International Journal of u- and e- Service, Science and Technology
Vol.9, No. 8 (2016), pp.467-476
http://dx.doi.org/10.14257/ijunesst.2016.9.8.39

Eye Movement When Solving Light and Shadow Problems

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Abstract

This research used an eye tracker to study the eye movement of elementary school students in solving a task involving the concept of light and shadow. Twenty-five fifth grade students (12 girls and 13 boys) participated. The task was created to study the students' concepts of light and shadow by tracking their eye movements. Tobii X2-60 was used to gather the data of their eye movements, and Tobii Studio 3.2.3 was used to design the experiment and analyze the data. Three tasks were presented to the students; each task was shown for 40 seconds. Based on the collected data, we separated the students into three groups according to their task achievement and knowledge of scientific concepts. We extracted a heatmap, the fixation duration, and the number of saccades between AOI(Area of Interest) to analyze their eye movement data by types. The results show a big gap between the students depending on their knowledge of scientific concepts. The students with more knowledge of scientific concepts had a longer fixation duration on the light source, and they also showed more saccades between the light and the object than the saccades of the other students. Therefore, with more knowledge of scientific concepts, the students who understood the cause of light and shadow used their knowledge to solve the tasks.

Keywords: *Eye-tracker, light and shadow, scientific concept, misconception*

1. Introduction

Students are exposed to scientific experiences every day. Most of all, light and shadow are general ones students have experienced frequently among natural phenomena [1]. For this reason, they have formed their own thoughts through daily experience [2]. However, what has been revealed in preceding research is that a concept that students have created through experience is not only not the same as that of scientists, but also wrong. In other words, scientists think of shadow as the absence of something, but students primarily comprehend it as the existence of something [3].

To figure out a misconception like this, in previous research students were required to see a phenomenon about light and shadow, and then explain it or have their understanding checked by being asked questions. The results showed that students believed that shadows exist in the dark [2] or in the object [4, 5]. They also thought that shadows were substantial, so students believe that shadows could be controlled or eliminated independently [2, 6]. Younger learners would even impersonate them [4].

ISSN: 2005-4246 IJUNESST

Furthermore, they recognized light as a cause for being able to see a shadow [2, 4, 6] or expressed that there might be light in the shadow, because they could not understand the relationship between the diffusion of light and the formation of shadow [7]. Also, younger learners said that light pushed out shadow [4].

The ability to understand concepts about light and shadow was as different as each student's degree of development [8, 9]. It appeared that the younger they were, the more intuitive and elementary concept they had.

For these reasons, students' concepts are different from scientific concepts. Galili and Hazan [6] described seven factors that make it difficult to understand scientific concepts about light. First, the physical parameters associated with light (*e.g.*, its speed and wavelength) are all far removed from the range of perception of the human senses. Therefore, macroscopic optical phenomena are perceived through an unconscious integration of microscopic signals and, as such, their analysis was reserved for the speculative theories developed over the generations. Second, optical phenomena are commonly observed in mass media, which often greatly modify the behavior of light from that in nature. The modified optical phenomena (light scattering, halos) impede interpretation in terms of elementary optics. Third, the observer in optics is an inherent part of the optical system. Generally, in classical physics, it is essential to exclude the disturbance caused by the observer. Not so in optics, where an explanation of the observed phenomenon presumes the inclusion of the observer's eye as part of the optical system. Fourth, language used in everyday life does not match the language of scientific knowledge. Phrases such as "her eyes shine" and "the tree casts its shadow" are at odds with contemporary optics. Although a naive interpretation of these terms serves well in everyday life, it must be shed in order to attain genuine understanding. Fifth, humans' cognitive process and reasoning depend deeply on everyday life. Therefore, a general concept that reflects the views, beliefs, and ideas of early theories is conveyed to students and then students will find an adequate knowledge that could explain the real world phenomena by using a general concept. Sixth, optics is essentially an interdisciplinary subject. Physics, physiology, and psychology are all needed for the comprehensive discussion of optical phenomena. Therefore, instruction for the comprehension of optics concepts is limited to a disciplinary. Seventh, optics concepts are conveyed to students by graphic symbolism, and the interpretation of these symbols by the student is usually individual and conforms to previous knowledge.

