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EFFECTS OF LEARNER-CENTERED INTERVENTIONS IN SCIENCE LEARNING: COMPARING EYE MOVEMENT IN EYE MOVEMENT MODELING EXAMPLES AND PROMPTING

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Abstract. *An integrated understanding of illustrations and texts is crucial for students to comprehend science teaching learning materials. Intervention methods can be employed to facilitate this integrated understanding. This study examined the effects of Eye Movement Modeling Examples (EMME) and Prompting interventions on the learning of illustrated scientific texts among primary school students. Furthermore, the study compared the reading strategies and learning comprehension of fifth-grade students who utilized EMME, an approach that facilitates learning through observational methods, with those who used Prompting, a method that directly guides learning through linguistic information. The study analysis revealed that EMME had a significantly greater effect on integrated reading strategies and learning comprehension compared with Prompting. Specifically, the EMME group exhibited an integrated reading strategy that involved relating the illustrations and texts, whereas the Prompting group and the control group did not demonstrate the same strategy. In addition, the post-test results indicated that the EMME group achieved higher average scores in verbal and pictorial factors compared with the other two groups.*

Keywords: *eye movement modeling examples, learner-oriented intervention, science education, science learning, South Korea*

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Introduction

Visual materials, such as illustrations and photographs, are not merely decorative or auxiliary elements in science textbooks. They play a central role in learning and are crucial for explaining scientific concepts (Ametller & Pintó, 2002; Pozzer & Roth, 2003). Scientific concepts are abstract and rooted in phenomena that students may find challenging to directly experience or observe. Consequently, scientific concepts cannot be effectively conveyed solely through linguistic information (Ametller & Pintó, 2002). When students encounter such abstract concepts presented only in textual form, without accompanying visual materials or experiences, they may generate multiple alternative concepts (Roth et al., 1999). However, when illustrations are included alongside the textual content, they significantly contribute to understanding scientific concepts (Pozzer & Roth, 2003). In addition, the use of illustrations to explain scientific concepts proves valuable for learning comprehension due to their ability to represent multiple relationships and processes that are challenging to express through linguistic information alone (Meneses et al., 2018; Vavra et al., 2011).

Teaching astronomy, which belongs to the macroscopic domain of science, presents challenges due to the inability of students to directly observe and fully perceive astronomical phenomena (Kim et al., 1998). To teach concepts about astronomy, textbook exploration activities often incorporate role-playing and model experiments. However, it is common for illustrations to be presented in the post-activity stage when summarizing the concepts. Simulations of celestial bodies' motion in the context of learning astronomical concepts often rely on elements presented in illustrations (Padalkar & Ramada, 2008). Thus, illustrations play a crucial role in the astronomy domain (Pena & Quliez, 2001). In astronomy illustrations, symbols such as arrows are frequently used to represent the direction of motion of celestial bodies. This inclusion of visual symbols is beneficial for students' concept formation (Cho et al., 2009).

In recent years, the importance of visual materials in educational resources has grown significantly, leading to a higher proportion of illustrations in textbooks and other teaching and learning materials (Lee & Kim, 2018;

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Lowe, 2003; Schnotz, 2002). Nevertheless, despite the increased presence of illustrations, learners focus more on the text rather than the illustrations to aid their understanding of the material (Liu & Chuang, 2011; Pozzer & Roth, 2003). Hannus and Hyönä (1999) and Shin (2017) revealed that learners primarily allocate their attention to the text, spending less than 10% of their time looking at illustrations. In particular, primary school students perceive text as more important than illustrations when learning scientific concepts (Shin, 2017).

However, to facilitate the understanding of scientific concepts, it is more effective to view text and illustrations together in an integrated manner (Mayer, 2003; Schnotz, 2002). Mason et al. (2013) reported that learning comprehension is higher in groups where the ratio of integrated connections between text and illustrations is higher in illustrated science text learning. However, when primary school students learn from science textbooks, there is a low ratio of integrative connections between text and illustrations (Yang & Kim, 2013).

To cope with this learning situation, teacher guidance and appropriate feedback are crucial to help students perceive the illustrations and text in an integrated manner (Scheiter & Eitel, 2015; Yang & Kim, 2013). In particular, in many cases, teachers may not always have control over the design of learning materials, and students may encounter poorly designed materials in real-life learning situations. To assist learners in this situation, more interventions that employ generic methods are required rather than solely teaching them how to approach the material (Renkl & Scheiter, 2017; Scheiter et al., 2017). Recently, Eye Movement Modeling Examples (EMMEs) have emerged as one such intervention method (Mason et al., 2015, 2016; Mason et al., 2017; Scheiter et al., 2017). Studies have demonstrated that groups exposed to EMMEs exhibit a higher number of eye movement transitions between related texts and figures, resulting in enhanced learning comprehension. Another intervention method called Prompting involves providing another learning method in reading strategies, either verbally or in written form (van der Meij & de Jong, 2011). When reading strategies are guided by Prompting, learners are more inclined to look at figures in text learning with illustrations, thereby improving their learning comprehension (Jian, 2019; Stalbovs et al., 2015). Accordingly, this study aimed to compare and analyze the effects of EMME, a reading strategy guide, and Prompting, a direct reading strategy guide, on primary school students (In Korea, this applies to students in grades 3-6.). The research questions of this study were as follows:

1. What are the characteristics of primary school students' reading process while learning science texts with illustrations?
2. Is there a transfer effect when applying learner-centered intervention methods such as EMME and Prompting during the learning process of science texts with illustrations?
3. How does the application of EMME and Prompting affect students' learning comprehension?

Research Methodology

Research Procedures

The research began by formulating a specific research problem based on the literature review. Science texts were selected for research, and EMME videos and Prompting forms were developed to facilitate learning. The content validity of the selected science texts, EMME videos, and Prompting forms was assessed by three experienced science education experts who were well-versed in eye-tracking research. In addition, the tasks developed underwent refinement through preliminary research. Three types of tasks were devised for the study: a task to test the homogeneity of the group, an intervention-applied task, and a task verifying the effects of the intervention). Initially, a pre-test was performed to ensure that participating learners exhibited homogeneity within the group. Thereafter, the learners were exposed to the intervention through the task designed for intervention application. Finally, the science textbook focusing on 'the rotation of the earth' was selected as the final task and the effect of 'intervention' was evaluated.

Sample Selection

The recruitment of research participants took place in three primary schools located in a small town in the capital area of Korea. Fifth-grade students without difficulties in eye tracking were invited to participate in the study. Consent forms from students and their parents were collected, and those who provided the necessary consent became the research participants. The final sample for the study comprised 106 fifth-grade primary school students. Fifth-grade students were selected due to their developmental stage in reading, as indicated by Chall's (1983) stages of reading development. During this stage, learners begin to form reading strategies and read for learning purposes.

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The study comprised three groups: a group whose reading strategies were guided by EMME as an intervention method, a group whose reading strategies were directly guided by Prompting, and the control group (a group who was not intervened). Due to the use of an eye tracker in the EMME group, 19 participants were excluded. These exclusions included participants who failed to calibrate their gaze, those with a tracking ratio below 80% on each task, and those who had preconceptions of the learning task. Thus, the final analysis totaled 87 participants, with 29 participants in each of the EMME, Prompting, and control groups. This study analyzed human eye movements and was pre-approved by the Institutional Review Board of the researcher's university.

