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### Determination of Conceptual Understanding Levels Related to Optics Concepts: The Case of Opticianry

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## Determination of Conceptual Understanding Levels Related to Optics Concepts: The Case of Opticianry

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### Abstract

Physics is directly related to various professions since it is a fundamental science. Opticianry is one of such physics related professions. In this study, it was aimed to determine the conceptual understanding levels of opticians related to the concepts of light and optics which are directly related to their professions. In the study, which was conducted via mixed method, the participants were determined with the convenient sampling method. A total of 203 opticians attended the study. Data were collected with the help of Light and Optics Conceptual Evaluation Test in addition to the Open-Ended Questions and Concept Cartoons selected from the literature. As a result of the study, it was reached that the conceptual understanding levels of opticians were low with several misconceptions and insufficiencies related to the light and optics concepts. In the light of the findings, the importance of physics education for opticianry was implied.

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### Introduction

Students have difficulty in learning science courses (Johnstone, 1991). One of the reasons of students' low level of achievement in science course when compared to the other courses is the fact that it involves a number of abstract concepts and the students experience difficulty while learning these concepts (Duit & Rhöneck, 1997). Therefore, various science education studies focus on students' concept learning (Ausubel, 1968; Novak, 1993; Novak & Gowin, 1984; Strauss, 1981). Another reason of students' low level of achievement in science course is students' possession of misconceptions instead of scientific concepts (Halim et al., 2018; Tanner et al., 2018). Misconceptions are incorrect conceptions which are accepted correct by the learner and utilized as the source of several abilities' performance (Gilbert, 1977; Gilbert, Osborne & Fensham, 1982; Palmer, 1999). Incorrect knowledge possessed by the students might induce the formation of misconceptions (Hewson & Hewson, 1983; Palmer, 1999; Skelly & Hall, 1993). Numerous researches have been carried out in terms of physics teaching in the literature beginning from 1980s in which the first misconception study appeared. With these researches, misconceptions of the students and the effects of several teaching strategies, methods and techniques on those misconceptions have been investigated (Akpınar & Çite, 2015; Brown, 1992; Çökelez & Yaşar, 2015; Istanda et al., 2012; Mann & Treagust, 2010; Rankhumise & Imenda, 2014). A particular section of misconception studies in physics teaching is comprised of the subjects related to the light and optics (Anderson & Smith, 1986; Goldberg & McDermott, 1987; Epik, Kalem, Kavcar & Çallica, 2002; Şen, 2003; Blizak et al. 2009; Galili & Hazan 2000; Açı, 2012; Uzoğlu et al., 2013; Djanette & Fouad, 2014; Thapa & Lakshminarayanan, 2013; Taşlıdere & Eryılmaz, 2015). Various misconceptions determined in those studies are explained below.

Şen (2003) investigated the conceptual understandings of the students related to the concepts of light, vision and mirrors. A total of 304 students studying in the third, fifth and seventh grade level attended the study. The results of the study indicated that students perceived light as a stationary object which filled up the atmosphere. The students asserted that the only thing which was necessary for the achievement of vision was light. Besides, they could not explain the relationship between the eye and light for image formation. According to their view, staring at an object or keeping the eye in light was sufficient for seeing the object. In another words, it was possible to see an object when light fell on it without any light rays reflected or emitted from that object. In that study, the students stated that a white object could be seen in dark but a black object could not. For those students, white objects are light source whereas black objects are not light source. Due to that reason, according to the students, white objects can be seen even there is no light in the environment. The students explained the fact that space was black by utilizing the misconceptions related to light and image formation. According to the students, the space is black because light is made up of small particles which cannot be seen by eye; air layer

makes the objects darker; light rays do not spread in the space; the sun is not enough to enlighten the space. In addition, the students expressed that the image on plane mirror formed inside the mirror or on the mirror. Anderson and Smith (1986) researched the conceptual understandings of the students about light and vision. A total of 227 fifth grade level students were involved in the study. As a result, it was found that students perceived the color of an object as a characteristic possessed by the object; they could not construct the relationship between the color of the object and the light rays reflected from the object. In the study, it was highlighted that students mostly held the opinion that during image formation, light made an area brighter, thus it could be seen. The students who had this opinion thought that light rays did not move. Instead light rays formed image by brightening. In the study, the students were asked the following question: "How can the image of a tree be seen in a sunny day?" The featured student responses were as follows: "Incident light rays on the tree are enough for image formation". "The light rays travelling from the eye to the tree make the image". Also, the students thought that light rays which came to the normal line of a reflective plane and a wooden plane with the same angle were reflected with different angles from those planes.