In summary, misconceptions are related to the shape and direction of shadow, the relationship between the light source and the shadow, and the student's degree of development. Also, the scientific concept has gaps with the experience of the phenomenon in reality. Furthermore, the unscientific concept influences the process of understanding the scientific concept [10]. It means, students' naïve concept of light will be changed, based on the unscientific concept, to an expert's understanding. Therefore, it is necessary to know not only the misconceptions students have, but also the cognitive process that helps students to understand the concept [6].

However, previous studies used the oral expressions of students, which made it difficult to draw inferences about their cognitive abilities and processes. And students could devaluate their cognitive ability even more, because of the oral expressions have a limitation of communication[1]. Accordingly, the students' cognitive process must be understood empirically to devise appropriate teaching methods.

It has been observed that students with misconceptions frequently use unrelated information in the process of inferring physical phenomena [11]. A convenient method for measuring what students pay attention to is measuring the movement of the eyes. The part students pay attention to is the one piece of information they need to do a task, and they concentrate their attention on it until they finish [12]. That is, eye movement and data processing are strongly connected [13], and the gaze tracking method is a useful and convenient means for discovering a student's cognitive process [14].

In a number of previous studies that compared attention between experts and novices [15, 16], the novices showed a higher frequency and duration of gazing at unrelated areas. It was also argued, based on an analysis of experts' eyes, that knowledge about a certain field influences where a person gazes. That is, since the movement of the eye is determined by the needs of cognitive information acquisition [17], measuring where a student focuses can provide fundamental data for understanding the incorrect perception processes of students.

Thus, this study attempted to obtain empirical data on the misconceptions of elementary school students regarding the scientific concept of light and shadow through a comparative analysis of their eye movements.

2. Materials and Methods

The research subjects consisted of fifth grade elementary school students from the Republic of Korea. The Index of Learning Styles (ILS) was conducted on a total of 190 students, and the students with a visual learning style were selected [18]. Among the selected students, those who were right-handed and did not have limitations in eye movement measurement were chosen to participate in the task. The eye movement data from the 25 participants (12 girls and 13 boys) who had a tracking ratio higher than 60% were used.

For the purpose of investigating the characteristics of the eye movement of the elementary school students during the process of problem solving a light and shadow task, three pivotal questions were prepared by referring to the accomplishment standard for learning content in the curriculum of Korea: (1) Do you know the reason for and the conditions of the shadow? (2) Do you know the direction of the shadow? (3) Do you know how different the size of the shadow is according to the distance between the light source and the object? According to these three questions, this study developed the worksheet that is reformed the worksheet of "Scott Foresman Science" published by Pearson Education in New Jersey. The task content consisted of pictures that had the wrong size and direction of the shadow corresponding to the light source. The pictures were modified with the assistance of tracking gaze experts in order to get clear results. These tasks were reviewed for validity by three specialists in science education; the average CVI was 0.88. The pictures for these tasks are shown in Figure 1.

The participants' eye movements were tracked using Tobii X2-60 and a 24-inch monitor. The measurement room had no windows and light and noise were blocked out. First of all, purpose of this study was explained to the participants, and the researcher asked for their consent. After that, the researcher showed the way to the laboratory. When each participant sat in front of the monitor, the researcher helped him or her to sit comfortably by adjusting the height of the chair. After calibrating, the researcher presented a task instruction, "Which of the following is not true about the picture?"; "The answer might be one or not, none or many." Each problem was shown to the students for 40 sec. When they finished each task, they gave their answers by oral speaking on a blank screen, and the researcher marked the results immediately as correct or incorrect.

