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

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The aims of this study are to investigate how Kepler found a scientific problem for the retinal image theory and to investigate how the science high school students respond when the same situation is applied to them. And their results was compared with general high-school students' results. 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 we applied the same situation to the Korean science high school and general high-school students, only a few of science high-school students found the scientific problem as same as Kepler's finding. From the results, it is suggested that in development of creativity teaching material, the situations like Kepler's problem finding need to be included in the programs.

Key Words: Vision perspective, Kepler, Problem finding, Creativity education, Science High-School

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.

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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) 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 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 scientists constantly have found problems and formulated hypothesis to solve the problems. For example, Galileo formulated the scientific problem of determining the velocity of light, but could not solve it by himself, whilst Hertz solved the scientific problem of the existence of electromagnetic wave in space predicted by Maxwell. On the other hand, Kepler solved the problem of vision image, which he himself found in old theories. 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 will be established. That is 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 one of them, which his thinking process and pattern can be analyzed more clearly because the term of the discovery is relatively short and the related literatures including his own treatise are enough for getting useful information. Therefore, in this research, how Kepler, who discovered that the seat of vision image is retina, found scientific problem and formulated hypotheses in the process of his discovery of retinal image formation is investigated and analyzed.[1] In addition, it was investigated that how many Korean Science High-School students found the same scientific problems with Kepler when the same situation that Kepler found the scientific problems were presented to them. And the results of science high-school students was compared with those of general high-school students.

1) This part was already researched by Kim (2007b), which is presented here for sequence of analysis.

II. Kepler's finding of a scientific problem in the vision image

When he discovered the retinal image theory, 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. Witelo had completed his text, itself based largely on Alhazen's, which was the most comprehensive treatise on optics then available (Wade, 1998; Crombie, 1990). However, it was Kepler's reaction that the thing omitted by Witelo was the optical analysis of the vision image (Wade, 1998). This analysis gave Kepler the background to discover, after rigorous calculation, that the old theories were wrong (Ferguson, 2002). Then, what was the Wittelo's explanation about vision image? And what was the problem in that theory?

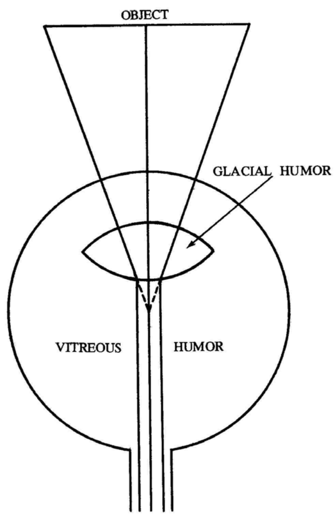
1. Vision theories before Kepler

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. 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: 62). Later, Euclid followed Plato's optics, mathematically equating light and vision. 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. And 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 8th century, and by the end of the 9th 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 13th 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 13th and 17th 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). But 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. But 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 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 (Crombie, 1990; Lindberg, 1976).

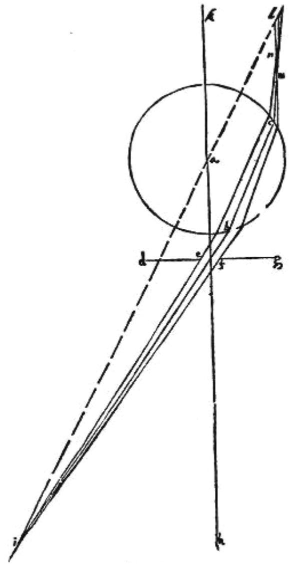


[Fig. 1] Alhazen's idea of vision (Diagram drew by Lindberg (1976))

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

As was mentioned above, Kepler attempted to analyze the Witelo's explanation of vision with his own need. 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 distinct near k.



[Fig. 2] Kepler's optical analysis about Witelo's vision theory
(From Kepler, De Modo Visionis, Crombie (trans), 1990, p. 301.)

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 problem which Kepler found was a kind of discovered (Getzels, 1987) or a potential problem (Dillon, 1982) that, by combining the elements in some way, the observer created or invented where none previously existed. Perhaps potential problems are most clearly seen in the invention process. The astute observer was able to identify a problem that had previously gone unrecognized. Kepler had relevant knowledge about contemporary optics so that he could give insight to grasp of faults in their explanation.