Development of Tasks

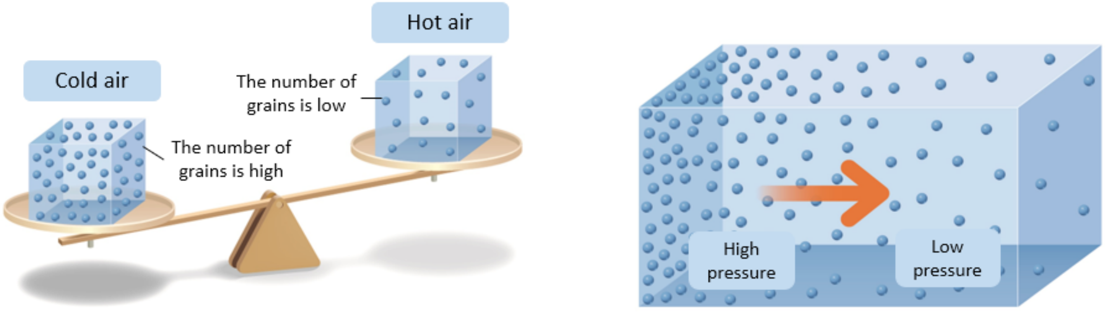
Three tasks were developed and used in this study: a task to test the homogeneity of the group, an intervention-applied task, and a task to verify the effects of the intervention. The criteria for selecting the tasks were as follows: (1) choosing a topic that the learners had no preconception of, (2) ensuring that the illustrations were complementary to the text according to Pozzer and Roth's (2003) criteria, and (3) selecting tasks from the geoscience domain where illustrations are highly useful. These criteria were chosen because a preconception can affect eye movement (Canham & Hegarty, 2010). In addition, the study aimed to guide reading strategies that integrated illustrations and text. Therefore, the tasks were specifically chosen to ensure a complementary relation between illustrations and text.

Considering the nature of primary school students' thinking, illustrations are more useful in geoscience due to the high percentage of abstract representations (Pena & Quliez, 2001; Woo et al., 1992). Thus, all tasks were developed for the geoscience domain. The content validity of the developed tasks was confirmed by three experienced science education experts in eye-tracking research. The tasks that were finally developed were "Why wind blows" (task to test the homogeneity of the group), "Sea breeze and land breeze" (Intervention-applied task), and "Earth's rotation" (task verifying the effects of the intervention) (Figure 1).

Figure 1
Developed Tasks

Air has weight. The pressing force generated by the weight of air is called atmospheric pressure. The greater the number of air particles in a certain volume, the heavier the air becomes and the higher the air pressure. Cold air has more air particles in a certain volume than warm air, so the air is heavier, and the air pressure is higher. This relatively heavy air is called high pressure, and light air is called low pressure.

If there is a difference in air pressure between any two points, air moves from high pressure to low pressure. The movement of air due to the difference in atmospheric pressure is called wind.



▲ Comparing the weight of high pressure and low pressure

▲ Air movement due to pressure difference

a. Task to test the homogeneity of the group

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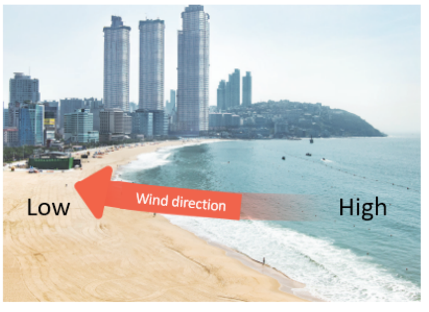
On a clear day, the direction of the wind blown during the day and at night is different at the beach. What causes the wind to change direction during the day and at night at the beach? During the day, the temperature of the land and the sea increases due to sunlight. At this time, the land is hotter than the sea because it heats up faster. Because the temperature on land is higher than that of the sea, it creates low pressure on land and high pressure on the sea. During the day, the wind blows from the sea to the land as air travels from high pressure to low pressure. This wind from the sea to the land is called a sea breeze.

At night, the temperature of the land and the sea decreases. Since land cools faster than the sea, the sea temperatures are higher than the land temperatures. Because the temperature of the sea is higher than that of the land, it creates low pressure above the sea and high pressure above the land. Therefore, the wind blows from the land to the sea. This wind from the land to the sea is called a land breeze. In this way, due to the temperature difference between the land and the sea during the day, the direction of the wind changes during the day and at night at the beach.



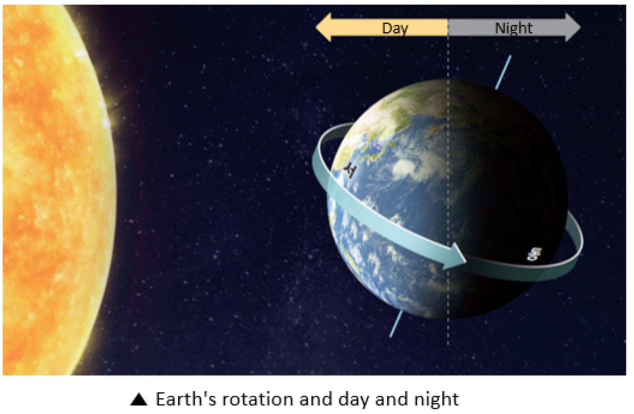
▲ Daytime breeze (sea breeze)

▲ Night breeze(land breeze)

b. Intervention-applied task

The Earth is moving. How does the Earth that we live on move? The Earth rotates once a day. It revolves around a virtual straight line connecting the North Pole and the South Pole, which is called the Earth's axis of rotation.

The Earth's daily rotation from west to east is around its axis. The Earth rotates counterclockwise when viewed from above the Earth's north pole.



▲ Earth's rotation and day and night

Because the Earth rotates from west to east, it seems to us that the sun is moving from east to west. The side of the Earth that receives sunlight becomes day, and the side that does not receive sunlight becomes night. Day and night change periodically because of the Earth's rotation.

c. Task verifying the intervention's effects

Content validity was verified for the following: ① Is the form of the task appropriate for learning? ② Is the amount of learning appropriate for a fifth grader? ③ Is the task free of content errors? Specifically, the content validity index (CVI) for science education experts was 0.90 for the task on "Why wind blows (task to test the ho-

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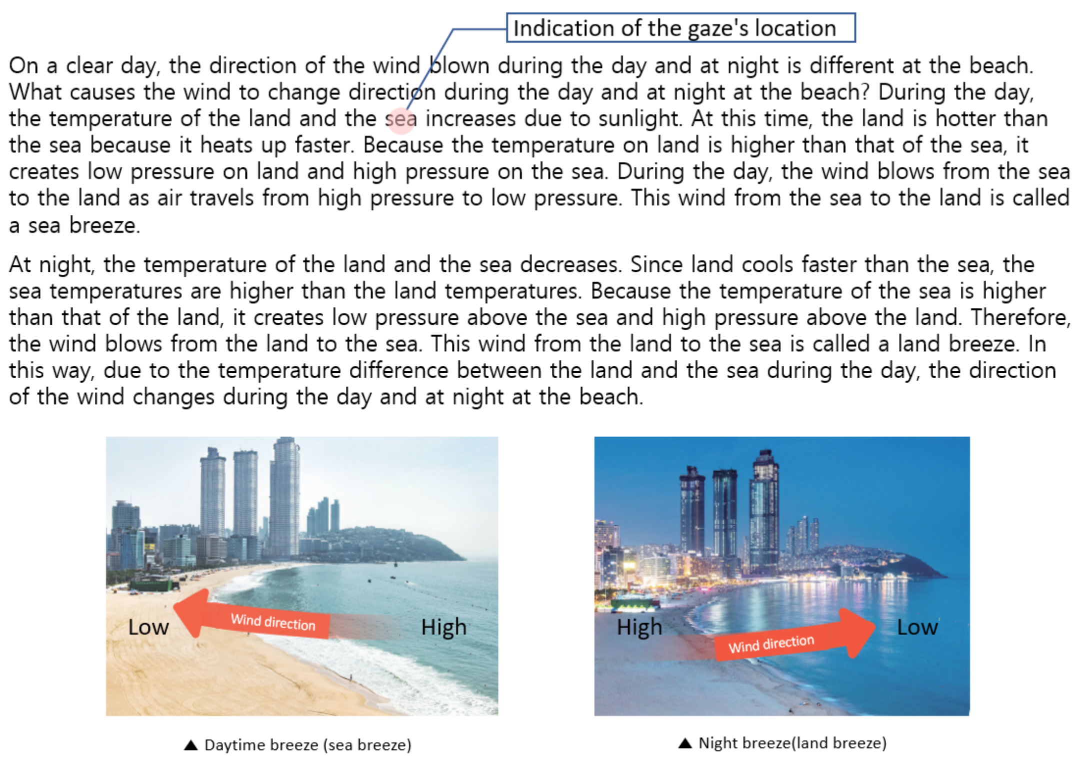
mogeneity of the group)" and 0.89 for the tasks on "Sea breeze and land breeze (intervention-applied task)" and "Earth's rotation (task to test the effects of intervention)."