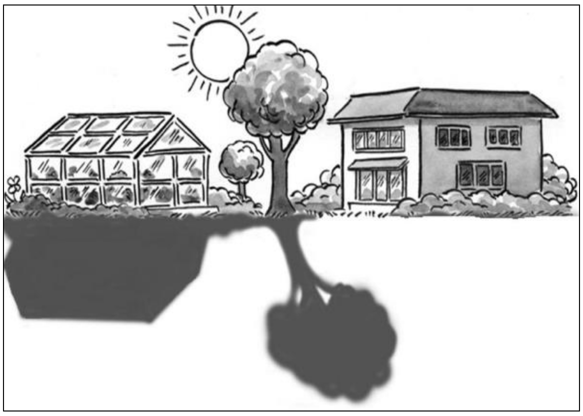
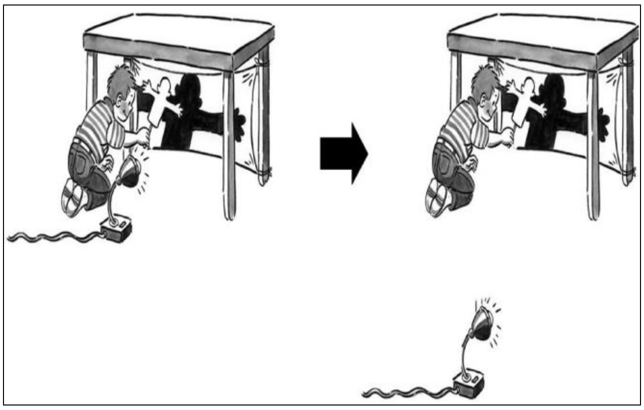
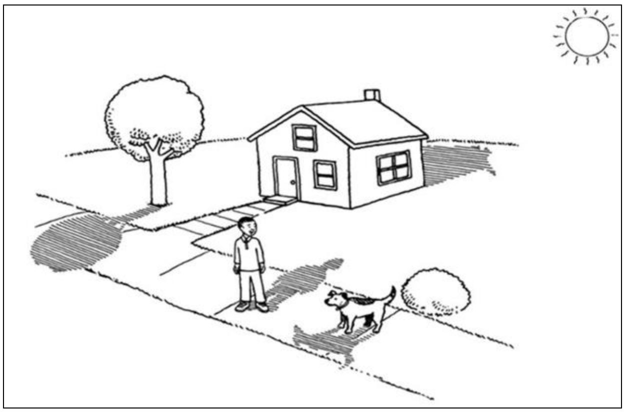
	Content
Task 1	 Which of the following is not true about the picture?
Task 2	 Which of the following is not true about the picture?
Task 3	 Which of the following is not true about the picture?

Figure 1. Light and Shadow Task Developed for this Study

After all the tasks were complete, semi-structured interviews were conducted to determine if the students understood the scientific concept behind the problem. The questions were as follows: “Why did you answer like that?” “What is the direction of the shadow?” “What are the conditions of the shadow?” “What relationship does the size of the shadow have with the distance between the light source and the object?” The interview results were recorded and then transcribed.

The students were categorized as A, B, or C types after being classified according to their problem achievement and their knowledge of the scientific concepts by using their answer sheets and the answers from their interviews. Type A students were those who were able to provide the correct answers and displayed knowledge of the related scientific concepts, type B students were those who were able to give the right answers without knowledge of the related scientific concepts, and type C students were those who gave incorrect answers and had no knowledge of the scientific concepts. An expert in science education found inter-rater reliability for the classified results (K = 0.76). The classification standards and results are shown in Table 1.

Table 1. Classification Standard and Result

Type	Task achievement	Concept formation	Participants		
			Task 1	Task 2	Task 3
A	Correct	O	11	11	11
B	Correct	X	7	8	9
C	Incorrect	X	7	6	5

The collected eye movement data was analyzed by the minimum fixation duration time, 200 ms, by Tobii Studio 3.2.3. Using the analyzing software, a heatmap was extracted. To find the eye movement tendencies of the students, the light source, the object, and the shadow were set to AOI(Area of Interest) for each task (Figure 2). In each problem, each fixation duration and gaze plot were extracted for a one-way ANOVA analysis to determine whether there was a meaningful statistical difference.

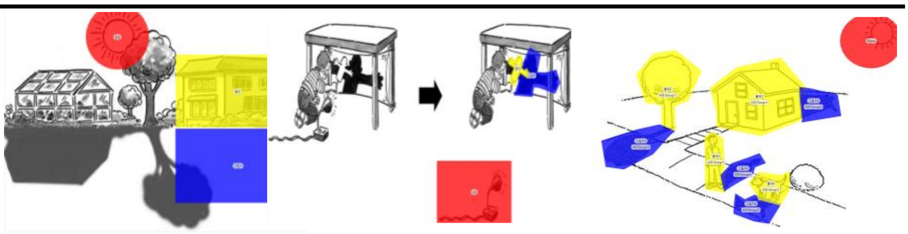
	Task 1	Task 2	Task 3
AOI			
Fig. color	Red: Light source, Yellow: Objects, Blue: Shadows		

Figure 2. AOI Setting Area by Task

3. Results and Discussion

The appendix shows where the students' visual attention was focused by using a heatmap according to each type and task (Appendix). The heatmap shows that type A students had more fixation on the light source than types B or C. Further, type A students showed an even fixation distribution on the light source, the object, and the shadow, but the other types' fixation distribution was mostly on the object and less on the light source or the shadow.