Blizak et al. (2009) conducted a research with the attendance of a total of 246 high school students. In this study, misconceptions of the students related to the concepts of optics were determined. In the study, it was reported that the students thought the image of an object formed with the help of the light rays travelling from the eye to the object. Besides, the students failed to explain the relationship between the eye and observed object during image formation. Additionally, they thought that it was enough to keep an object under light to get the image of the object. In the study, it was also found that the students thought light rays could not spread in space. Moreover, the students expressed that all of light emission of a point size light source was blocked by a ball placed in front of the light source; a screen positioned in that experiment set up (a screen, a ball and light source) was totally seen black. For the same experiment set up, the students thought that the screen would be totally bright when a wider light source was used. In the same study, it was also reached that the students thought the image of an object on a plane mirror would form on the surface of the mirror. Galili and Hazan (2006) made a study with the attendance of 166 high school students. In this study, the students explained the image formation of an object without making any physical connections between the eye and the object observed. For instance, looking at the object carefully by focusing on it was sufficient for the students in order to see that object. Also, lightening of eye or lightening of the object observed was enough for image formation. Besides, the students thought that light rays spread only in one direction in every part of the light source just like it spread from one point in the center of a spherical light source. When the students made the drawing of light rays travelling to a convex lens emitted from a source, they only drew the part of the light rays which reached the lens. Furthermore, the students supposed that half of the image disappeared when half of the convex lens was covered with black tape.

The conducted research also indicates that university level students hold misconceptions related to the concepts about optics. Misconceptions possessed by the university level students show similarity with the ones in primary and secondary school level. Goldberg and McDermott (1987) researched the conceptual understanding levels of the students related to real image formation in concave and convex mirrors. A number of misconceptions were determined in the study conducted with the attendance of 80 university students. The research indicated that the students failed to understand the functions of lenses, mirrors and screens utilized in the image formation. The students supposed that the image of an object could be obtained on a screen without using lenses and mirrors. Also, the students who could determine the place of the image of an object in a problem successfully failed to determine the correct place of the image in an experimental set up. The students thought that the image of an object was only formed by the special light rays during the image formation in lenses and mirrors. Moreover, it was also determined that the students had difficulty in explaining image formation in eye. Similar findings as reported in that research (Goldberg & McDermott, 1987) were also concluded by Epik et al. (2002). In that study, several students were detected to possess misconceptions related to the concepts of light, light ray, light source, emission of light ray, image formation in lenses and mirrors and image observation. It was found that the students could make a correct drawing for the image of an object which was placed vertically in the optical axis. On the other hand, they could not make a correct drawing for the image of an object which was placed in parallel position with the optical axis. Also, it was seen that the students utilized only one special light ray while making image drawings in convex mirrors. According to the students, placing a block between the mirror and the object would not prevent image formation. This consequence was interpreted as the confusion of image formation in geometrical optics with the image observation in eye. What is more, the students thought that an image obtained from a convex lens could always be seen by the observers. This consequence showed insufficient level of students' knowledge related to image formation in eye. The study also indicated misconceptions related to light ray. The students expressed light ray as an extension of the object, not a symbol for demonstrating how light took place in the space. The students were identified to draw bent light rays while

making a drawing related to shadow formation. Additionally, the students were found to draw all light rays as if they were emitted from a point located in the center of spherical light source.

In another study conducted with 252 university students, the students were determined to hold various misconceptions about the subjects of light and optics (Ahçı, 2012). The students were determined to have misconceptions related to the motion of light rays in different refractive index environments and they thought light rays could move on the normal line after being refracted. Also, it was reached that the students had difficulty in determining the size and the place of the image in concave and convex lenses. Several students thought that image could be inverse or larger than the object in concave lens; the image of an object could be inverse or smaller than the object when it was located at a point between the focal point and lens in a convex lens. Also, the study indicated that the students thought that an object placed beyond the twice the focal length of a convex lens would give a straight image or an image larger than the object; an object placed between the twice the focal length and focal point of a convex lens would give a straight image or an image smaller than the object. Several students stated that half of the image would disappear when half of the lens was covered by an object or they indicated that the image would totally disappear when the center of the lens was covered.

