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TURKISH STUDENTS' MENTAL MODELS OF LIGHT TO EXPLAIN THE SINGLE SLIT DIFFRACTION AND DOUBLE SLIT INTERFERENCE OF LIGHT: A CROSS – SECTIONAL STUDY

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Abstract. *In this study, it was tried to explore mental models of light utilized by the Turkish students for the explanations of single-slit diffraction and double-slit interference of light. This research has been carried on the group of 294 students made up of 175 introductory and 119 advanced level students studying in the departments of engineering, physics and physics teachers at a Turkish University. Open - ended questions pertaining drawings and explanations were used as data collection tool. As a result of quantitative and qualitative analysis, three mental models which were named as wave, ray and particle being used by the students while explaining these subjects, were described. Serious difficulties were observed towards the usage of these models for the both levels of the student groups and some differences were indicated between the introductory and advanced level university students in terms of usage of these models.*

Key words: *double slit interference, light models, mental models, single slit diffraction, students' alternative ideas.*

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Introduction

"Scientific models are the foundations of science and they constitute the most rationalized notions for the world." (Raftapoluos et al., 2005, p.654). Because of the abstract nature of science, it entails an analogous explanation and scientific models to observe the phenomena (Park, 2006). Light is an extraordinarily interesting phenomena as well. Scientific understanding of the nature of light requires the comprehension of two dominant scientific models of light, namely the wave and particle models. The wave model which is also known as the physical optics model, describes propagation of light energy similar to ocean waves move through the water. The particle model for light which is also known as the quantum optics model, explains light as tiny packets of energy termed photons. Besides of these two scientific models, the geometrical model (ray model) could be considered much more as the teaching model widely use in optics teaching. The ray is a geometrical construction that gives the direction of propagation of light that can be imagined as a wave or particle (Hubber, 2006).

Most of time, students come to their classes with ideas which do not match with understanding of scientific models. Some ideas that are contradictory to scientific facts are known misconceptions. The studies related to misconceptions (alternative ideas) introduce the 'mental model' term in science education (Çepni & Keleş, 2005). "A mental model is an internal representation which acts out as a structural analogue of situations or processes." (Greca & Moreiro, 2001, p.108). Greca and Moreira (2001) stated that comprehension of a scientific theory requires the construction of mental models. Norman (1983) stated that ideally there is a simple and linear relation between a conceptual model and a mental model.

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So, the analysis of mental models can give us useful information about the understanding of students' perception and learning (Park 2006). Duitt and Glynn (1996) stated that meaningful learning depends on the evaluation of the students' mental models formed by their conceptual models. Mental models can offer valuable information about the learners' conceptual framework in science education (Coll & Treagust, 2003). Witmann (2001) mentioned that models of student reasoning should give us information about developing of student understanding over the instruction. Beside of this, Wittman and et al. (1999) stated that, students' mental models are often inconsistent with scientific data.

Investigations have showed that alternative understanding of light phenomena constructed by students was different from scientific models (Bendall et al., 1993; Galili et al, 1993; Galili & Lavrik, 1998; Goldberg & McDermott, 1986). Student often misinterpret the role of light rays in optical phenomena (Galili & Lavrik, 1998). Hubber (2006) reported on the longitudinal investigation three types of year 12 students' mental model of the nature of light during the explaining of various light phenomena (colour, refraction, diffraction, photoelectric effect etc.). During an investigation of student understanding of physical optics researchers (Ambrose et al., 1999b; Steinberg et al., 1996) also found that students use of a hybrid model with elements of geometrical and physical optics. These different conceptions of the students hinder them to make appropriate connections between the important physical phenomena and the scientific models of light. Interference and diffraction of light which are the subjects of this work are the important physical phenomenon. These phenomena are explained by the wave model of the light, but the research indicated that many students have the lack of understanding of the nature of light as an electromagnetic wave (Ambrose et al., 1999a).

The literature regarding to students' understanding of the nature of interference and diffraction of light is not adequately comprehensive. Nevertheless, some important studies investigated students' understanding of the nature of interference and diffraction of light. These studies indicated that many students do not have a functional understanding of the wave model that they can apply to predict and explain interference and diffraction effects (Ambrose 1999; Wosilait 1996; Wosilait et al., 1999) and have a number of serious difficulties with important concepts in physical optics, such as path length difference, and phase difference, and the relationship between them (Ambrose et al., 1999b). The students don't use concepts of phase and the amplitude in superposition principles correctly, confuse temporal and spatial coherences and have difficulties about concept of coherence (Romdhane & Maurines 2003, 2005). The other two studies, which have some disagreements, focused on how students understand situations which involve both geometrical optics and wave optics, showed that connecting these models and their application seems to be very difficult for students (Colin & Viennot 2001; Maurines 1999).