In terms of task development, the final task on "Earth's rotation" was designed to test the effects of the intervention. Unlike the other two tasks, the illustrations in this task were positioned at the bottom left rather than at the bottom of the text. This placement aimed to examine whether the transfer effect of reading strategies occurred regardless of the arrangement of illustrations and text. The study also examined the formation of preconceptions among typical fifth-grade students regarding the "Earth's rotation" task. The findings indicated that only 1 in 25 students had preconceptions about "Earth's rotation," suggesting that the influence of preconceptions on the study results was unlikely to be significant.

The study aimed to compare the effects of two learner-centered interventions, namely EMME and Prompting, on learners' learning situations using eye tracking. A crucial aspect of the research was the development and application of EMME videos. In this study, EMME videos were created to deliver a reading strategy promoting the integrated reading of related illustrations and text. These videos were developed by modeling the teacher's (researcher's) eye movements when viewing illustrated science texts. To develop the video, an eye tracker was used to record the teacher's eye movements while learning the treatment task "Sea breeze and land breeze," which was previously selected for intervention application (Figure 2). In this case, the researcher performed the task in a way that allowed the delivery of the reading strategy in a didactic manner after becoming familiar with the integrative reading strategy.

Figure 2
EMME video screen



For the development of the EMME video, this study analyzed previous research on integrated reading strategies for text and illustrations and adopted the following two perspectives: First, the researcher asked the participants to make connections between relevant pictorial factors when reading the text or to integrate the parts of the text related to the illustrations with the text. This was based on Mayer's Cognitive Theory of Multimedia Learning, which suggests that alternating and integrating the viewing of related text and figures enhances learning comprehension in multimedia contexts (Mason et al., 2013; Mayer, 2003). Second, based on the work of Mason et al. (2017),

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the researcher gazed at the illustrations and their descriptive captions before reading the text. In a previous study on integrated text and figure viewing using EMME (Mason et al., 2017), different groups were assigned to figure-first, text-first, figure-last, and control conditions to determine the effectiveness of delivering integrated reading strategies. The figure-first EMME group, which emphasized looking at the figure before reading the text, exhibited the highest rate of integrated eye movement. The post-test results indicated a statistically significant difference when compared with the control group. The EMME videos were developed based on the results of these previous studies. Additionally, before viewing the EMME task, students were informed about EMME through the instruction that said, "The red dots in the video are the eye (gaze) movements of a good student. Study by fixating your gaze on the red dots in the video." The term "student" was used in the instruction to help students recognize the similarity between themselves and the model in the EMME video. Previous research has indicated that for novice learners, the effectiveness of observational learning with EMME increases when there is a higher similarity between the model and the observer (Krebs et al., 2019).

Prompting tasks to guide reading strategies for integrating text and illustrations were developed by selecting one for each of the reading strategies for text processing, figure processing, and integration presented in the study by Stalbovs et al. (2015) (Table 1).

Table 1
Reading Strategies used to Develop Prompting Tasks

Multimedia course	Directions
Text processing	When you're done, reread every paragraph carefully (McNamara et al., 2004; Zwaan & Singer, 2003).
Illustration processing	When looking at a figure, look for important parts of the figure that are relevant to your learning (Hegarty & Just, 1993; Hegarty & Sims,1994).
Integration	When reading the text, try to find the parts described in the text in the figure (Mason et al., 2013; Mayer, 2009).

Test Tools

A questionnaire was developed and used to assess the learned content to determine if the learner-centered intervention was effective for learners' science learning. The questionnaire comprising three items was developed for this study, fitting on a single sheet of A4 paper. The questionnaire was developed based on the achievement criteria outlined in the curriculum. The content validity of the developed questionnaire was verified twice by three science education experts who had experience in conducting eye tracking research and working in primary schools. The final CVI value was .87. The developed test was administered after the "Earth's rotation" task to verify the effects of the intervention. The questionnaire comprised open-ended items, with one item requiring the participants to indicate the direction of Earth's rotation, an item featuring a figure that illustrated how day and night occur, and an item where the participants were asked to describe Earth's rotation. A pilot study was conducted with 13 fifth-grade primary school students to confirm that no issues existed in the questionnaire design.

Task Paradigm and Data Collection

The overall procedure of the study was as follows: pre-test, pre-task (Why wind blows, the task of testing the homogeneity of the group), intervention-applied task (Sea breeze and land breeze), intervention effect verification task (Earth's rotation), and post-test. The entire process of assigning tasks was conducted on a per-student basis because of the need for eye tracking. The eye tracker used was the X2-60 Eye Tracker from Tobii. Since eye tracking can be distracted by environments such as ambient noise or illuminance (Bojko, 2013), the measurements were conducted in a soundproofed consultation room to minimize these. The paradigmatic organization of the pre-task is indicated in Figure 3.