III. Science high school and general high-school students' problem finding in the same situation that Kepler experienced

Kepler's problem finding situation was applied to the Korean science high-school students (*N*=30, 10th grade, sampled from a science high-school in a big city of Korea) and to the general high-school students (*N*=27, 11th grade, sampled from a general high-school in a big city of Korea). They were volunteers for this research, one science teacher in each high-school administered the test tool to the students for about thirty minutes. The test tool consists of Kepler's problem finding situation as shown in Fig. 2 and Witelo's explanation such as in below word box and four questions in the bottom of word box. Student's responses were analyzed according to the criteria, which was used for the middle school students (Kim, 2007b).

> 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]. But 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. But 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 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) Do you think the above explanation for eye vision is right?
(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) Draw a diagram and explain how we see an object.

<Table 1> and <Table 2> show science high-school and general high-school students' responses to the Witelo's explanation about eye vision, respectively.

<Table 1> Science high-school students' responses to the Witelo's explanation about eye vision

Q 1	Q 2		Q 3		Q 4		
No 30	① Perpendicular light	4	①	2	Erect image at retina	1	
					Focused image at retina	1	
			②	2	Inverse image at retina	1	Cross in lens
						1	Cross after lens
	② Without crossing	5	②	4	Erect image at lens	1	anterior of lens
					Inverse image at retina	1	Scientific*
						1	Cross in lens
						1	Cross before lens
			No ans	1	No response	1	No diagram
	③ Seat of image	0					
	①+②	8	①+②	8	Inverse image at retina	6	cross after lens
					Focused image at retina	2	
	①+③	8	①+③	8	Inverse image at retina	3	Scientific*
						2	Cross in lens
					Focus image at retina	2	
					No response	1	
	①+②+③	5	①+②+③	5	Inverse image at retina	1	Scientific*
						1	Cross in lens
						1	Cross after lens
					Focused image at retina	2	
Yes 0							

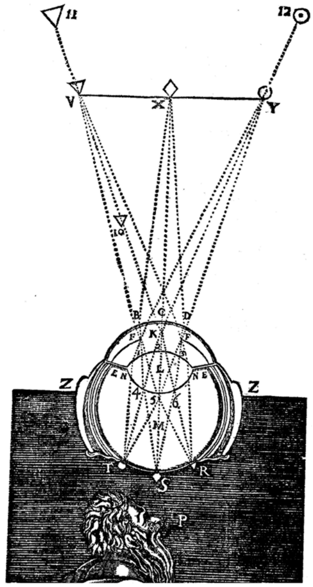
*Scientific

<Table 2> General high-school students' responses to the Witelo's explanation about eye vision