Those responses indicate that students' knowledge related to image formation is based on memorization. They fail to provide correct explanations when different cases are asked them. In the study of Thapa and Lakshminarayanan (2013) conducted with 173 university students, it was asserted that the students' knowledge related to the optics was not in a sufficient level. The study reported that the ratio of correct responses related to the questions on Snell Law was high whereas this ratio was low for making drawings related to image formation in the lenses. Moreover, it was stated that the optometry students needed to reach a better understanding level in that subject in order to keep up with the recent status of optometry profession considering the technological developments in the area of eye health (laser surgery, wavefront aberration measurement and correction, etc.). Taşlıdere and Eryılmaz (2015) determined various misconceptions in their study conducted with a total of 317 university students about vision. In the study, it was found that students had unscientific opinions about the location of the image beyond the mirror, the role of light in vision and shadow formation. The students supposed that the size and location of the image of an object on plane mirror depended on the location of the observer and light source rather than the location of the object. According to the students, light rays needed to go to the object from the eyes of the observer in the case of vision. The students believed that light source needed to be directed to the eyes rather than the object in order to see a point or object clearly in a dark environment. It was found that the students perceived shadow as black in color whereas they perceived light as white in color. Also, they believed that the color of grey was made of by mixing those two colors. Also, the students thought that shadows were formed only by the objects which were not light sources. In addition, they stated that the shadows of the objects always looked like the objects themselves. Moreover, the students failed to explain the formation of semi-shadow and they confused the terms - clarity of the shadow and size of the shadow. Another point found in the study was that the students thought only one light ray from each point on the surface of the bulb was emitted in the direction of the radius of the bulb. However, there are light rays which are emitted to all directions from each point on the surface of the bulb. The reason of the fact that the students confused the clarity of the shadow with its size rested on that view. It is surprising to encounter such misconceptions in university level students. Uzoğlu et al. (2013) made a research on light with the attendance of 212 university students. The aforementioned surprising findings were also encountered in that study. The students supposed that image could be formed without any light rays being emitted or reflected from an object. The students stated that a white cat could be seen in a dark room whereas a black cat could not. According to the students, white objects were light sources whereas black objects were not. Another misconception determined in the study was that the students thought the distance that a light ray could reach varied according to the geometric shape of the light source. They supposed that light rays reached more distant points when it was emitted from a torch with a larger or smaller surface area. In addition, the same study concluded that scientifically unacceptable opinions of the students about light and image led to the construction of scientifically unacceptable opinions about celestial bodies, space and the images of the celestial bodies. Students' scientifically unacceptable opinions about that subject were as follows: "The stars cannot be seen in day light since they reflected moonlight." "The stars reflect sun light but they could not be seen in day light since their light was not as bright as the sun." "The part of space close to the sun is bright whereas the other parts of it are dark." "The space is dark since it is huge." "The space is bright during daytime and dark at night." In the study of Djanette and Foud (2014) conducted with 52 university students, it was found that the students expressed that light rays went to the object from the eye during image formation. In that study, the students stated that enlightening of the object or eye by the light rays was sufficient for image formation. Besides, students supposed that the light rays were reflected from the eye during image formation. Also, they thought that the eye gave color to the objects.

Physics is one of the fundamental sciences. Therefore, it is related to various professions. Opticianry is one of such physics related professions. Opticians prepare and apply optics instruments (spectacles, contact lenses etc.) for the patients according to the doctors' prescription (Özdemir & Yazar, 2016). Opticians generally prepare spectacle for the patients. Spectacles are tools made of a pair of lenses fitted in a frame which improve the vision of a patient or they protect the eyes from the harmful effects of sun light (Özdemir & Kabak, 2018). The spectacles can be used as the tools to support the sight of patients who have the refractive errors such as myopia, astigmatism, hypermetropia or presbyopia.

Additionally, some special spectacles can be utilized for poor vision, vision lose and strabismus (McCleary, 2009). Therefore, opticianry is a profession that is directly related to optical lenses. Spectacles have physical properties that eliminate the negative effects of diseases related to refractive errors, strabismus and vision loss. The features of the spectacle lenses have been improved with various applications to the lenses. For instance, scratches resistance and hydrophobic property of the lenses are increased and light reflections are decreased by coatings on the lens surface (Essilor, 1997; Özmumcu, 2011). In addition, spectacle lenses are given the ability to block ultraviolet rays (Irie, 2000) and polarizing filter feature (Büyükyıldız, 2012; Chevallier et al., 2011; Chen et al., 2016). Since the profession of opticianry is directly related to the physics, opticians are required to have a comprehensive knowledge of the concepts related to the light and optics in order to perform their profession in a way to keep the eye health of the society.