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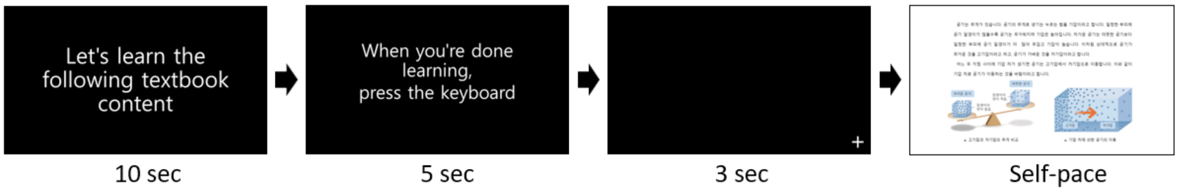
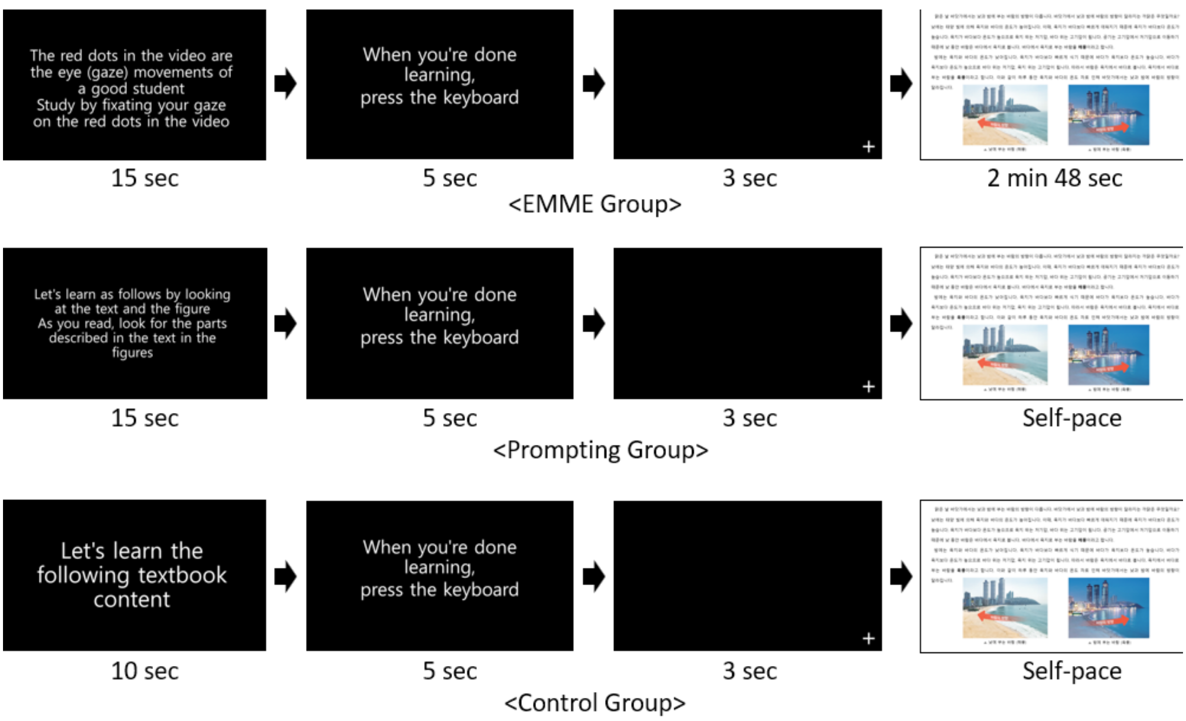
Figure 3
Pre-task Paradigm



The pre-task was followed by the intervention-applied task and the intervention effect verifying task, using the paradigm in Figure 4. The entire process of eye tracking was with the learner's learning, that is, self-reading of the learner, which is essentially a high-level cognitive process. Hence, it was carried out so that the learners could learn according to their reading speed without setting a time limit for the reading process (van der Schoot et al., 2012).

For the intervention application task, as indicated in Figure 4, the EMME group was allotted 2 minutes and 48 seconds to watch a video illustrating a series of processes demonstrating the teacher's reading strategies for an illustrated text material on the topic of sea breeze and land breeze. The Prompting group studied an illustrated text about sea breeze and land breeze at their own pace after being instructed, "As you read, look for the parts described in the text in the figures." The control group, which did not receive any intervention, followed the same procedure as the pre-task paradigm presented earlier, starting with the instruction "Let's learn the following textbook content."

Figure 4
Paradigm of the Intervention-applied Task



After a 10-minute break at the end of the intervention-applied task, the task for verifying the effect of the intervention was conducted, as indicated in Figure 5. The intervention-applied task was identically conducted to the procedure applied to the pre-task and control group. After all the tasks were completed, students in the study participated in a post-test, a written assessment to determine their learning comprehension of the tasks.

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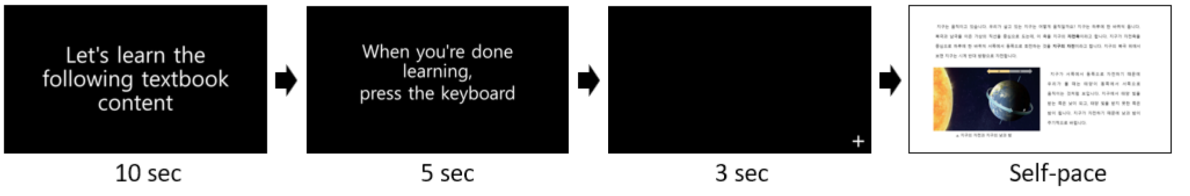
Figure 5
Paradigm of the Intervention Effect-verifying Task

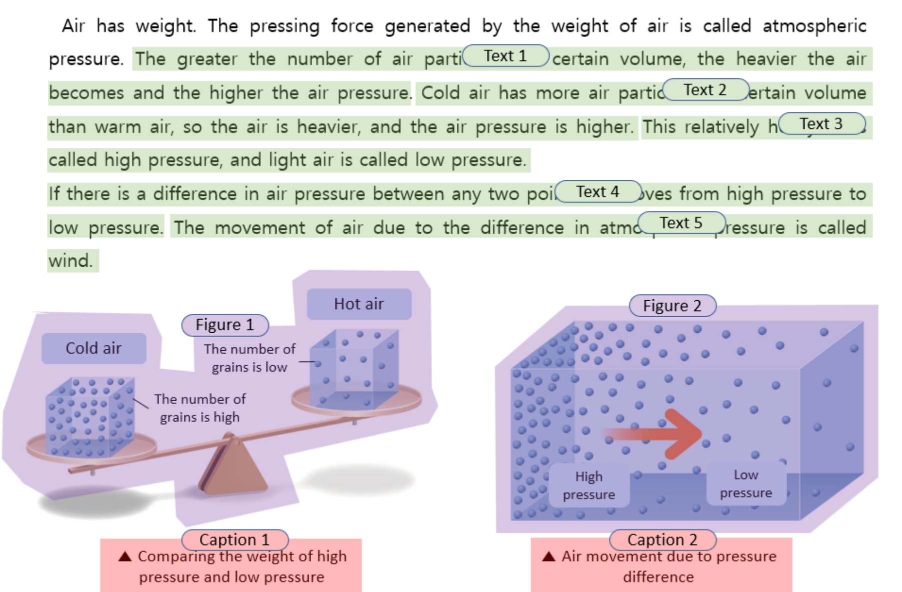


Data Analysis

The eye-tracking data of the two groups (EMME, Prompting) and the control group following the learner-centered intervention were analyzed using Tobii Pro Lab software from Tobii Company. Of the 106 students who participated in the study, 19 students with preconceptions of the learning tasks and 19 students with eye-tracking rates below 80% for each task were excluded. Accordingly, data from 87 students (EMME: 29 people, Prompting: 29 people, Control: 29) were analyzed. In the process of extracting the eye movement data to a file using Tobii Pro Lab software, a minimum eye fixation time of 100 ms was set based on previous studies on the reading process (Andrews et al., 2004; Jian & Wu, 2015; Jian, 2016). To do this, a fixation filter was set up using Tobii Pro Lab's I-VT filter algorithm.

In consultation with three science education experts, areas of interest (AOIs) were set on a sentence-by-sentence basis, as in the study by Hyönä et al. (2003). The AOIs were set only for the parts related to the illustrations. As a result, 9 parts were analyzed for the pre-task: 1 to 5 articles, 1 to 2 figures, and 1 to 2 captions. In cases where sentences were line-broken, the eye-movement data were extracted into an Excel file and the eye fixations were modified for Text 1-1 and Text 1-2 to Text 1 and for Text 2-1 and Text 2-2 to Text 2. For the intervention-applied task, to see the effects immediately after the Prompting was presented, the AOI was set as a total of 10 parts, including Text 1-6, figures 1-2, and captions 1-2 as shown in Figure 6. In cases where sentence-by-sentence line breaks occurred, a similar process was applied in the Excel file, merging the eye fixation data for Text 2-1 and Text 2-2 into Text 2 and Text 6-1 and Text 6-2 into Text 6.