The studies in the related literature tried to put forward the students' perceptions towards interference and diffraction through the prediction of the related patterns. However, this situation may prevent students, who even had ideas of interference and diffraction, from thinking of principle of physical optics and may direct the students using the principle of geometrical optics. This situation, may constrain the students' ideas on explanation of how the patterns of interference and diffraction occur by making them perceive the question as the question of geometrical optics despite the special conditions for the slits and the wavelength of the light given.

Moving form these ideas the purpose of this study is to understand primarily the students' mental models of light to explain diffraction from single slit and interference from double slit. In addition, it was also aimed to find out the students' understandings about these models to explain the double slit interference and single slit diffraction patterns, and at last it was tried to compare the introductory and advanced level university students with respect to the above mentioned aspects. Therefore, the forms of questions as data collection tools were changed in this study to be different from the ones stated in the literature. Instead of guessing the patterns being formed on the screen, formed patterns were shown to the students and they were asked how these patterns were formed. So this study indicated certain forms in detail than being stated in the literature for the different forms of models were used by the students. Besides, this study brings an additional contribution with respect to having views about these phenomena for the different level students.

Methodology of Research

Sample

The context of sampling for this study was made of the total of 294 students studying in the departments of environment and mining engineering, physics, and physics education at a state university in Turkey. These students came from the different high schools applying common educational programme.

The group of students named as the introductory level (IL) students (17-19 age) has not never taken optics, vibration and waves, modern physics and quantum physics at the university level, and besides interference and diffraction issues, they have not taken yet the other aspects of light at the university level. These students had the experiences on light models with the subjects of single slit diffraction and double slit interference at the last year of high school. This group consisting of 175 students is made up of the first year students from the departments of environment and mining engineering, physics, and physics education. A group of 119 students (19-22 age) who were described as the advanced level (AL), is made up of higher level students who had the experiences on light models at the university level. These students have taken the courses of optics studying at the second year physics, and vibration and quantum physics studying at the third and forth year physics with third, fourth and fifth year physics education departments. On the basic level, the aims of the physics instruction in high school and the university department thought physics in Turkey are similar to that of the developed countries.

Instrument

The survey method was used in this current investigation. Since the samples were from the group of students consisting of two different educational levels as introductory and advanced, this work is a cross – sectional study. "A cross-sectional study is one that produces a 'snapshot' of a population at a particular point in time." (Cohen et al., 2001, p.175). Two open-ended questions were used for this study in terms of in-depth study and we implemented a large number of students for generalization.

These questions are towards how the patterns of the double slit interference and single slit diffraction given on the screen occured. In these questions, the researcher did not focus on Fourier optics. Instead, the questions focused on a different situation, when diffraction and interference are observed in the absence of lenses.Three experts evaluated the questions for their content validity and they approved that the questions were directly related to the objective of the investigation. In the questions, students were asked to draw the required shapes between the slit and screen, and explain their drawings. The students' drawings and explanations provide much and extensive information about students' difficulties (Ambrose et al., 1999b; Çepni & Keleş 2005; Wosilait et al., 1999).

Data Analysis

The data were analyzed quantitavily and qualitatively. Firstly, the common drawings and explanations were collected under three different mental models. In order to form these groups, it was inspired from the scientific light models and the works of Hubber (2006). The limitations of which drawings collected under which mental models were given in Table 1. Secondly, these data were labeled as understanding, misunderstanding and no understanding (Abraham et al., 1994; Çepni & Keleş, 2005). Wave Model and Beam Ray Model was thought as understanding with a scientifically correct explanations, all of the models was thought as misunderstanding with a scientifically uncorrect explanations and all of the irrelevant or unclear responds was thought as no understanding. Lastly, the students' explanations which labeled as misunderstanding were categorised in more general description and given in the tables under the title of alternative ideas. The analysis was repeated after three months to assure qualitative research reliability. The level of agreement between the two analysis processes was 0.95.