The literature indicates various problems related to the understanding of optics concepts by all age group students. Hence, the present study aims to approach this issue from a different perspective, namely from the perspective of opticians. This paper focuses on the conceptual understandings of the opticians related to light and optics concepts. The research questions are as follows:

- i) What are the conceptual understanding levels of opticians about the concepts related to the optics?
- ii) What are the widespread misconceptions of opticians about the concepts related to the optics?

The study is expected to contribute to the literature by presenting opticians' knowledge level because examination of their understandings is believed to be important as they take place in the application part of this field.

## **Method**

In the present study, the conceptual understanding levels and misconceptions of opticians about Light and Optics were researched. A mixed method which was carried out by using the qualitative and quantitative data collection instruments together was utilized in the study. The qualitative part of the study is more dominant than the quantitative part. Hence, the study is also in qualitative dominant status. Details of the participants, data collection instruments and data analysis were explained below.

## **Participants**

The sample of the study was comprised of 203 opticians working at various optical stores located in a metropolis in the west part of Turkey. The sample of the study was determined via convenient sampling method (Teddlie & Yu, 2007). It was considered that the sample could be easily accessed by the participants during the study. The participants had a diploma proving their two-year degree. All of the participants took Fundamental Physics and Optic Physics courses during their university education period. 36% of the participants were females whereas 64% of them were males. Working period of the participants as opticians were determined as 1-4 years for 42% of them; 5-9 years for 19% of them; 10-14 years for 12% of them; 15 years and above for 27% of them. Also, 64% of the participants were aged 20-29 years whereas 26% of them were aged 30-39 years and 10% of them were aged 40 and above.

## **Data Collection Instruments**

Open Ended Questions, Concept Cartoons and Light and Optics Conceptual Evaluation Test were implemented to the participants in the present study. Data collection instruments were applied simultaneously. Those instruments are explained below.

### *Qualitative Data Collection Instrument: Open Ended Questions (Light and Image Formation) and Concept Cartoons*

Seven open ended questions and two concept cartoons related to light and image formation constituted the qualitative data collection instrument of the study. Five of the open-ended questions in this instrument were taken from the literature. The adaptation studies of those questions to Turkish language were carried out by Uzoğlu et al. (2013). Those questions were related to the subjects of light and image formation (questions 1, 7, 8, 9) and light and lighting (question 4). The rest of the open-ended questions (two open ended questions) were developed by Anderson and Smith (1986). Those questions were related to the subjects of reflection of light (questions 6) and light and image formation (question 3). Besides, two concept cartoons were also utilized in the qualitative data collection instrument. One of those concept cartoons (question 2) was developed by Keogh and Naylor (2004). Its adaptation study was also carried out by Uzoğlu et al. (2013). The other concept cartoon (question 5) was organized in the form of a concept cartoon by the researchers from a two-tier diagnostic multiple-choice test question (Anderson & Smith, 1986).

The questions in the qualitative data collection instrument were examined by two experts in physics education area. Several necessary changes were made on the questions in the light of the experts' opinions. Also, 20 opticians' opinions were asked in order to check the intelligibility of the questions. Data obtained from the open-ended questions and concept cartoons were examined by one of the researchers and categorized. The categories constructed for each question were presented with respect to their frequencies. The reliability of the data analysis was calculated by examining the inter-rater consistency obtained from the analysis of the data by the other two researchers. As a result, the inter-rater consistency was calculated to be 72%. The results of the analysis were presented in the form of tables.

### *Quantitative Data Collection Instrument: Light and Optics Conceptual Evaluation Test*

Light and Optics Conceptual Evaluation Test developed by Sokoloff (2006) was utilized as the quantitative data collection instrument in the study. The test was developed in terms of a project - Learning in Optics and Photonics which aimed to improve the quality of optics teaching in developing countries (Sokoloff, 2006). A total of 51 questions took place in the test. Fifty of the questions were in the form of multiple test questions whereas one of them was related to image drawing. The questions in the test were related to image formation, reflection, refraction, lenses, polarization, diffraction, interference and shadow formation. The adaptation studies of the test to Turkish language were carried out by Ahçı (2012). In this adaptation study, the Cronbach Alpha value was found to be .630. The difficulty index of the questions in the test varied between .14 - .77. Only four of the questions in the test were determined to have a difficulty level .50 and above whereas the rest of the questions' difficulty index stayed below .50. The questions in Light and Optics Conceptual Evaluation Test were categorized according to the subjects. The percentages of average correct were presented in the form of a table.