Figure 6
Set up Learning Task AOIs



a. Task to test the homogeneity of the group

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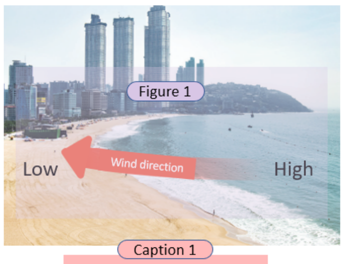
On a clear day, the direction of the wind blown during the day and at night is different at the beach. What causes the wind to change direction during the day and at night at the beach? During the day, the temperature of the land and the sea increases due to sunlight. At this time, the land is hotter than the sea because it heats up faster. Because the temperature on land is higher than that of the sea, it creates low pressure on land and high pressure on the sea. During the day, the wind blows from the sea to the land as air travels from high pressure to low pressure. This wind from the sea to land is called a sea breeze.

At night, the temperature of the land and the sea decreases. Since land cools faster than the sea, the sea temperatures are higher than the land temperatures. Because the temperature of the sea is higher than that of the land, it creates low pressure above the sea and high pressure above the land. Therefore, the wind blows from the land to the sea. This wind from the land to the sea is called a land breeze. In this way, due to the temperature difference between the land and the sea during the day, the direction of the wind changes during the day and at night at the beach.

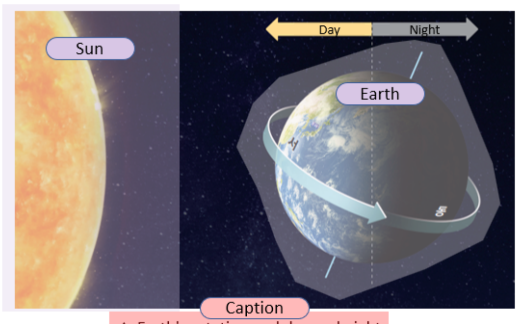


Caption 1
▲ Daytime breeze (sea breeze)

Caption 2
▲ Night breeze(land breeze)

b. ntervention-applied task

The Earth is moving. How does the Earth that we live on move? The Earth rotates once a day. It revolves around a virtual straight line connecting the North Pole and the South Pole, which is called the Earth's axis of rotation. The Earth's daily rotation from west to east is around its axis. The Earth rotates counterclockwise when viewed from above the Earth's north pole.



Caption
▲ Earth's rotation and day and night

Because the Earth rotates from west to east, it seems to us that the sun is moving from east to west. The side of the Earth that receives sunlight becomes day, and the side that does not receive sunlight becomes night. Day and night change periodically because of the Earth's rotation.

c. Task verifying the intervention's effects

To identify the cognitive processes involved in learning illustrated science texts, this study utilized the Lag Sequential Analysis method proposed by Bakeman & Gottman (1997) to analyze the reading strategies indicated in group reading tasks. Sequential analysis methods can be used to infer reading strategies in the context of learning illustrated text by analyzing the number of moves between AOIs (Bakeman & Gottman, 1997; Jian, 2016). Sequential analysis is a statistical approach used to examine the significance of the order of transitions between consecutive areas in a series of observations (Hsu et al., 2019). The study utilized the sequential analysis method outlined by Hsu et al. (2019) and utilized a sequential transfer diagram to interpret reading strategies. Here, the study focused on the number of eye movement transitions between two AOIs, following the sequential analysis algorithm, and repeated eye movements to the same AOI were ignored in the analysis (Bakeman & Gottman, 1997; Hsu et al., 2019).

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To determine the effect of the learner-centered intervention on science learning, the analysis of the post-test results assessing learning outcomes was scored separately for the pictorial and verbal factors. To analyze the results, the factors were extracted and analyzed, as shown in Table 3. A maximum of 4 points were separately assigned for the illustration factors and text factors, resulting in a total of one point each. For these items, assessment item factors were selected in consultation with three science education experts. The post-assessments of 87 participants were evaluated by three raters, yielding an inter-rater agreement of Cronbach's α = .940 for the pictorial factor and .956 for the verbal factor.

Table 2
Assessment of Item Factors for the Post-test Items

Pictorial factor	Verbal factor
Representation of rotation direction arrows	Counterclockwise, from West to East
Representation of West and East	One lap per day
Representation of the phenomenon of day and night occurring	The sunlit side is day, the side without sunlight is night
Representation of the slope of the rotation axis	Circling around the axis of rotation is rotation

Research Results

Intergroup Homogeneity as Revealed by Pre-Task and The Features of The Reading Process in Fifth-Grade Students' Science Learning

One of the objectives of this study was to investigate the reading process of EMME and Prompting intervention methods on the eye movements of students. To verify this, it is critical to confirm that no difference exists between groups. To do so, the study analyzed eye movement data from the pre-task activity titled "Why the wind blows" before administering the EMME and Prompting interventions, respectively, using Bakeman and Gottman's (1997) sequential analysis method. This study utilized an expanded version of the Data Analysis Tool (DAT) vl.7, developed by Jeong (2003), to conduct sequential analysis. Based on the frequency of gaze transition between the indicated AOIs, a transformation probability matrix was created to extract the z-score matrix (tables 3–5). The z-values presented in Tables 3–5 exceeded 1.96 ($p < .05$), implying the statistical significance of eye movement transitions between the two AOIs (Jian, 2016).

Table 3
Z-score Matrix Table for the Pre-task Learning Process of the EMME Population

	Text 1	Text 2	Text 3	Text 4	Text 5	Figure 1	Figure 2.	Caption 1	Caption 2
Text 1	-	4.08	0.11	-0.54	-1.25	0.35	-0.21	-1.02	-1.02
Text 2	4.93	-	6.72	-1.09	-1.39	-0.96	-2.70	-1.64	-1.64
Text 3	0.40	4.72	-	5.74	-0.59	-1.66	-1.72	-1.86	-1.86
Text 4	-1.34	-1.15	3.40	-	5.33	-1.04	0.28	-1.79	-1.79
Text 5	-1.78	-2.05	-1.82	1.84	-	5.51	-0.16	-1.61	-0.87
Figure 1	0.70	-0.51	-1.20	-2.19	2.61	-	2.90	6.45	-1.11
Figure 2.	-0.47	-0.47	-2.47	-0.27	-1.92	2.64	-	-1.37	8.75
Caption 1	-1.13	-0.40	-0.69	-1.39	-1.25	4.12	0.53	-	-1.02
Caption 2	-1.31	-1.51	-1.04	-0.13	-1.45	-1.97	5.76	2.64	-

Note. Shading indication z > 1.96 (*p* < .05)

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Table 4
Z-score Matrix Table for the Pre-task Learning Process for the Prompting Group

	Text 1	Text 2	Text 3	Text 4	Text 5	Figure 1	Figure 2.	Caption 1	Caption 2
Text 1	-	5.02	-0.72	-1.07	-0.58	0.35	-0.41	-0.78	-1.04
Text 2	7.36	-	4.96	-0.99	-1.43	-2.58	-2.09	-1.12	-1.50
Text 3	-1.67	3.95	-	7.36	-0.19	-2.56	-2.62	-1.32	-1.77
Text 4	-1.47	-0.64	3.77	-	3.64	0.18	-0.88	-0.22	-1.64
Text 5	-0.84	-2.34	-0.71	0.68	-	5.16	0.59	-1.22	-0.87
Figure 1	-0.69	-1.05	-2.27	-1.64	1.53	-	4.95	2.99	0.03
Figure 2.	-1.21	-0.88	-1.55	-1.99	-0.11	2.31	-	2.14	6.80
Caption 1	-0.80	-0.89	-0.91	-1.07	-0.85	1.20	2.29	-	1.13
Caption 2	0.46	-0.97	-0.99	-0.10	-0.92	-1.16	4.04	-0.50	-

