How Many Korean Middle-school Students Find the Same Scientific Problem as Kepler Found in Optics and Physiology?

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Abstract: The aims of this study are to investigate how Kepler found a scientific problem for the retinal image theory and to investigate how Korean middle-school students respond when the same situation is applied to them. Kepler found the scientific problem in the eye vision through the critical analysis of contemporary theories of vision, based on his relevant knowledge of optics. When the same situation was applied to the Korean middle-school students, only a few students found the same scientific problem as Kepler. From the results, it is suggested that in developing creativity teaching materials, situations like Kepler's problem finding need to be included in programs.

Key words: Kepler, scientific problem, optics, physiology, secondary school, Alhazen, Witelo, eye vision, vision image

I. Introduction

Creativity in science is so important that it may be included in general science curricula as one of main objectives as well as in gifted education (McCormack, 1992), and creativity in the context of scientific discovery is asserted as a form of problem-solving (Langley, *et al*, 1987). The process of problem solving, in general, begins with problem finding, although sometimes defined problems are given.

A person good at generating creative solutions to defined problems is a creative thinker. However, if neither this person nor any other can find any problem for this creative person to solve, his or her creative talent will never be expressed. In other words, without people who discover problems, there would be no creative solutions. Einstein and Infeld (1938, p.92) asserted the importance of problem-finding: "The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, require creative imagination and mark real advance in science." In productive thinking, Wertheimer also pointed out that the function of thinking is not just solving an actual problem but discovering, envisaging, probing into deeper questions. He further pointed out that envisaging and formulating the productive question is often a more important and greater achievement than the solution to a set question (Dillon, 1982). And Polya (1962), Subotnik and Steiner (1994), Starko (2000) also asserted that the problem finding is distinct from and perhaps more important than problem-solving, or stated that the act of finding and formulating a problem is a key aspect of creative thinking.

In the past and nowadays, creative physicists constantly have found problems and formulated hypothesis to solve the problems. Therefore, if we understand how they have found scientific problems, and formulated hypotheses for solving the problems, the directions and theoretical basis of programs for developing students creativity need to be established. This is the reason why the teachers and curriculum developers who hope to attain the goal of scientific creativity will most certainly be interested in knowing how creative scientists are thinking while engaged in scientific discovery.

Kepler's discovery of the retinal image formation is an example of a situation which allows the thinking process and pattern of a scientist be analyzed more clearly because the term of the discovery is relatively short, and the related literature including Kepler's own treatise are sufficient for obtaining useful infor-

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mation(Kim, 2006). The purposes of this research are to analyze how Kepler, who discovered that the seat of vision image is retina, found a scientific problem in the process of his discovery of retinal image formation through literature review, and to investigate Korean middle-school students' responses when the same problem finding situation faced by Kepler applied to them. In addition, some ideas for teaching problem finding and developing materials for creativity in physics based on the research results are suggested.

II. Kepler's Scientific Problem Finding in the Eye Vision Image

1. Vision theories before Kepler

In ancient and medieval ages, some scholars thought light was emitted from the eye (extramission theory), while the others thought light came into the eye from outside (intromission theory) to see objects. The idea of vision depending on the 'fire in the eye' was elaborated by Plato in his cosmological dialogue the Timaeus, which was enormously influential in the medieval age and beyond. Plato argued that visual fire streamed out of the eye and combined with daylight to form a "single homogeneous body" which served as an instrument for detecting and reporting visual objects (Plato, 1965, p.62). Later, Euclid followed Plato's lead and defined optics mathematically, thus equating light and vision. He based his optics on the then well-known fact that light travels in straight lines. Vision was restricted to the cone of rays emanating from the eye and meeting the objects within it (Wade, 1998). Ptolemy carried Euclid's extramission ideas further and combined them with Galen's work on the anatomy of the eye (Gross, 1999).

On the other hand, the atomists such as Democritus and Epicurus believed that isomorphic images streamed off objects and entered the eye, where they were sensed. Aristotle argued that the Plato's extramission view was inadequate, and developed a rather complicated intromission theory. He assumed that a transparent medium, something like the modern ether, is found in air and water and is necessary for vision. Light is the state of this transparent medium, and the movement of the medium is sensed by the eye, yielding visual sensation. However, Aristotle's conception of light was not widely adopted (Wade, 1998).