## **Findings**

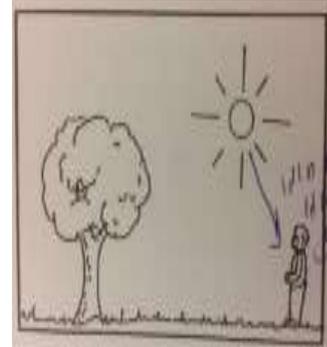
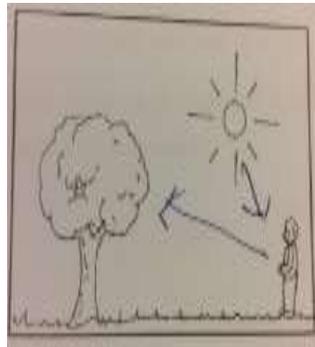
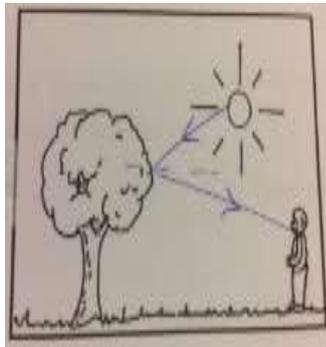
Analyses of the data obtained from the qualitative and quantitative data collection are presented separately and the findings are interpreted below.

### **Findings Obtained from Qualitative Data Collection Instrument**

Table 1 presents the percentage distribution of the opticians' responses to the open-ended questions and concept cartoon related to the image concept. The findings on Table 1 indicate that more than half of the participants give correct responses to the question 1. On the other hand, various opticians are identified to hold the following misconceptions or deficiencies related to the concept of image formation: Image is formed with the help of rays emitted from the object. Additionally, less than half of the participants give correct responses to question 2. Responses other than the correct ones also demonstrate the following misconception among the opticians: Image is formed with the help of the rays emitted from the object. Besides, less than half of the participants give correct responses to the question 3. It is seen that about half of the opticians do not respond to that question since it is related to making a drawing. Also, several drawings cannot be collected under a category. Responses given to that question indicate the following misconceptions and deficiencies among the opticians: (i) Falling of light on an object is enough for image formation. (ii) Falling of light on eye is enough for image formation.

Table 1. Findings related to the image concept

Question 1 (Pictorial Open-Ended Question): Can we see a piece of white and black paper in a room which gets no light from the outer environment and has no light source in it?	
Opticians' Responses	%
Neither piece is seen. *	53
In dark, white piece of paper is seen.	30
In dark, black piece of paper is not seen but white is seen.	15
Not coded or no response	2
Total	100
Question 2 (Concept Cartoon): Can you see a white cat and its eyes in a room which gets no light from the outer environment and has no light source in it?	
Opticians' Responses	%
The cat and its eyes are not seen. *	44
In dark, the white cat is not seen but its eyes are seen.	31
The cat is seen.	21
Not coded or no response	4
Total	100
Question 3 (Pictorial Open-Ended Question): How do we see a tree in a sunny day?	
Opticians' Responses	%
Not coded or no response	48
Image of tree is formed by reaching of sun rays to the eye via their reflection on the trees.*	27
Image of tree is formed by reaching of sun rays to the tree via their reflection on the eye.	13
Image of tree is formed by reaching of sun rays to the eye.	12
Total	100

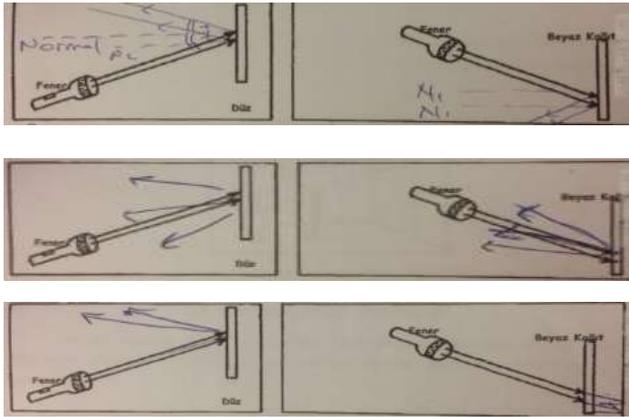


\*indicates the correct responses.

Table 2 demonstrates the percentage distribution of the opticians' responses to the open-ended questions and concept cartoon related to the light concept. Table 2 signifies that question 4 is responded correctly or partially correctly by very few opticians who attend the study. From the responses, it is figured out that various opticians hold the following misconceptions and deficiencies related to the concept of light: (i) Light rays reach more distant points as the surface of light source becomes smaller. (ii) Light rays reach more distant points as the surface of light source becomes larger. Besides, question 5 is responded correctly by less than half of the participants. Responses obtained demonstrate the following misconception and deficiencies among the opticians: (i) Light rays make objects visible by brightening them. (ii) Light rays allow image formation by filling up an environment.