Note. Shading indication z > 1.96 (*p* < .05)

Table 5
Z-score Matrix Table for the Control Group's Pre-test Course of Study

	Text 1	Text 2	Text 3	Text 4	Text 5	Figure 1	Figure 2.	Caption 1	Caption 2
Text 1	-	3.95	0.36	-0.38	-1.48	-0.50	0.08	-0.80	-0.93
Text 2	7.05	-	8.12	-2.51	-2.48	-2.22	-2.51	-1.33	-1.55
Text 3	-0.76	6.41	-	5.67	-1.32	-2.75	-2.27	-0.91	-1.28
Text 4	-0.76	-2.66	3.65	-	4.51	0.64	-1.12	-1.39	-0.86
Text 5	-0.18	-2.20	-2.21	2.58	-	5.25	-0.17	-1.41	-0.89
Figure 1	-2.36	-0.92	-2.00	-0.87	4.20	-	4.07	4.53	-0.56
Figure 2.	-0.34	-0.63	-1.14	-0.19	-0.53	1.06	-	-0.24	6.17
Caption 1	-1.07	0.24	-1.64	-1.66	-0.53	4.07	-0.56	-	1.67
Caption 2	-1.15	-1.53	-1.76	-1.78	-1.48	0.86	6.41	1.93	-

Note. Shading indication z > 1.96 (*p* < .05)

To identify eye movement tendencies, only statistically significant cases are represented by arrows in Figure 7, which is represented as a gaze transition diagram. The values shown next to the arrows represent the transformation probabilities documented in Tables 3–5.

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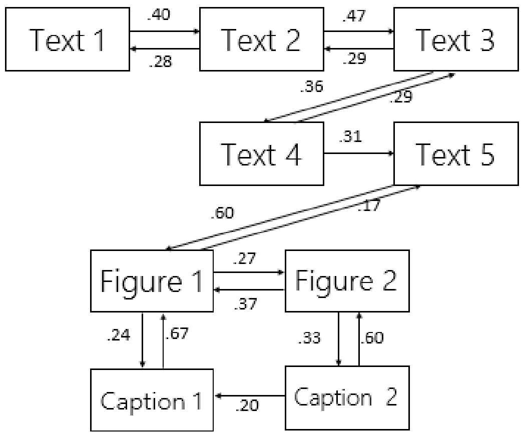
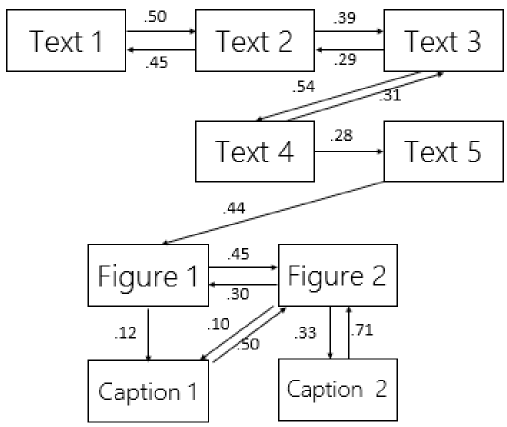
Figure 7

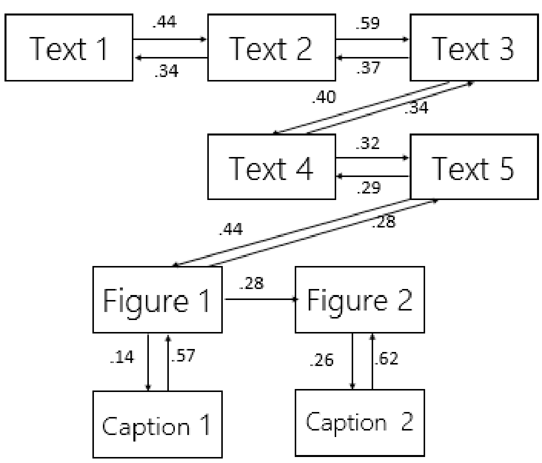
Diagram of Gaze Transitions between Areas of Interest in the Process of Pre-task Learning by Group



EMME group



Prompting group



Control group

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As a result of completing a gaze transition diagram (Figure 7) through sequential analysis to determine the reading strategies by group, similar eye movement tendencies were observed during the learning of illustrated science texts. This finding confirms the homogeneity among the three groups, indicating that they exhibit comparable reading tendencies during science learning.

Based on the results above, the characteristics of the reading process of fifth-grade students can be characterized as follows: First, there appeared to be no connection between texts and figures, indicating no bidirectional reading between the illustration and the text. Second, learners exhibited a higher tendency to regress to previous sentences in the text. The frequent regression to the previous paragraph can be viewed as learners monitoring their own understanding. It can be viewed as a behavior that results from the absence of preconceptions.

Comparison of the Learner's Eye Movements after Applying a Learner-Centered Intervention

After applying EMME and Prompting as learner-centered intervention methods to the "Sea breeze and land breeze" task, these methods were applied to the "Earth's Rotation" task for EMME, Prompting, and control groups to check the transferability of the interventions. To analyze the transition effect, a z-score matrix was obtained by generating a probability matrix for transformation between areas (Table 6). Based on these, the reading strategy for each group was schematized, as shown in Figure 8.

Table 6
Z-score Matrix Table in the Learning Process of the Intervention Effect-verifying Task (earth's rotation) by Group

EMME Group	Text 1	Text 2	Text 3	Text 4	Text 5	Text 6	Earth	Caption	Sun
Text 1	-	4.64	-1.94	-0.83	-1.07	-0.79	-0.79	-1.10	0.18
Text 2	1.60	-	3.47	-0.87	-2.14	-1.57	3.85	-1.00	-0.60
Text 3	-1.05	2.16	-	0.49	-1.00	-1.26	1.49	1.73	-1.56
Text 4	-0.79	-2.36	-0.08	-	3.20	-0.95	2.40	-0.45	-1.17
Text 5	-0.44	-0.77	-1.31	-0.56	-	-0.53	3.39	-0.74	-0.66
Text 6	1.14	-1.61	-0.41	-0.77	0.12	-	1.23	0.06	1.52
Earth	0.41	3.22	2.39	1.98	1.32	2.31	-	1.11	2.03
Caption	-0.65	-0.62	-1.28	0.50	-0.02	2.00	1.35	-	0.18
Sun	-0.61	-0.99	-1.82	-0.77	0.12	0.74	2.93	0.06	-

Prompting Group	Text 1	Text 2	Text 3	Text 4	Text 5	Text 6	Earth	Caption	Sun
Text 1	-	3.94	1.83	-1.54	-1.40	-1.18	-1.68	0.00	-1.18
Text 2	4.34	-	2.32	0.51	-1.62	-1.37	0.19	0.00	-0.42
Text 3	-1.51	3.27	-	3.77	-0.25	-1.51	-0.80	-0.01	-1.51
Text 4	-0.98	-1.47	0.51	-	5.10	0.23	-0.47	0.00	-0.98
Text 5	-0.26	-0.57	2.14	-0.34	-	-0.26	-0.51	0.00	-0.26
Text 6	-0.80	-1.76	-1.46	-1.05	-0.95	-	5.30	0.00	0.62
Earth	0.22	-0.89	-0.57	-0.60	0.45	3.75	-	-0.01	3.75
Caption	-0.52	-1.15	0.37	-0.68	-0.62	1.57	1.50	-	-0.52
Sun	-0.59	-0.22	-1.07	-0.77	-0.70	-0.59	3.38	0.00	-