<table>
<tr><th>Q 1</th><th colspan="2">Q 2</th><th colspan="2">Q 3</th><th colspan="3">Q 4</th></tr>
<tr><td rowspan="20">no 26</td><td rowspan="6">① Perpendicular light</td><td rowspan="6">7</td><td>no response</td><td>1</td><td>Inverse image at retina</td><td>1</td><td>cross in lens</td></tr>
<tr><td rowspan="2">①</td><td rowspan="2">3</td><td>image at posterior of lens</td><td>2</td><td>Inverse</td></tr>
<tr><td>image at cornea</td><td>1</td><td>erect</td></tr>
<tr><td>①+②</td><td>1</td><td>image at posterior of lens</td><td>1</td><td>Inverse</td></tr>
<tr><td rowspan="2">others</td><td rowspan="2">2</td><td>image at posterior of lens</td><td>1</td><td>erect</td></tr>
<tr><td>Inverse image at retina</td><td>1</td><td>cross after lens</td></tr>
<tr><td rowspan="3">② Without crossing</td><td rowspan="3">5</td><td>②</td><td>2</td><td>Focused image at retina</td><td>1</td><td></td></tr>
<tr><td>①+②</td><td>2</td><td rowspan="2">Inverse image at retina</td><td rowspan="2">3</td><td rowspan="2">cross after lens</td></tr>
<tr><td>no response</td><td>1</td></tr>
<tr><td rowspan="2">③ Seat of image</td><td rowspan="2">2</td><td rowspan="2">①</td><td rowspan="2">2</td><td>erect image at retina</td><td>1</td><td>cross after lens</td></tr>
<tr><td>no response</td><td>1</td><td></td></tr>
<tr><td rowspan="4">①+②</td><td rowspan="4">7</td><td>①</td><td>1</td><td>no response</td><td>1</td><td></td></tr>
<tr><td rowspan="2">①+②</td><td rowspan="2">5</td><td>Inverse image at retina</td><td>3</td><td>cross after lens</td></tr>
<tr><td>Focused image at retina</td><td>2</td><td></td></tr>
<tr><td>Others</td><td>1</td><td>Focused image at retina</td><td>1</td><td></td></tr>
<tr><td>①+③</td><td>1</td><td>①</td><td>1</td><td>image at retina</td><td>1</td><td>same with Witelo</td></tr>
<tr><td rowspan="3">①+②+③</td><td rowspan="3">3</td><td rowspan="3">①+②+③</td><td rowspan="3">3</td><td>Inverse image at retina</td><td>1</td><td>cross after lens</td></tr>
<tr><td>focused image at retina</td><td>1</td><td></td></tr>
<tr><td>image at posterior of lens</td><td>1</td><td></td></tr>
<tr><td>No response</td><td>1</td><td>②</td><td>1</td><td>Focused image at retina</td><td>1</td><td></td></tr>
<tr><td>yes 1</td><td>No response</td><td>1</td><td>①</td><td>1</td><td>image at posterior of lens</td><td>1</td><td></td></tr>
</table>

For the first question, all of the science high-school students (100%) and almost all of the general high-school students (96%) responded the Witelo's explanation is wrong. They all might find one or more wrong point(s) in the Witelo's explanations.

For the second question, the reasons why they think they are wrong: ① Perpendicular light only penetrates the pupil and the lens; ② The lights passed lens will not cross before reaching retina; and ③ The seat of image is on the anterior of lens. Then, only 5 Science High-School students (17%) and 3 general high-school students (11%) presented all the three reasons, 16 (53%) and 8 (30%) students of each group said two reasons, and 9 (30%) and 14(52%) students said only one reason. In fact the very important reason, which Kepler found, but all the students could not find, was that the light rays from a point of an object go into many directions and cover the pupil or lens so that it may be a base of a visual cone [Fig. 3].



[Fig. 3] Kepler’ s theory of the retinal image (Lindberg, 1976, p. 193)

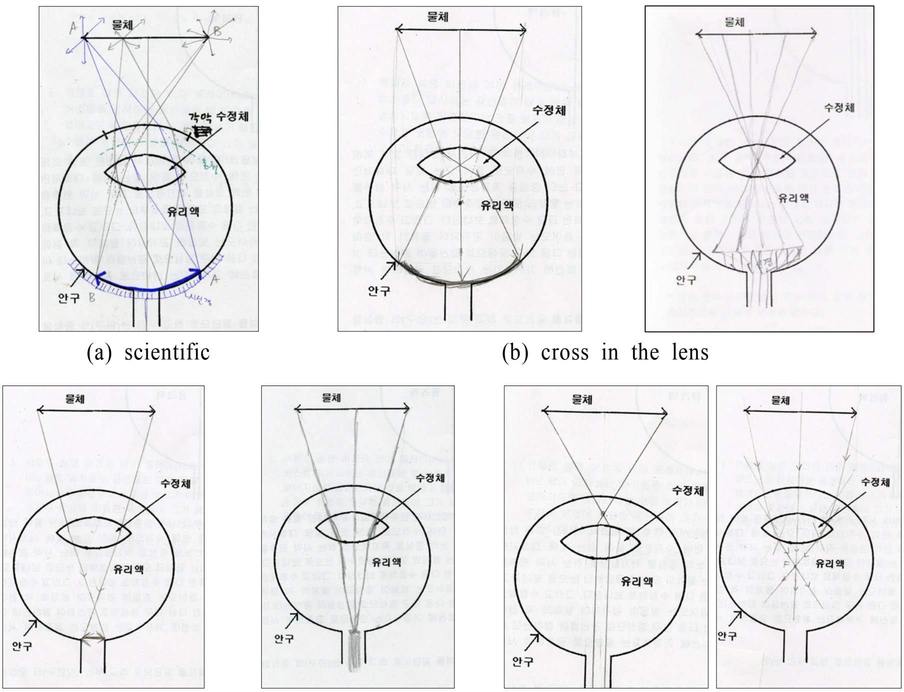
After second question, a hint of optical impossibility was given to the students in question (3), their responses about the reasons why the above explanation is wrong are almost same with the reasons in question (2).