In Europe, soon after the deaths of Ptolemy and Galen, interest in studying the natural world declined and then virtually disappeared. Scientific inquiry gradually shifted to Islamic centers of learning. Translation of Greek scientific works into Arabic began in the 8^{th} century, and by the end of the 9^{th} century, the achievements of Greek science were being actively discussed and often extended (Crombie, 1969). The nature of vision and light were of great interest to Islamic scientists. Some natural philosophers such as Al-Kindi defended and expanded Euclid's extramission views. Al-Kindi considered that only an extramission theory could account for perceptual constancy (Lindberg, 1976). The primary achievement of Islamic visual science was to merge the two strains of Greek visual theory and eliminate the inadequacies of each. This synthesis was accomplished by Ibn Al-Haythem, known in the West as Alhazen. When translated into Latin in the beginning of the 13^{th} century, Alhazen's Book of Optics dominated physiological optics in Europe for 200 years until Kepler (Gross, 1999). Alhazen's achievement had two parts. The first was to destroy extramission theory, and the second was to introduce a fundamentally new type of intromission theory which incorporated Euclid's rays and the visual cone of Ptolemy's extramission theory. His theory became enormously influential and became the basis of most of the subsequent work in optics in Europe between the 13^{th} and 17^{th} centuries (Gross, 1999). Galen's theory of vision was physiological, he thought that the "seat of vision" resides in the lens of the eye. Because of strictures against dissection, Galen's anatomy and physiology of the eye was generally accepted by Islamic scholars (Wade, 1998).

Alhazen adopted the theory that vision is brought about by light sent out, from the object seen, along the 'visual cone' to the eye. The sensitive part of the eye (the glacial humor or lens, following Galen) responds only to the perpendicular rays and these form a cone with the visual field as the base and the center of the eye as the vertex (Crombie, 1990; Lindberg, 1976). Following Galen in believing that the glacial humor (crystalline lens) was the seat of vision, he attempted to give an analysis of the mechanism of vision by combining these ideas with the geometrical optics developed in the treatise by Euclid and in that attributed to Ptolemy. He assumed that rays were sent to the eye from every point on the object seen; those meeting the cornea perpendicularly passed through it to the lens; and those falling perpendicularly on the anterior surface of the glacial humor gave rise to sensation by producing there an 'image' made up of points corresponding to points on the object seen (fig. 1) (Lindberg, 1976). However, he had to avoid what he saw as a difficulty. The normal incident rays passing through the anterior surface and body of the lens into the vitreous humor would intersect at the common center of curvature of this surface and of the cornea, change sides, and so produce an inverted image on the nerve at the back of the eye. Alhazen could not accept this inverted image, so he supposed that the rays converging towards the center of curvature were, before they intersected, refracted away from each other at the posterior surface of the glacial humor (lens), and so reached the nerve without crossing. However, Ptolemy had shown that oblique incident rays were refracted toward the perpendicular drawn to the interface when passing from a rarer into a denser medium, and away from the perpendicular when passing from a denser

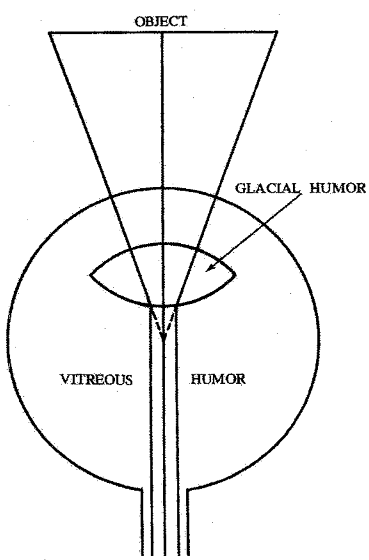


Fig. 1 *Alhazen's idea of vision (Diagram drew by Lindberg (1976))*

into a rarer medium. To bring about the refraction of the rays in the direction he required, Alhazen had to assume that the glacial humor (crystalline lens) was optically rarer than the vitreous humor.[1] (Crombie, 1990; Lindberg, 1976).