Moreover, very few participants make correct drawings for the question 6. Similar to the question 3, it is seen that nearly half of the opticians do not respond to that question since it is related to making a drawing. Also, several drawings cannot be collected under a category. Responses given to that question indicate the following misconceptions and deficiencies among the opticians: (i) Light rays are reflected in a diffused way from reflective planes. (ii) Light rays are reflected from reflective planes, but they pass through white planes. (iii) Light rays are reflected from reflective planes, but they are absorbed by a piece of white sheet.

Table 2. Findings related to the light concept

Question 4 (Pictorial Open-Ended Question): What can you say about the lighting distance and lighting width of two different size torches with identical bulbs?	
Opticians' Responses	%
Bigger torch lights greater area, smaller torch lights more distant place.	50
Not coded or no response	18
Bigger torch lights wider area than the smaller torch. **	14
Bigger torch reaches more distant points than the smaller torch.	10
Smaller torch reaches more distant points than the bigger torch.	7
Both torches light the same distance but bigger torch lights a wider area. *	1
Total	100
Question 5 (Concept Cartoon): A girl switches on a lamp in a dark room. What happens?	
Opticians' Responses	%
Light released from the lamp hits on the objects in the room and the images of the objects are formed. *	39
The lamp lights the room (brightens).	26
Not coded or no response	26
Light continues to be released from the lamp until it fills in the room totally. It does not move after it has filled in the room.	9
Total	100
Question 6 (Pictorial Open-Ended Question): What happens to a beam of parallel light rays which fall with the same angle on a smooth and reflective plane and on a thick piece of paper?	
Opticians' Responses	%
Not coded or no response	49
Light rays are reflected in a scattered way from the surface of smooth plane and white paper.	15
Incident and reflected rays on both surfaces make the same angles with normal. *	13
Light rays are reflected on the smooth plane. They pass through the white paper.	14
Light rays are reflected on the smooth plane. They are not reflected on white paper (absorbed).	9
	
Total	100

\*indicates the correct responses. \*\*indicates the partial correct responses.

Table 3 shows the percentage distribution of the opticians' responses to the open-ended questions related to Sun, star and space concepts. When Table 3 is examined, it is seen that about half of the opticians give correct responses to the question 7. On the other hand, about an equal percentage to correct responses is found not to respond to that question or the responses cannot be collected under a category.

Responses given to the question 7 show the following misconceptions and deficiencies related to the concept of light sources among the opticians: (i) Stars are not light sources. (ii) Stars are seen with the help of the reflection of rays that fall on them. Moreover, very few opticians are determined to give correct responses to the question 9. Those responses indicate the following misconceptions and deficiencies: (i) The reason of the fact that space is dark stems from the insufficiency of star and sun light for lighting such a huge area. (ii) Space is in black color.

Table 3. Findings related to the concepts of light resources (Sun and stars) and space

Question 7 (Pictorial Open-Ended Question): How do we see the Sun?	
Opticians' Responses	%
Sun is a light source. The image of Sun is formed by reaching of Sun light to our eyes.*	45
Not coded or no response	40
We can see thanks to the reflection of the Sun rays.	9
We can see it because it lights its surrounding.	6
Total	100
Question 8 (Pictorial Open-Ended Question): How do we see the stars?	
Opticians' Responses	%
Stars are light sources. The images of stars are formed by reaching of star light to our eyes.*	51
Stars reflect the light which falls on them.	28
Stars do not emit light.	16
Not coded or no response	5
Total	100
Question 9 (Pictorial Open-Ended Question): How is space seen?	
Opticians' Responses	%
Not coded or no response	49
Space is dark.	18
Light emitted by the stars and the Sun is not sufficient to light the space and so the space is dark.	13
Space is black.	12
Reflection of the light emitted by the light sources, Sun and stars does not take place in the space since there is no matter in space. Hence the image of space is not formed. *	8
Total	100

\*indicates the correct responses.

### Findings Obtained from Light and Optics Conceptual Evaluation Test

Table 4 shows the distribution of average correct responses of the opticians to Light and Optics Conceptual Evaluation Test.