For the question (4), the diagrams which students drew and their explanation were analyzed, the resultant patterns are shown in <Table 3>.

<Table 3> Student conception patterns

Pattern	Sci. H	Gen. H		Sci. H	Gen. H
Inverse image at retina	19	8	Scientific	5	0
			Cross in lens	5	1
			Cross after lens	9	7
Focused image at retina	7	6			
Image at posterior of lens	0	5			
Erect image at retina	1	2	Inverse	0	4
			Erect	0	1
Erect image at lens	1	0			
Erect image at cornea	0	1			
etc	0	3			
No diagram	2	2			

<Table 3> shows that just only 5 (17%) out of 30 science high school students showed scientific conceptions like (a) in [Fig. 4], the other all students thought that one light rays from a point of an object can make image of that point on the cornea by going through pupil and lens or by going through pupil but being refracted by lens like (b) - (e) in [Fig. 4]. In addition, <Table 3> shows that science high-school students presented four patterns, while general high-school students showed six and more patterns, which means they have various incorrect ideas about image formation in the eye.



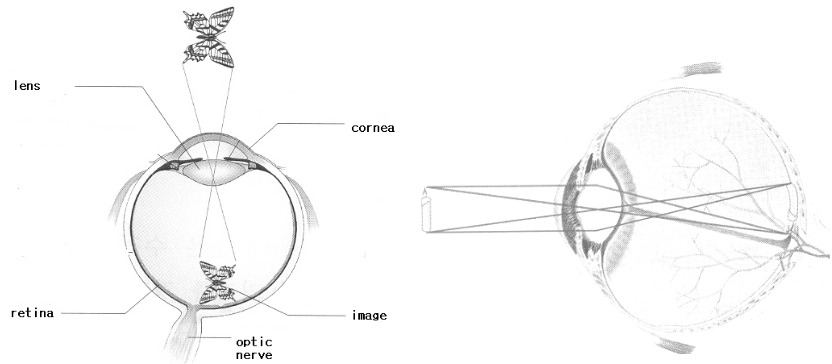
(a) scientific (b) cross in the lens

(c) cross after the lens (d) focused image on retina (e) others

[Fig. 4] student diagram about how we see the object.

IV. Explanation about eye vision in Korean secondary school science textbook

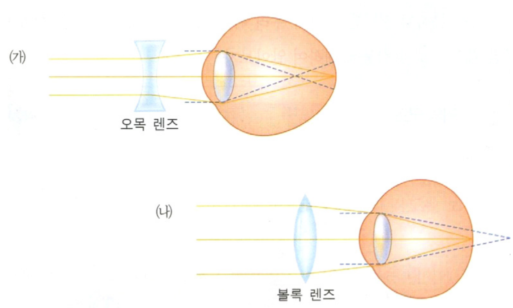
The Korean secondary school science textbooks for the explanations about how we see an object were investigated and analyzed. The explanations about eye vision are presented in the science textbooks for 8th grade. Eight kinds of science textbooks for 8th grade were analyzed. The key presentations about eye vision in those books are shown in [Fig. 5]. Three kinds of them presented (a) type in [Fig. 5] and five kinds showed (b) type.