Relatively little was added to the science of optics in the late medieval period. In the sixteenth century, Witelo had completed his text, itself based largely on Alhazen's, and published in 1572. Witelo followed Alhazen's theory of vision in all essentials (Wade, 1998; Crombie, 1990).

2. Kepler' s analyses about Witelo' s explanation and problem finding

Kepler attempted to analyze the Witelo's explanation of vision with his own need. Then, Kepler was absorbed in writing two books of 'The Optical Part of Astronomy' and 'Commentaries of the Theory of Mars'; therefore, for the writing he began to consider many elements of optics, and he needed to delve into the function of the human eye (Ferguson, 2002). Kepler began to consider the Witelo's explanation about vision perspective in respect of optics. At that time, his optical analysis was confined to transparent spheres as the precedent scientists had used. Kepler explained the actual circumstances of vision by placing an aperture before the transparent sphere. Let *a* (fig. 2) be the center of the sphere and *ef* the aperture placed before it. Let *hi* be the visible object, and suppose the paper to be placed at *kl* (*k* and *l* being the cusps of the caustics formed by radiation issuing, respectively, from points *h* and *i*). Rays from *i* pass through the aperture and, after two refractions, come to an intersection in the region *mn*. Without the screen and aperture, the strongest image of point *i* would be at *l* rather than at *mn*; but since the screen prunes away the rays directed toward the center of the sphere, the peripheral rays that remain produce their sharpest image somewhat closer to the sphere, and at *l* there will be a certain blurring of the image. Rays from point *h*, on the other hand, pass only through the central region of the sphere and produce a relatively sharp image at *k*. It is clear from this demonstration that the paper *kl* bears an inverted image of the object at *hi* and that the image is most

[1] This shows a theory laden inference.

distinct near *k* (Crombie, 1990).

According to this analysis, the seat of image could not be on the anterior of glacial humor. As Kepler believed the results of optical experiments and analysis, he doubted about Alhazen and Witelo's vision theory which was not explained by the results of optical experiments, even though it was accepted widely at that time. This optical analysis showed that their explanation was optically impossible, and gave him the background to find and formulate an important scientific problem. That is, Alhazen and Witelo's theory of vision was an incomplete explanation without optical analysis and wrong explanation based on inference fitted to their own idea of non-inverted image, so that, in their explanation, optical impossibility may be included internally. Kepler, however, recognized the omitting of the optical analysis in it, and knew, after rigorous calculation, that their explanation was wrong. After analyzing them, Kepler took it as the point of departure from them (Crombie, 1990). Hence, how the human eye works and where the seat of vision is became a new scientific problem to be solved again. The thinking process in Kepler's finding and the formulating of the scientific problem can be inferred as shown in Fig. 3 (Kim, 2006).

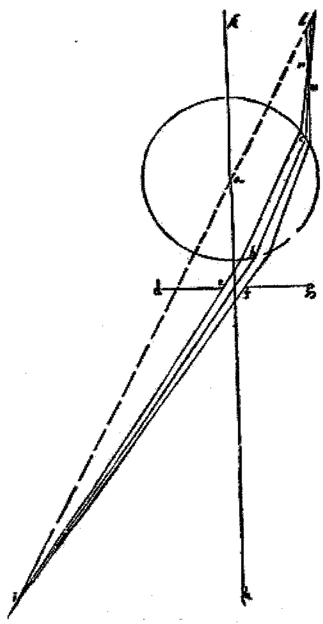


Fig. 2. *Kepler's optical analysis about Witelo's vision theory (From Kepler(1990, p. 301))*

Their theory is not correct, therefore, new theory is needed.
(Finding and formulating a new scientific problem)

▲

Recognition of optical impossibility in their explanation
(Analysis of the explanations according to his relevant knowledge in optics)

▲

Critical Reading of Alhazen and Witelo's theory of vision
(Reviewing literature for his own writing)