Table 4. Findings related to the subjects of light and optics

Subject	Average Correct Response (%)	Subject	Average Correct Response (%)
Characteristics of images on concave and convex lenses	38	Image formation on concave and convex lenses	40
Focal lengths of concave and convex lenses	23	Polarization	27
The law of refraction	35	Interference and diffraction	38
Refractive error	68	Shadow formation	31
Image formation on plane mirror	45	Total Average	38

According to Table 4, it is seen that the ratio of correct responses of the opticians related to the subjects of Light and Optics were low. The ratio of correct responses is under 50% except from one subject (refractive error). The subjects with the least correct responses related to the Light and Optics subjects are as follows: The focal lengths of concave and convex lenses, polarization. The subjects with the highest correct responses belong to the subjects of refractive error and image formation on plane mirrors. When the responses of the opticians are examined in detail, the following findings which indicate several problems are reached.

*Image Formation on Plane Mirror:* Opticians experience difficulty in drawing the place of the image on plane mirrors with the help of rays sent to the mirror. They think of the following points at this respect (i) The image on plane mirror forms in front of the mirror. (ii) The image is smaller than the object (iii) The place of the image changes due to the change of the position of the observer. (iv) The image of the object gets smaller as the object moves away from the mirror.

*Focal Lengths of Concave and Convex Lenses:* Opticians experience difficulty in comprehending the relationship between the optical power of a lens and its geometric shape. They think of the following points at this respect; (i) The optical power and magnification of plano-convex/plano-concave lenses are bigger than

biconvex/biconcave lenses. (ii) The focal length of plano-convex/plano-concave lenses is shorter than biconvex/biconcave lenses. (iii) The optical power of concave lenses increases as the edge thickness decreases. (iv) The focal length of concave lenses decreases as the edge thickness decreases. (v) A plano-convex lens is used for the refractive error of myopia.

*The Law of Refraction:* Opticians do not consider Snell's Law for explaining the transition of the rays from one medium to another with different refractive indices. They think of the following points at this respect (i) The rays coming from a medium with a larger refractive index passes to a medium with a smaller index by approaching to the normal or they pass without refraction (ii) The light rays refract by moving away from the normal in the media with the same refractive indices. (iii) Light rays which travel from one medium to another with the same refractive indices make total internal reflection.

*Refractive Error:* Refractive error constitutes the subject with the highest ratio of correct responses obtained from the opticians. Despite this finding, several opticians think that convex lenses are used for the improvement of the refractive error of myopia and concave lenses are used for the improvement of the refractive error of hypermetropia.

*Characteristics of Images on Concave and Convex Lenses:* The opticians do not consider the lenses equations in solving the questions related to image formation in concave and convex lenses. They think of the following points at this respect (i) A reverse image is formed in a concave lens (ii) A reverse image is formed when an object is located between the focal point and center of a convex lens (iii) An image which is bigger than the object is formed when an object is located beyond  $2F$  of a convex lens.

*Image Formation on Concave and Convex Lenses:* It is realized that opticians do not possess sufficient experimental experience related to the images in concave and convex lenses. The following aspects are determined from the responses of the opticians to the questions related to reverse image formation in convex lenses: (i) A brighter and smaller image is formed as the screen on which the image fell is moved away from the lens. (ii) The image totally disappears when the optics center of the lens is covered with an opaque circular tape. (iii) When the object is moved away from the lens and the image on the screen is clarified, a new image which has the same height with the previous image is obtained.

*Polarization:* It was realized that opticians have insufficient knowledge related to the ideal polarized filters. Low levels of correct responses are obtained especially from the question related to the polarization of light in blurred liquid. The opticians think that (i) three quarters of a beam of un-polarized light passes from the polarized filter. (ii) the total amount of vertical polarized light passes from a horizontal polarized filter.

*Interference and Diffraction:* The principle of superposition and the concept of phase are not fully comprehended by the opticians. The study shows the following aspects (i) the opticians cannot determine the constructive and destructive interferences formed by two wave sources correctly. (ii) They think that central bright band will decrease as the slot width decreases in the diffraction experiment.

*Shadow Formation:* The opticians give correct responses to the question which is related to image formation by a point light source passing through a triangular gap. On the other hand they are found to give incorrect responses to a similar question related to a thin and long light source. It is thought that the image formed by a thin and long light source when it passes through a triangular gap is trapezoid and reverse.

