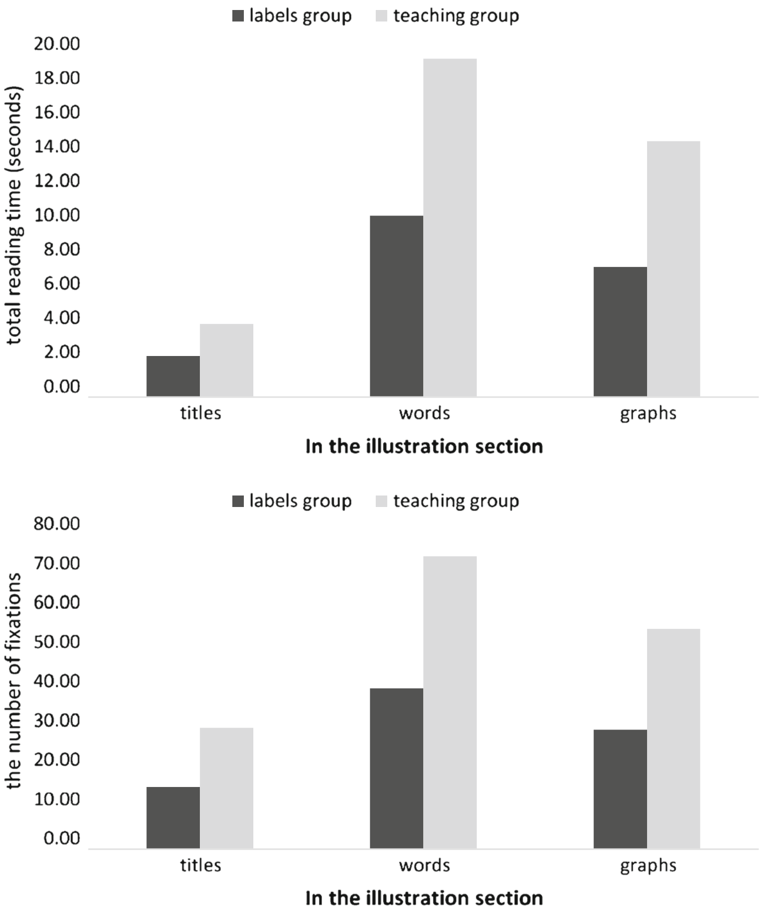


Fig. 4 Total reading time and the number of fixations of areas (title, words of labels, and graphs) in the illustrations section for labels and teaching groups

in the reading test, especially in the pictorial items and integration items, which are important points of the reading instructions provided in this study.

As for explaining the reading processes of the signaling principle in young readers, eye movements are supposed to reflect the cognitive processes of reading (Just & Carpenter, 1980; Rayner, 1998); thus, the processes of identifying and mapping the corresponding signals should be reflected in eye-movement behaviors. Identifying and mapping the corresponding text and pictorial elements has a great influence on the construction of the mental model of the learning article (Mayer, 2014; Schnotz, Ludewig, Ulrich, Horz, McElvany, & Baumert, 2014; Seufert, 2003). This study indicated that young readers could not use labels to identify and map the corresponding signals between text and illustrations by themselves unless they received appropriate instructions. This was supported by evidence that students in the labels group showed no differences in saccade numbers between text and illustrations compared to the no-labels group, but the students in the instruction group had more saccade numbers between text and illustrations compared to the other two groups and outperformed them in the reading test. These data also implied that young readers are deficient in learning knowledge about the purpose of including signals in textbooks, and that this needs to be taught to students.

Moreover, the two groups (labels and no-labels) were not significantly different on eye-movement indicators for total reading time, number of fixations, and proportion of reading time for the whole article or its component text and illustration sections. Interestingly, when reading strategy instructions for young readers to read labeled learning material were added, the reading processes of the signaling principle were very different from conditions without reading instructions. According to the guiding-attention hypothesis (De Koning, Tabbers, Rikers, & Paas, 2007; Ozcelik et al., 2010) and the visual-search hypothesis (Jamet, 2014; Ozcelik et al., 2010), integration signals in multimedia ensure that learners identify and map relevant information from the text and illustrations at the right time without engaging in additional visual search. The results of this study showed that the two hypotheses applied to young readers after they received reading instructions to read the labeled learning material. This was supported by several pieces of evidence in this study. First, the teaching group had more transitions (saccades) between text and illustrations than the labels group. Second, the proportions of readers in the teaching group who read the words “Diagram 1” and “Diagram 2” and immediately transferred their eye fixations to look at Diagram 1 and Diagram 2 in the illustration were significantly higher than those in the labels group. In contrast with what was expected, less than 50% of sixth-grade students in the labels group were triggered to look at the corresponding illustrations. It might be that these labels are within the peripheral view of the readers but they choose to ignore the information, or that the readers simply did not see these labels. Regardless of the possible explanations, this phenomenon is worth paying attention to, because this design of signals is very commonly seen in science articles and textbooks, but it does not work (no signaling effect) for many elementary school students.

Why is it that many young readers do not pay attention to the labels inserted in the text when they read illustrated science text? One possibility is that they do not think viewing diagrams is helpful but rather rely on text information for reading comprehension. Text-driven behavior in illustrated text reading is very common in eye-movement research, whether among adult readers (Hegarty & Just, 1993) or young readers (Jian, 2016, 2017; Hannus & Hyönä, 1999). Another possibility is that young readers had poor ability to decode diagram information (McTigue, 2009; Moore & Scevak, 1997), so they gave up viewing the diagrams directly to avoid exhausting cognitive resources. In the informal interview of this study, many young readers expressed that they were incapable of reading science diagrams, and that their science teachers did not teach them. The results of this study have an important instructional implication that teachers should demonstrate exactly how to use signals in science text to refer to relevant information contained in diagrams, and teach young students reading strategies for decoding diagrams and text-and-illustration integration.

Another interesting finding is that adding reading instructions for young readers to read labeled learning material makes them devote more cognitive effort and leads to them showing more skill in reading illustration information. Previous research has found that young readers paid little attention to and showed little cognitive engagement with science illustrations compared to text in multimedia learning (Jian, 2016; Hannus & Hyönä, 1999). However, reading strategy instructions could improve young readers’ diagram literacy and prompt them to spend more time reading illustration information to learn science concepts (Jian, 2017). This study confirmed that this is so. The teaching group in this study had higher total reading time, a higher number of fixations, and a higher proportion of reading time on the illustrations compared to the labels group. The students in the teaching group also spent more total reading time and had a higher number of fixations on viewing detailed components (titles, words, graphs) of the illustrations than the students who read the same labeled illustrated text but without receiving reading instructions.

In conclusion, this study revealed that the signaling principle (Richter et al., 2016; Van Gog, 2014) in multimedia learning cannot be generalized to young readers, but that when combined with reading instructions, it can apply to them. The reading processes of the signaling principle can also be changed if young readers receive reading strategy instruction to read signaled learning materials.

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