Fig. 3 *Kepler's thinking process in his problem finding*

Galen thought that the "seat of vision" resides in the lens of the eye. Because of strictures against dissection, Galen's anatomy and physiology of the eye was generally accepted by Islamic scholars. Alhazen adopted the theory that vision is brought about by light sent out, from the object seen, along the 'visual cone' to the eye. The sensitive part of the eye (the glacial humor or lens, following Galen) responds only to the perpendicular rays and these form a cone with the visual field as the base and the center of the eye as the vertex. Following Galen in believing that the glacial humor (crystalline lens) was the seat of vision, he attempted to give an analysis of the mechanism of vision by combining these ideas with the geometrical optics developed in the treatise by Euclid and in that attributed to Ptolemy. He assumed that rays were sent to the eye from every point on the object seen; those meeting the cornea perpendicularly passed through it to the lens; and those falling perpendicularly on the anterior surface of the glacial humor gave rise to sensation by producing there an 'image' made up of points corresponding to points on the object seen (fig. 1). Alhazen could not accept the inverted image, so he supposed that the rays converging towards the center of curvature were, before they intersected, refracted away from each other at the posterior surface of the glacial humor (lens), and so reached the nerve without crossing. To bring about the refraction of the rays in the direction he required, Alhazen assumed that the glacial humor (crystalline lens) was optically rarer than the vitreous humor.

Questions: (1) Do you think the above explanation for eye vision is right? (yes, no)
(2) If the above explanation is wrong, explain the reason why.
(3) Kepler found the optical impossibility from the above explanation, what do you think are they?
(4) Explain how we see an object in your own words.

Ⅲ. Applying Kepler's Problem Finding Situation to Korean Middle-school Students

The Kepler's problem finding situation was applied to Korean middle-school students, 111 students (48 students in 7^{th} grade and 63 students in 8^{th} grade from two middle schools in one large city in Korea). At first, Kepler's problem finding situation was presented to the students by figure shown in Fig. 1, and then the explanation shown in above word box was presented. In addition, the four questions in the bottom of word box were asked to them.

Table 1 and Table 2 show the students' responses to Witelo's explanation of eye vision.

For the Question (1), 97 students (87%) out of 111 responded that Witelo's explanation is wrong. The reasons students presented for the Question (2) and Question (3)[2] are: ① Non- perpendicular light also penetrates the pupil and the lens; ② The light rays passing through lens should cross at one point before reaching at retina; and ③ The seat of image can not be on the anterior of lens. Only five students (10%) of 7^{th} grade and sixteen students (25%) of 8^{th} grade presented all the three reasons, thirteen students (27%) of 7^{th} grade and fifteen students (24%) of 8^{th} grade presented two reasons, and twenty-two students

Table 1

Middle-school student responses to Witelo's explanation of eye vision (7th grade - School A & B)

Question 1		Question 2		Question 3		Question 4		
No	19[a]/21[b]	① Perpendicular light to lens (or cornea)	8/6	①	9/6	Erect image at retina	2/1	almost the same with Witelo
						Point image at retina	3/2	
						Inverse image at retina	1/1	cross after lens
						No response	3/2	
		② Without crossing	2/1	②	2/3	Point image at retina	1/2	focus at retina
						Inverse image at retina	0/1	cross after lens
						No response	1/0	
		③ Seat of image	1/1	③	1/1	Erect image at lens	1/0	at posterior of lens
						Inverse image at retina	0/1	cross in lens
		①+②	1/4	①+②	1/4	No response	1/0	
						Point image at retina	0/4	
		①+③	4/4	①+③	4/4	Erect image at retina	1/0	& inverse image at lens
						Point image at retina	0/1	
						Inverse image at retina	1/1	cross in lens/ cross after lens
						Others	2/0	diverse after lens cross before lens
						No response	0/2	
		①+②+③	2/0	①+②+③	2/3	Point image at retina	1/1	
						Inverse image at retina	1/2	Cross after lens(1/1) almost scientific(0/1)
Yes	3/5					Erect image at lens	3/5	same with Witelo

a): The former number is the number of students from School A.
b): The latter number is the number of students from School B.

2)The Question (3) was asked to the students in order to provide a hint that there are scientifically incorrect points in the explanation.