## Discussion and Conclusions

The results of the present study indicate that opticians possess low levels of conceptual understanding related to optics concepts in addition to having various misconceptions and insufficient learning (Ahçıl, 2012; Dervić et al., 2019; Epik et al., 2002; Goldberg & McDermott, 1987). Insufficiencies of the opticians' knowledge are mostly related to the speed of light. It is realized that opticians do not have the knowledge that light travels with a speed which is independent from its source. Opticians indicate that the path covered by light is related to the magnitude of the light source (Djanette & Fouad, 2014). Besides, it is reached that opticians have insufficient knowledge related to natural light sources (Epik et al., 2002; Uzoğlu et al., 2013). It is determined that opticians frequently think that Sun and Stars are not light sources and they reflect the light which falls on them (Uzoğlu et al., 2013). Also, they explain the reason of the darkness of the space as the insufficient amount of light emitted by the light sources such as Sun and the stars and thus a black color is produced in the space. Another problem determined in the study was that opticians do not explain the image formation in the objects which are not light

sources with the help of reflection of light (Uzođlu et al., 2013). Additionally, the opticians think that light is reflected in a diffused way on plane reflective surfaces. According to that view, a beam of incident rays coming to a smooth surface with a definite angle are totally reflected from that surface. On the other hand, they are not reflected from a white piece of sheet and they pass through the sheet (Anderson & Smith, 1986). The fact that opticians do not comprehend the concepts of reflection and image formation stem from the misinterpretations on image formation. They explain the cause of image formation with the help of rays emitted from the objects which reach eye; brightening or shining of eye by light (Şen, 2003; Anderson & Smith, 1986).

As well as the misconceptions and insufficiencies in learning, the study also indicates that opticians have high levels of learning related to refractive errors which are directly related to their profession. However, it is seen that their learning related to focal length of concave and convex lenses and polarization which are also directly related to their profession is not in sufficient level (Thapa & Lakshminarayanan, 2013). It is astonishing that the opticians know the applications of lenses despite the fact that they do not know those instruments and their characteristics. The reason of that fact can be interpreted as follows. They have learnt about the lenses which they use for refractive errors with the help of memorization of knowledge due to the experience in their profession. Also, the opticians have low levels of learning related to the polarization of light (Thapa & Lakshminarayanan, 2013). When the questions related to that subject are examined, it is seen that the ratio of giving correct responses is high for polarized glasses question. The reason of those responses might be the memorization of the polarization of the sun glasses which results from their professional experiences. Besides, they do not fully comprehend the electromagnetic wave structure of light and the function of polarized filters.

Another result obtained from the study is that the opticians have difficulty in understanding the relationship between the optical power of the lens and its geometric shape. Accordingly, it is realized that the opticians think that a thin lens has more optical power than a thick lens. The reason of that response can be explained as follows: The surface of glass lenses which is more distant to the eye is smooth. The optical power of a pair of glasses is supplied with the help of sphericity brought to the surface which is closer to the eye. Thus, the opticians respond to the questions related to the optical power of the lenses by marking the lens which looks like the glasses' lenses most in shape. Opticians think that optical power increases as the edge thickness of a concave lens decreases. Besides, it is found out that opticians think that myopia can be eliminated via convex lenses. Those incorrect responses might stem from the effect of memorization knowledge related to refractive errors and the use of lenses at this respect. Moreover, it is determined that the opticians have incorrect views related to image formation in concave and convex lenses. The opticians cannot explain the change in image when the location of the lens or object is changed after an image is obtained from the lens. That situation might be related to not having sufficient experimental experience on image formation in concave and convex lenses (Goldberg & McDermott, 1987).

In the study, it is realized that conceptual understanding levels of opticians related to image formation on plane mirror is better than various other subjects similar to the results of Ahçı's (2012) study. On the other hand, it is determined that the opticians cannot make correct drawings related to reflection of light rays from a smooth reflective surface similar to the results of Anderson and Smith's study (1986). The reason of the fact that the opticians solve the questions related to drawing of image on plane mirrors correctly despite not drawing image on smooth plane surfaces might stem from the effect of their daily life experiences and intuitive responses (Goldberg & McDermott, 1987). Also, their inability to draw image on plane mirror results in experiencing difficulty for determining the shape and magnitude of the image on plane mirror and giving incorrect responses to the multiple-choice test (Epik et al., 2002). In sum, when the results obtained from the study are considered in a general manner, it can be concluded that the conceptual understanding levels of the opticians related to optics which are directly related to their professions are low. They are required to reach a better conceptual understanding level on the aforementioned subjects in order to adapt their profession's future status which consider eye health and gain a specific structure with the recent innovations in the technology (Thapa & Lakshminarayanan, 2013).

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