Therefore, type A students, who had knowledge of the related scientific concepts, understood the relationship between the object and the shadow around the location of the light source and paid more attention to the wrong direction of the shadow than the other types did. However, no difference was seen between types B and C. In other words, without the knowledge of the related scientific concepts, types B and C students had the same thought process, even though the type B students were able to achieve the correct answers.

One of the misconceptions students had about the shadow was that the direction of the shadow does not relate to the source of light, the shape of the shadow was the same as the shape of the object, like the image in a mirror, and the role of the light source is for showing the shadow [6]. Type A solved the problem using differences in the shadow direction and shape, which means that the students understood the scientific concept about the light source properly.

A study by Segal and Cosgrove [4] showed that developmental concepts of 4 ages' children about light and shadow, when students did not have an precise concept about shadows in the early part of learning, they mostly talked about the shape of the shadow. However, as time went by, they mentioned the sun, the light source, and the role of the light source in the process of forming the concept. In another study, students had misconceptions about light. They thought that light was the source of that shadow is seen or what lightened the shadow [2,6]. After all, the students who had the misconception lacked the understanding about the role of the light source and the relation of the light source and shadow.

To determine the students' focal points in each task, an AOI was set on the light source, the object, and the shadow to compare the gap between fixation durations by using a one-way ANOVA test.

Table 2 suggests a meaningful distinction between the fixation durations on the light source ($F(2, 72) = 7.273$, $p < .01$).

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		
	Total	75	0.67	0.879		

**p < .01

Scheffe's post-hoc test, conducted to determine the gap between each type, showed a statistically meaningful difference between type A and types B and C ($p < .01$) but no difference between types B and C.

Because they considered the importance of the light source in solving the task process, type A students showed different fixation durations. That is to say, students with scientific knowledge concentrated on the light source longer than those without the same knowledge.

According to Feher and Rice's study [2], research on the light concept knowledge of children between the ages of 8 and 14 showed that approximately half of them did not know the importance of the light source. In the problem-solving process, students focused on their knowledge of the scientific concept at hand. In conclusion, the students who succeeded in solving the problems paid more attention to the related factors, but the ones who failed to pay attention to the related factors were unsuccessful because they tended to try to solve the problems using knowledge alone [19,20].

The number of saccades between the light source, the object, and the shadow were compared using a gaze plot, which directly examined how the students handled the information [6]. Therefore, comparing the number of eye movements between each AOI determined what students considered significant or interesting in their information processing.

The one-way ANOVA test was used to determine whether the number of each type of saccade between the light source and the object was different. Table 3 shows the meaningful difference that was found ($F(2, 72) = 10.906$, $p < .001$).

Table 3. F-test Results for the Number of Saccades between the Light Source and the Object according to each Type

Saccade	Type	N	M	SD	F	Scheffë
Between the light source and the object	A	33	1.90	2.141	10.906*** (p = .000)	B, C < A
	B	24	0.33	0.637		
	C	18	0.22	0.548		
	Total	75	1.00	1.684		

***p < .001

The results of Scheffe's post-hoc test showed that type A students exhibited a meaningful statistical difference from types B and C ($p < .001$), while types B and C showed no meaningful relation to each other. That is, students with scientific knowledge integrated with the light source and the object as well as essentially recognized the relationship between the light source and the object in their problem solving.

It could be a characteristic of novice learners to attend to the salient areas in a purposeful situation [16]. If the students paid more attention to the relation of cause and effect of the light source and the object than the shadow and the object, which was relatively highlighted in the task, then the factor of having or not having knowledge of the scientific concept decided the effect of the salient areas while focusing on the problem [21].

Focusing on the relationship between the light source and the object suggests that knowledge of the related scientific concept enabled the students to explore with the purpose of discovering the perceptible and salient area.

