participants for 10 seconds, and each task was displayed for 40 seconds. After each task, a black screen was presented for a fixed period of time, in which the research participants were told to vocally provide the answer to the task. The researcher marked the correct and incorrect answers of the research participants on an answer sheet. After completing all the tasks, a semi-structured interview was conducted to investigate whether the research participant had a scientific understanding of the concept. The collected interview data were recorded.

Based on the checklist of correct answers for each task and the interview data, the subjects were classified as Types A, B, or C based on task achievement and having a scientific understanding of the concept. Type A students answered the tasks correctly and had a scientific understanding of the concept. Type B students answered the tasks correctly but did not show a scientific understanding of the concept during the interview. Type C students answered the tasks incorrectly and did not have a scientific understanding of the concept. An expert in science education found inter-rater reliability for the classified results (K = 0.76).

The collected eye-movement data were analyzed using an analysis software, Tobii Studio 3.2.3, with a minimum fixation duration of 200 ms. Qualitative heatmap data were derived using the analysis software. In order to understand the tendencies of elementary school students' eye movements according to the characteristics of the light and shadow task, AOI was set on the light source, the object, and the shadow in each task. Fixation duration was extracted by AOI for each type. Statistically significant differences were investigated using one-way ANOVA.

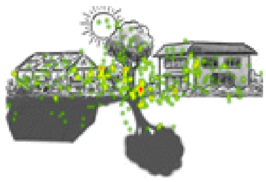
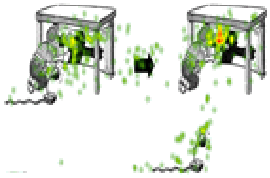
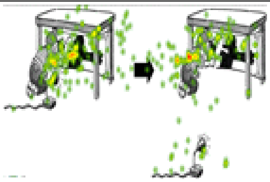
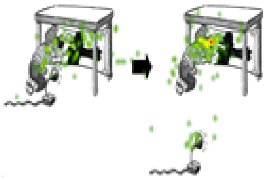
3 Results

This study describes the eye distribution results of the 25 participants, who were classified into three types based on task achievement and their understanding of the concept, by comparing their heatmaps and fixation durations for each task.

Table 1 presents the heatmap that depicts the visual attention by task for each type. In comparing the heatmap of each type, Type A shows more fixation on the light source compared to Type B and Type C. While fixation is evenly distributed to the light source, object, and shadow in the case of Type A, the fixation for Type B and Type C is densely distributed to the object rather than to the light source or shadow.

This means that Type A students, who have a scientific understanding of the concept, interpret the relationship between the object and the shadow as being centered on the light source. Moreover, Type A students paid more attention when the direction of the shadow was incorrect (e.g., a shadow that stretches toward the light source from the object) in comparison to Types B and C students.

Table 1. Heatmap by task according to Types A, B, and C

	A	B	C
Task1			
Task2			
Task3			

No distinct differences were found between Type B and Type C students; neither group had a scientific understanding of the concept, but they showed differences in task achievement. It can be said that those without a scientific understanding of the concept shared a similar thinking process, regardless of whether they chose the correct or incorrect answers for the tasks.

To examine the location of attention according to the type of task, AOI was set on the light source, object, and shadow, and the fixation duration was compared and analyzed. To investigate whether there was a difference in the fixation duration on the light source according to each type, an F-test (one-way ANOVA) was conducted. The analysis results indicated a significant difference, as shown in Table 2 ($F(2, 72) = 7.273$, $p < .01$). Specifically, the Scheffë post hoc test was conducted to investigate differences among each type. The analysis results indicated a statistically significant difference between Type A and Types B and C ($p < .01$ in all cases). However, no statistically significant difference was found between Type B and Type C.

The fixation duration on the light source differed depending on whether the student had a scientific understanding of the concept. This means that students perceived the light source as an important factor in the task-solving process. The students with a scientific understanding of the concept paid attention to the light source longer in comparison to the students who did not have a scientific understanding of the concept. Feher and Rice [1] examined the concept of light among children aged 8–14 and reported that approximately half of the research subjects were unaware of the necessity of a light source.

Table 2. F-test results for the fixation duration on the light source AOI according to each type

AOI	Type	N	M	SD	F	Scheffë
Light Source	A	33	1.07	1.088	7.273** (p=.001)	B,C<A
	B	24	0.30	0.458		
	C	18	0.42	0.532		
	계	75	0.67	0.879		

**p<.01

The results above show that the factors that receive attention in problem solving differ according to the level of knowledge. Students solve problems based on knowledge [8]. Thus, a student who successfully solves a problem focuses more on the related factors, while a student who fails to solve the problem does not focus on the related factors during the problem-solving process [9].

An F-test (one-way ANOVA) was conducted to investigate whether there was a difference in the fixation duration on the object and the shadow according to each type. The analysis results indicated no significant differences, as shown in Table 3.

Table 3. F-test results for the fixation duration on the object and shadow AOI according to each type

AOI	Type	N	M	SD	F
Object	A	33	3.28	6.169	.418 (p=.66)
	B	24	3.17	3.481	
	C	18	2.07	2.439	
	계	75	2.96	4.673	
Shadow	A	33	0.86	1.047	.378 (p=.68)
	B	24	0.62	0.846	
	C	18	0.83	1.300	
	계	75	0.78	1.047	

4. Conclusion

Based on the analysis results, the following conclusions were drawn.

A salient difference in the fixation location for light and shadow was observed among the students based on whether they had a scientific understanding of the concept. The fixation duration on the light source by the students with a scientific understanding of the concept was significantly longer than for those without a scientific understanding of the concept. This can be interpreted to mean that the students with a scientific understanding of the concept perceived that the light source was an important factor in the process of solving the light and shadow task. That is, they are clearly aware of the reason for the shadow creation, and they used this knowledge in their problem solving. As the factors that the students paid attention to differed based on their knowledge, whether they had a scientific understanding of the concept could be determined based on where they focused their attention. Moreover, the impact on problem solving of an attentional focus induced by misconception can also be understood.

Through these study results, we learned that understanding the concept of a light source is important. A teacher should explain the causal relationship between the light source and the shadow when teaching students about shadow creation, as this will support understanding. Moreover, it is also necessary for teachers to link the light source and materials when teaching students about the factors that can affect the direction and size of a shadow.

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