(a) (b)

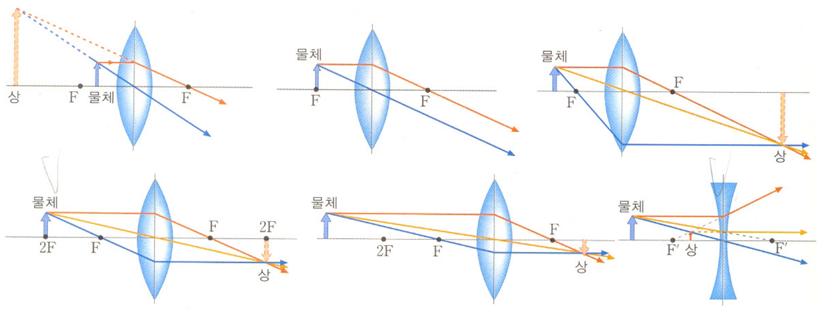
[Fig. 5] Explanations about how we see the object in science textbooks

The type (a) is simple, but may cause of misconception that one light ray can make image of a point of object. The type (b) includes Kepler's idea that many light rays come from a point of object and they make a image of the point of object. Furthermore, in [Fig. 6] which is presented in a Korean science textbook, the focal point of lens is on the retina, which may cause student's misconception of 'focused image on retina', shown in [Fig. 4].



[Fig. 6] Diagrams that explain remedy of eye-sight. Focal point lies on retina after remedy (Kim, 2007a)

In Korean physics textbook, image formation mechanisms by convex and concave lenses are taught using diagrams in [Fig. 7], but the science high-school students as well as the general high-school students showed that they do not relate these mechanisms to the eye vision mechanism, even though they are closely related, which means that they do not have correct and enough knowledge about eye vision mechanism so that may find scientific problems from the Witelo's wrong explanations about how we see an object.



[Fig. 7] Image formation mechanisms by convex and concave lenses

V. Conclusions and implications for physics education

The present analysis concludes that 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, but none of Korean science high-school students found the same problem with Kepler. According to their diagram about how we see an object, it is found that some of them have ability to find the same scientific problem with Kepler in the same situation.

To improve their ability to find scientific problems, the situations like Kepler's problem finding need to be included in the science textbooks, which is not found in current Korean science textbooks. Or special program for improving student ability to find scientific problems should be developed based on the research. Certainly a start could be made with a science lesson in which students make the same analysis made by Kepler in the eye vision theory. Students could then attempt to explain those analyses through the generation of alternative hypotheses and expectations. Student brainstorming could then be followed by subsequent analyses in which the alternative hypotheses are tested by the comparison of expected and analyzed results.

According to the result of science textbook analysis, some Korean science textbooks explain incorrectly about how we see the object, which may cause misunderstanding or misconception about image formation at retina. Science textbooks should be developed considering student misunderstanding or misconceptions. In addition, it should be taught that relevant scientific knowledge is important for scientific problem finding.

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= 국문초록 =

얼마나 많은 과학고등학교 학생들이 케플러가 광학과 생리학에서 발견한 과학적 문제를 발견하는가?

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이 연구의 목적은 케플러가 어떻게 망막 상 이론 형성과정에서 문제를 발견하였는지를 조사하고 그 당시 상황을 과학고등학교 학생들에게 제시했을 때 얼마나 많은 과학 고등학교 학생들이 케플러가 발견한 것과 같은 문제를 발견하는가를 조사하는 것이었다. 그 결과를 일반 고등학교 학생들의 경우와 비교하였다. 케플러는 당시의 시각이론에 대해 비판적으로 분석하고 과학적 실험에 근거한 지식을 기반으로 문제를 발견하였다. 과학고등학교 학생들은 중학교 과정까지 상당한 정도의 광학 개념과 생리학적 개념을 학습하였다. 그럼에도 있음에도 불구하고 케플러 당시의 문제 발견 상황을 제시했을 때 케플러가 발견한 것과 같은 광학적 불가능성 문제를 발견하여 제시한 학생은 한 명도 없었다. 다만 30명 중에서 5명의 학생이 시각 개념을 과학자적으로 표현함을 볼 때 이들은 케플러와 같은 문제 발견 가능성을 보였다. 교과서 분석을 포함한 본 연구 결과는 창의성의 핵심 요소인 과학적 문제를 발견하는 능력에 대한 체계적 교육이 필요함을 시사하고 있다.

주제어: 시각 개념, 케플러, 문제 발견, 창의성 교육, 과학고등학교

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