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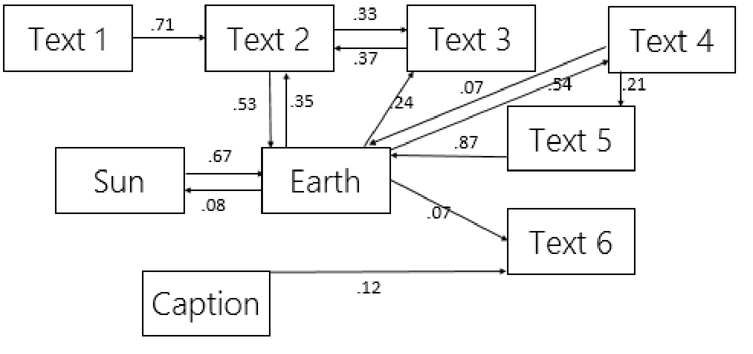
Control group	Text 1	Text 2	Text 3	Text 4	Text 5	Text 6	Earth	Caption	Sun
Text 1	-	6.59	-1.64	-1.32	-1.57	-1.23	-2.22	-0.45	-0.64
Text 2	3.31	-	5.32	-0.88	-1.32	-1.61	0.49	-0.59	-0.84
Text 3	-1.32	1.69	-	2.60	-0.72	-1.23	1.08	-0.45	-0.64
Text 4	0.09	-2.57	-0.32	-	3.71	-0.98	1.31	2.79	-0.51
Text 5	-0.56	-0.26	-0.97	1.42	-	3.70	-0.94	-0.19	-0.27
Text 6	-0.75	-1.83	-1.31	-0.75	1.74	-	2.82	-0.26	2.59
Earth	-0.46	0.26	-0.56	0.48	-0.04	3.71	-	-0.48	1.15
Caption	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-	0.00
Sun	-0.28	-0.67	-0.48	-0.28	-0.33	-0.26	2.17	-0.09	-

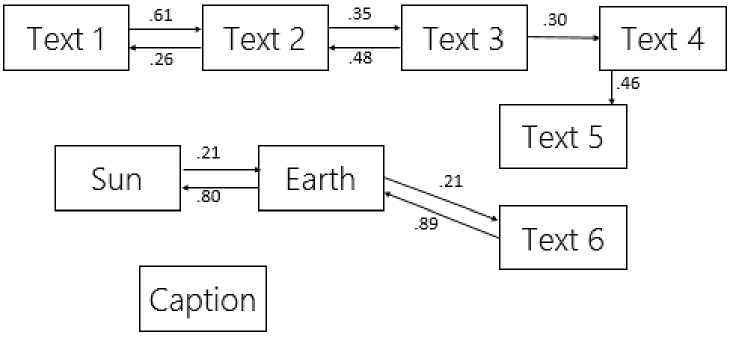
Note. Shading indication z > 1.96 (*p* < .05)

Figure 8

Diagram of Gaze Transition between Areas of Interest in the Learning Process of the Intervention Effect-Verifying Task (earth's rotation) by Group



EMME group



Prompting group

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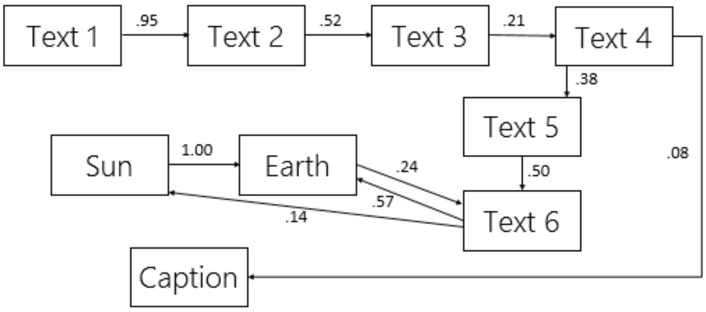

Control group

When seeing the gaze transition diagram of the EMME group (Figure 8), it can be observed that the AOI in the illustration, "Earth," is centered on Text 2, Text 3, Text 4, Text 5, and Text 6, which are connected by arrows. Arrowed connections between AOIs indicate statistically significant eye movements. In other words, the EMME group was able to make an integration between the visual information of the illustrations and the linguistic information of the text. When considering the probability of gaze transition between areas, represented by arrows, the probability of going from Text 2 to Text 3 (.53) exceeded the probability of going from Text 2 to Earth (.33). This observation shows different results from the learners reading the text sequentially and then looking at the figures before the EMME intervention. After the EMME intervention, learners exhibited a cognitive process of locating the parts mentioned in the text in the illustrations. This is evidence that the intervention utilizing EMME impacted learning-integrated reading strategies between illustrations and text.

In the Prompting group, the portion of text associated with the pictorial factor "Earth" demonstrated an integrated reading strategy only in the last part of the text, "Text 6." This was similar to the eye movement tendency to look at the figures after finishing the text when studying the pre-task prior to the intervention. Furthermore, as shown in Figure 8, this eye movement tendency is similar to the reading strategies of the control group, who were not informed of the intervention. The control group also showed connections only in "Earth" and "Text 6" and no integrated connections between illustrations and text. This shows that the Prompting intervention had no effect on learners' learning of integrated reading strategies.

When intervening with Prompting, no integrated reading strategies between the illustrations and text were indicated either in "Sea breeze and land breeze" immediately after the intervention. The study found no change in reading strategies immediately following the Prompting intervention and no effect on reading strategies in subsequent learning tasks to determine the transferability of the intervention.

Analysis of the difference in Learning Comprehension between EMME and Prompting Interventions

To assess the difference in learning comprehension by learner-centered interventions between groups, the tasks used were analyzed by dividing them into pictorial and language elements.

First, a one-way ANOVA was conducted to determine if there was a statistically significant difference in post-test scores for the pictorial factors across groups (Table 7). The EMME group had the highest post-test score for the pictorial factors at 2.38, and the Prompting group had the lowest score at 1.24. This difference was statistically significant. Post-hoc tests revealed significant differences between the EMME and Prompting and EMME and control groups, as shown in Table 8, and no statistically significant differences were observed between Prompting and control groups.

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Table 7
Comparison of Post-test Scores for Pictorial Factors by Group (one-way ANOVA)

Group	*n*	*M*	*SD*	*F(p)*
EMME	29	2.38	1.12	9.20**
Prompting	29	1.24	.83	
Control	29	1.45	1.24	

* *p* < .01, ** *p* < .001

Table 8
Scheffé Verification Results of Post-test Scores for Pictorial Factors

Group	EMME	Prompting	Control
EMME		1.14*	.93*
Prompting			.21
Control			

* *p* < .01, ** *p* < .001

Second, a one-way ANOVA was conducted on the post-test scores for the language element by group. The post-test score for the language element was highest for the EMME group at 2.24 and lowest for the control group at 1.00. A one-way ANOVA revealed statistically significant differences between the groups (Table 9). Post-hoc tests showed statistically significant differences only between the EMME and control groups, with no statistically significant differences between the other groups, as shown in Table 10.