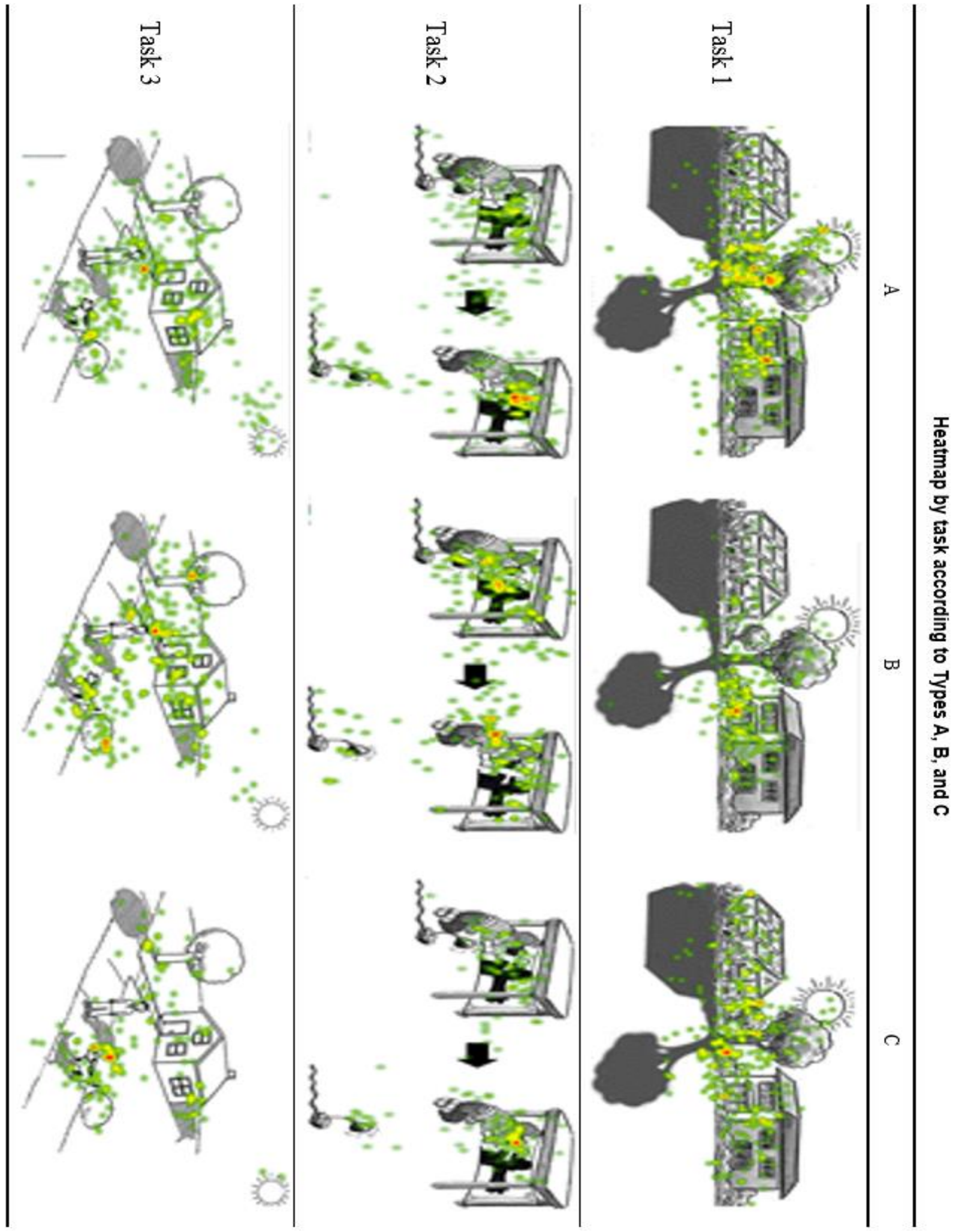
4. Conclusion

A significant 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 an understanding of the scientific concept was significantly longer than for those without an understanding of the scientific concept. This can be interpreted to mean that the students who understood the scientific concept perceived that the light source was an important factor in the process of solving the light and shadow task. That is, they were 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 understood the scientific 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.

There was also a gap between the number of saccades depending on whether or not students had knowledge of the scientific concept. Students with knowledge of the scientific concepts related to light and shadow had more saccades than other students did. Thus, it was possible to determine what students considered significant or what they were interested in during the task-solving process according to whether or not they had knowledge of the related scientific concept. Once they obtained knowledge of the scientific concept, students paid more attention to the significant causal relationship than what was visually salient.

Therefore, it is important to consider the significance of studying light concepts. When teachers explain why shadows are created, they should explain it in a way that makes it easier for students to understand the causal relationship of the light source to the shadow. In addition, teachers need to account for the relationship of the light source to the object when they teach the effect of the light source, the size of the shadow, and the direction of the shadow.

Appendix



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