Table 2
Middle-school Student responses to Witelo's explanation of eye vision (8th grade - School A & B)

<table>
<tr><th colspan="2">Question 1</th><th colspan="2">Question 2</th><th colspan="2">Question 3</th><th colspan="3">Question 4</th></tr>
<tr><td rowspan="19">No</td><td rowspan="19">30[a)]/27[b)]</td><td rowspan="3">① Perpendicular light to lens or cornea</td><td rowspan="3">6/7</td><td rowspan="3">①</td><td rowspan="3">9/9</td><td>Erect image at retina</td><td>1/1</td><td>Almost the same with Witelo</td></tr>
<tr><td>Point image at retina</td><td>5/3</td><td></td></tr>
<tr><td>Inverse image at retina</td><td>3/4</td><td>Cross in lens[c)] /Cross after lens</td></tr>
<tr><td rowspan="3">② Without crossing</td><td rowspan="3">6/0</td><td rowspan="3">②</td><td rowspan="3">6/1</td><td>Point image at retina</td><td>4/1</td><td></td></tr>
<tr><td>Inverse image at retina</td><td>2/0</td><td>cross in lens[c)]</td></tr>
<tr><td>No response</td><td>1/0</td><td></td></tr>
<tr><td>③ Seat of image</td><td>1/0</td><td>③</td><td>1/0</td><td>Point image at lens</td><td>1/0</td><td></td></tr>
<tr><td rowspan="2">①+②</td><td rowspan="2">4/0</td><td rowspan="2">①+②</td><td rowspan="2">4/4</td><td>Point image at retina</td><td>1/6</td><td></td></tr>
<tr><td>Inverse image at retina</td><td>3/2</td><td>cross after lens</td></tr>
<tr><td rowspan="3">①+③</td><td rowspan="3">2/2</td><td rowspan="3">①+③</td><td rowspan="3">2/5</td><td>Inverse image at retina</td><td>1/1</td><td>almost scientific /cross after lens</td></tr>
<tr><td>Point image at retina</td><td>1/4</td><td></td></tr>
<tr><td>Point image in vitreous humor</td><td>0/1</td><td></td></tr>
<tr><td rowspan="7">①+②+③</td><td rowspan="7">7/4</td><td rowspan="7">①+②+③</td><td rowspan="7">8/8</td><td>Point image at retina</td><td>2/3</td><td>consider refraction(2/2)</td></tr>
<tr><td rowspan="3">Inverse image at retina</td><td>1/1</td><td>scientific</td></tr>
<tr><td>3/0</td><td>cross in lens[c)]</td></tr>
<tr><td>1/3</td><td>cross after lens</td></tr>
<tr><td>Point image in vitreous humor</td><td>0/1</td><td>almost scientific</td></tr>
<tr><td>No response</td><td>1</td><td></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Yes</td><td>3/3</td><td></td><td></td><td></td><td></td><td>Erect image at lens</td><td>3/3</td><td>same with Witelo</td></tr>
</table>

a): The first number is the number of students from School A.
b): The second number is the number of students from School B.
c): Similar diagram in his/her science textbook

(46%) of 7th grade and twenty-six students (41%) of 8th grade replied only one reason. Actually, the important reason which Kepler found, but none of all the students found, was that the light rays from a point of an object spread into so many directions; therefore, cover the pupil or lens so that it may be a base of a visual cone like shown in Fig 4. Although a hint was given to the students in Question (3), their responses about the reasons why the above explanation is wrong are almost same with the reasons in Question (2).

For Question 4, students' conceptions from their diagrams and their explanations are shown in Table 3.

Just only one student (2.1%) out of forty-eight 7th grade and only four students (6.3%) out of sixty-three 8th grade students showed scientific conceptions in their diagrams and explanations concerning eye vision, the other all students thought that just one light ray from a point of an object can make image of that point on the retina by going straight through pupil and lens, or by going through pupil but being refracted by lens (Students' diagram patterns are shown in Fig. 5.).