Table 9
Comparison of Post-test Scores for Language Elements by Group (one-way ANOVA)

Group	*n*	*M*	*SD*	*F(p)*
EMME	29	2.24	.91	12.01**
Prompting	29	1.62	1.08	
Control	29	1.00	.89	

* *p* < .01, ** *p* < .001

Table 10
Scheffé Verification Results of Post-test Scores for Language Elements

Group	EMME	Prompting	Control
EMME		.62	1.24**
Prompting			.62
Control			

* *p* < .01, ** *p* < .001

The results showed that the EMME group had higher learning comprehension than the other two groups. Based on the above results, it can be interpreted that the EMME group exhibited integrated reading strategies

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between illustrations and text during the learning process of the "Earth's Rotation," forming a coherent mental representation. This resulted in successful learning compared with the other two groups.

Discussion

A science textbook encompasses illustrations along with the text. Compared with other subjects, text alone is insufficient to convey learning concepts (Ametller & Pintó, 2002). According to Slykhuis et al. (2005), textbook content consisting of illustrations and text is more effective when the illustrations and text are complementary. As such, it is an effective teaching strategy to encourage learners to have an integrated understanding of illustrations and text when learning science. In this regard, this study analyzed the effects of two learner-centered intervention methods, EMME and Prompting, to intervene in the learner's integrated reading of illustrations and text.

Prior to the learner-centered intervention, pre-task results revealed that the fifth-grade students, the study subjects, did not read illustrations and text in an integrated manner. These reading tendencies observed in young learners align with the findings of Moore and Scevak (1997) and Jian (2016). Moore and Scevak (1997) utilized think-aloud protocols and confirmed that young learners do not integrate text and illustrations in a cohesive manner. Through eye tracking to map reading strategies using a sequential analysis method, a study reported that while adults exhibited bidirectional connections between illustrations and text, sixth-grade students indicated no connections between text and illustrations. In addition, Yang and Kim (2013) demonstrated similar results, indicating that all students had poor integration of linguistic and visual information, regardless of the learning style.

However, students who viewed the EMME videos, one of the learner-centered intervention methods used in this study, were more likely to use the strategy of integrating illustrations and text than other groups. Moreover, they also achieved significantly higher scores than the other groups on the learning comprehension test administered as a post-test. This superior performance was observed not only on the pictorial factors but also on the verbal factors of the test. These results suggest that EMME videos are a good intervention method to teach reading strategies to learners. According to Mayer (2014), when studying multimedia materials consisting of text and figures, mental representation is necessary for learning. When learning from multimedia materials, comprehension of the content implies that the learner has a good mental representation of the text and figures through an integrated understanding. EMME helps learners' mental representation through an integrated understanding of text and figures. The EMME intervention-induced changes in reading strategies identified in this study are consistent with the findings reported in prior research (Mason et al., 2015, 2016; Mason et al., 2017; Scheiter et al., 2017): EMME interventions increase eye movements in integrated reading when learning with multimedia materials consisting of text and illustrations.

EMME videos show eye movements of a person (usually an expert) as they perform a task (Mason et al., 2015; Mason et al., 2017). EMME is an example-based learning, which is related to Sweller's (1988) cognitive load theory.

From a cognitive load theory perspective, providing step-by-step solutions with example-based learning helps learners create schemas for problem-solving, thereby helping them store schemas for problem-solving in long-term memory (Sweller et al., 2011). The resulting troubleshooting schema is used when encountering similar issues in the future. It supports the learner's representational process for problem-solving. According to cognitive load theory, example-based learning reduces extrinsic cognitive load. It provides working memory capacity for the germane load associated with learning (Pass & van Gog, 2006; Renkl, 2011). Consequently, EMME can help learners learn by lowering their cognitive load and making efficient use of their working memory capacity.

In addition to the EMME method, this study also used Prompting as a learner-centered intervention method. However, the Prompting method was not as effective as EMME and instead produced results similar to the control group that received no intervention. It was observed that the EMME method was more effective than the Prompting method, which uses written or verbal prompts to guide learning because it uses the gaze of an expert or a higher-level learner to show learning strategies.

Previous studies using EMME to study changes in learners' eye movements have mostly focused on middle-school students (Mason et al., 2015, 2016; Mason et al., 2017) and college students (Scheiter et al., 2017). Accordingly, the results of this study suggest that applying EMME interventions can influence cognitive processes and reading strategies even in primary school students who have not yet formed reading strategies.

In addition, the topic of "Earth's rotation" was selected as a learning task in this study. The concept of "Earth's rotation" has been associated with various misconceptions among young learners (Plummer et al., 2011; Plummer et al., 2014). Prior research on Earth's rotation has suggested that consistent presentation of illustrations in

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textbooks is effective for concept acquisition and retention (Cho et al., 2009). Cognitive processes for illustrations are critical because learners construct simulations based on pictorial factors presented in illustrations (Padalkar & Ramada, 2008).

In this regard, the higher post-test scores of the EMME group on the pictorial factors and verbal factors compared with the other two groups implied that the integrated reading strategy between the illustrations and the text influenced learning comprehension of "Earth's Rotation." In other words, when learning about "Earth's rotation," a concept for which learners have many misconceptions compared with other concepts, the cognitive process of providing illustrations in a learning process such as EMME can be an important learning variable.

Science education should develop inquiry ability and reasoning in students, rather than the simple acquisition of scientific knowledge, and support their experience of creative problem-solving. EMME can help facilitate the learning of beginners. EMME is useful for solving various tasks such as observation and classification (Jarodzka et al., 2010), problem-solving (van Gog et al., 2009), and synthesis and analysis of materials (Litchfield et al., 2010). The use of EMME facilitates the visualization of the perceptual process and cognition of experts and the education of reasoning based on visual observation.

Furthermore, the materials used by students in school comprise highly visualized materials, unlike the past when they were text-centered. As students advance to higher grades, the materials become more diverse, so the ability to understand texts and illustrations in an integrated manner will be even more emphasized. While students acquire information in order to use materials like textbooks, they will approach several complex materials, such as hypertext, in a nonlinear manner in the future. Thus, acquiring information processing methods using visual observation technology through EMME will be useful in science education hereafter.

Conclusions and Implications

Students primarily acquire knowledge in school through reading. Illustrations in science textbooks play a crucial role in conveying important information. To promote students' integrated understanding of illustrations and texts, a learner-centered intervention method is necessary. The purpose of this study was to analyze the learning process of learners following a learner-centered intervention method using eye trackers and examine their learning comprehension. Based on the study findings, the following conclusions can be drawn: First, when primary school students were exposed to observational learning using EMME, which incorporated the teacher's gaze movement information, it had an impact on their cognitive processes and reading strategies during science learning. The reading strategies exhibited in the process of learning an illustrated science text (specifically, Earth's rotation) were analyzed through eye movements and diagrams. Compared with the other groups, only the EMME group demonstrated a connection between the pictorial factor "Earth" and the sentences associated with the illustration. A change in reading strategies was observed after the EMME intervention. Second, the EMME intervention improved learning comprehension in science learning. The EMME group, which demonstrated integrated reading strategies between illustrations and text, scored higher on the post-learning test compared with the other two groups, and this difference was statistically significant. These findings confirm the influence of the integrated reading strategies of illustrations and text on learning comprehension.

Based on this research, the following suggestions can be made for science learning in schools: When guiding primary school students through science learning with a learning intervention, they should be instructed through integrated reading strategies that incorporate illustrations and text presented in the learning materials. Moreover, guided reading strategies, such as the EMME learning interventions identified in this study, are more effective when they showcase adults' reading process through observational learning rather than solely presenting linguistic information. Since the teacher's presentation of linguistic information alone is insufficient to influence learners' reading strategies, methods such as EMME, which demonstrate a series of concrete processes, should be considered to provide appropriate feedback.

Declaration of Interest

The authors declare no competing interest.

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