Ⅳ. Explanations of Eye Vision in Korean Middle-school Science Textbooks

In order to know if students' ideas about eye vision are related to the explanations in science textbooks, the explanation patterns concerning how we see an

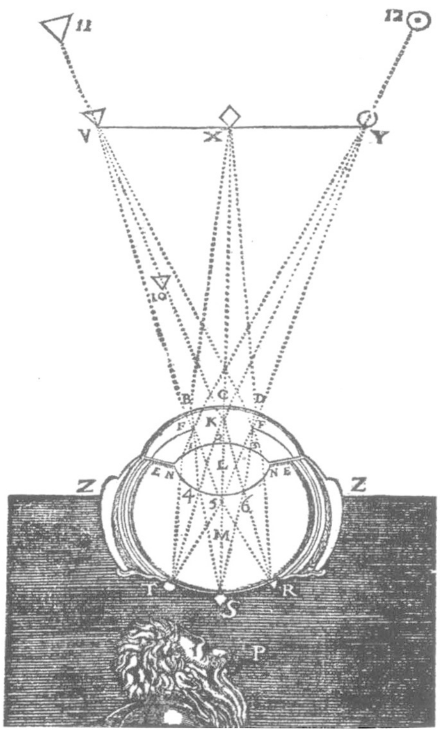


Fig. 4 *Kepler's idea of the retinal image [22]*

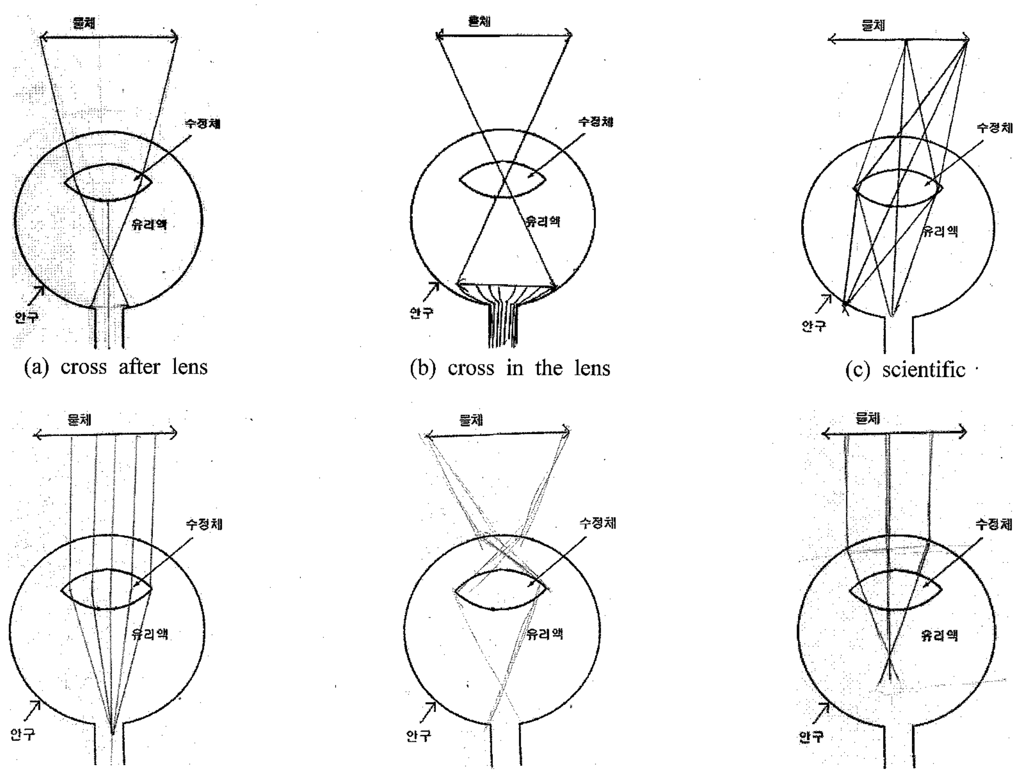
object in the Korean middle-school science textbooks were investigated and analyzed. Analyzing nine kinds of science textbooks for 8th grade students in which explanations of eye vision are presented, it is found that five kinds of them presented the eye vision

Table 3

Students' ideas concerning vision image

	7th grade (N=48)	8th grade (N=63)	Total (N=111)
(1) Inverse image at retina	8 (16.7%)	23 (36.5%)	31 (27.9%)
Scientific	1 (2.1%)*	4 (6.3%)*	5 (4.5%)
Cross in lens	2 (4.2%)	8(12.7%)	10(9.0%)
Cross after lens	5(10.4%)	11(17.5%)	16(14.4%)
(2) Point image at retina	13(27.1%)	29(46.0%)	32(28.8%)
(3) Erect image at retina	3 (6.3%)	2 (3.2%)	5 (4.5%)
(4) Erect image at lens	10(20.8%)	6 (9.5%)	16(14.4%)
(5) Others	14(29.2%)	3 (4.8%)	16(14.4%)

* Scientific conception



(a) cross after lens
(b) cross in the lens
(c) scientific
(d) point image at retina
(e) others (left: erect image at retina, right: erect image at lens)

Fig. 5 *Student diagrams of how we see on object.*

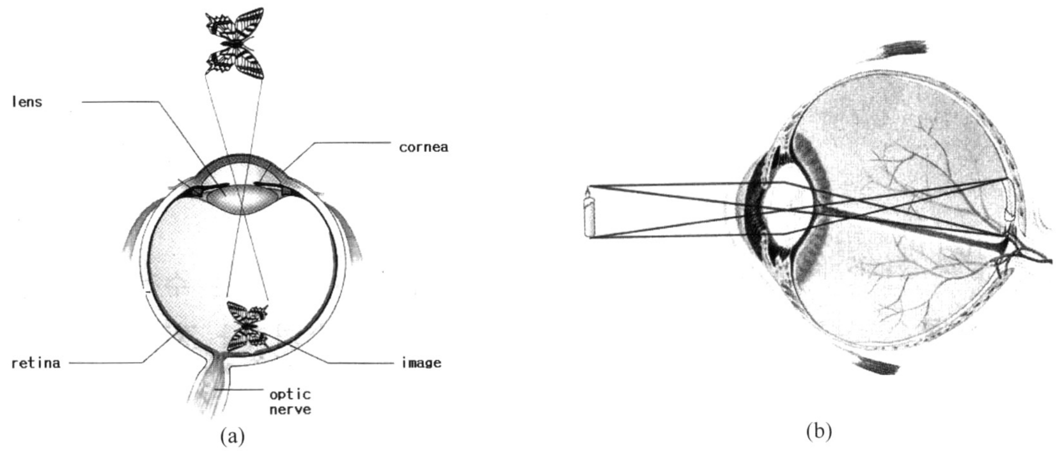


Fig. 6 *Explanations of how we see the object in science textbooks*

Table 4

Eighth-grade students' ideas concerning eye vision by presentation types in science textbooks

Students' ideas		School A* (N=33)	School B* (N=30)
Inverse image at retina	Scientific	2 (6.1%)	2 (6.7%)
	Cross in lens	8(24.2%)	0 (0%)
	Cross after lens	4(12.1%)	7(23.3%)
Point image at retina		12(36.3%)	17(56.7%)
Erect image at retina		1 (3.0%)	1 (3.3%)
Erect image at lens		3 (9.1%)	3(10.0%)
Others		3 (9.1%)	0 (0.0%)

* The students from School A learned presentation type (a) in Fig. 6 concerning eye vision, and those from School B learned presentation type (b) in Fig. 6.

pattern like (a) in Fig. 6, while the other four kinds presented the pattern like (b) in Fig. 6. Table 4 shows that eight students (24%) from School A presented the same eye vision pattern shown in their science textbook, while none of School B students presented this kind of pattern. This result shows that the students' ideas about eye vision are deeply related to the presentations given in their science textbooks.

V. Conclusions and Implications for Science Education

Kepler found the scientific problem in his discovery of retinal image theory through critical analysis of contemporary theories of eye vision, based on his relevant knowledge of optics. However, the present study concludes that only about 6% of Korean 8th grade students were able to find the same problem as Kepler, even though they had been taught about light refraction and image formation. Moreover, it was found that some Korean science textbooks insufficiently explain how to see the object.

From the results, a few directions for teaching creativity in Science are suggested. First, in the development of creativity teaching material, situations like Kepler's problem finding should be developed, and need to be included in the programs. Certainly a start can be made with a physics lesson in which students make the same analysis made by Kepler in the eye vision theory. Students would then attempt to explain those analyses through the generation of alternative hypotheses and expectations. Secondly, it should be taught that relevant and correct scientific knowledge is important for scientific problem finding. Lastly, science textbooks should be developed considering students misconceptions, and experts from all related science areas should corporate for the development of sound science textbooks.

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