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Table 1. Mental models of light utilized by the students in order to explain single slit diffraction and double slit interference and limitations on the models.

Mental models of light	Limitations of the models
Wave model (WM)	Light must travel out from a luminous object like water waves in all directons from a central point.
Beam ray model (BRM)	Light must travel out from a luminous object like thin beams called rays. Light must travel out from a luminous object like continuous sinus waves which have same properties of rays.
Particle model (PM) / Particle ray model (PRM)	Light must travel out from a luminous object like particles. Rays or sinus waves constitute streams of particles

Results of Research

In this section, the data collected with open-ended questions were analyzed as quantitatively and qualitatively. Interference and diffraction patterns in Questions were shown in color in the original survey. Since the original survey contained Turkish descriptions on the figures, the figures were redrawn by hand in this section.

Mental Models of Light Used by Students to Explain Single - Slit Diffraction Phenomenon of Light

Question: The pattern, with a red laser source and single slit, is shown in the figure below. a) Could you remember this pattern? b) How does the pattern on the screen occur? Explain the reasons for your answer and demonstrate your answer with drawings by using propagation of light between slit and screen.

At the first stage of this question (Question 1a); 146 introductory level students out of 175 and 115 advanced level students out of 119 stated that they could remember the pattern. Finally, those student answers to Question 1b were analyzed. Table 2 gives which models were used while introductory and advanced level students were explaining the single-slit diffraction. This table also gives the understanding level of these students with the percentages.

Table 2. Students' mental models and understanding level about single slit diffraction.

	Students' level	
	Introductory level (f_{IL}=146) %	Advanced level (f_{AL}=115) %
Understanding		
Wave Model	-	4
Misunderstanding		
Wave Model	22	39
Beam Ray Model	56	55
Particle Model	12	-
No understanding	10	2

As seen from Table 2, only the some usage of wave model was indicated as "understanding". Misunderstandings were intensified in beam ray model, wave model and particle model, respectively. In both level, most of the students used the ray model to explain diffraction. The advanced level students used wave model with 43%, while the introductory level students used same model with 22%. However, only 4% of the advanced level students who used wave model were in understanding level.

In order to explain diffraction, the students used the wave model in three different ways (Figure 1).

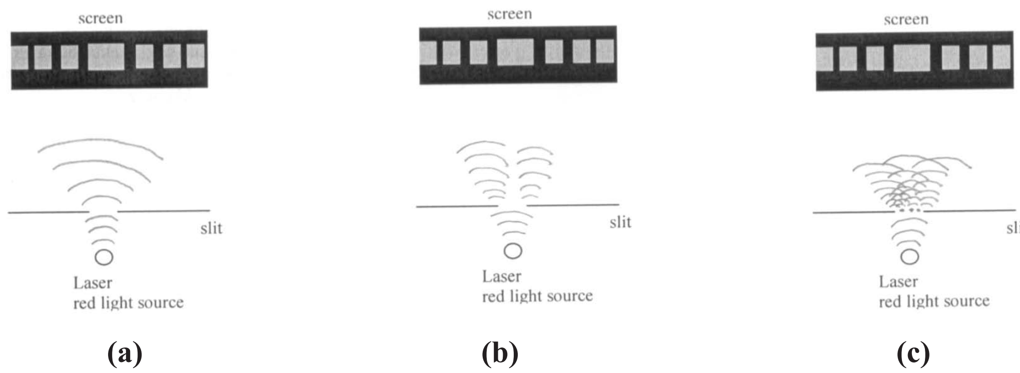

Figure 1. Diagrammatic descriptions of a wave model used by students to describe single slit diffraction.

The students' alternative ideas which were categorised by taking into consideration their explanations about their drawings were presented in Table 3. Also, which figures the introductory and advanced level students drew to exspress the pattern was showed with frequency distrubition.

Table 3. The students' alternative ideas about their drawings in Figure 1.

Students' Alternative Ideas	f_{IL}	f_{AL}
Fig 1a	**28**	**35**
Single slit behaves a pointlike source.		
Single slit can only form single image.		
Fig 1b	**4**	**3**
Scattering can only be formed at the edges of slit.		
Fig 1c	**-**	**11**
Each wave spreading out from pointlike sources on a single slit forms single fringe.		

Students used the beam model in four different ways to explain diffraction (Figure 2).

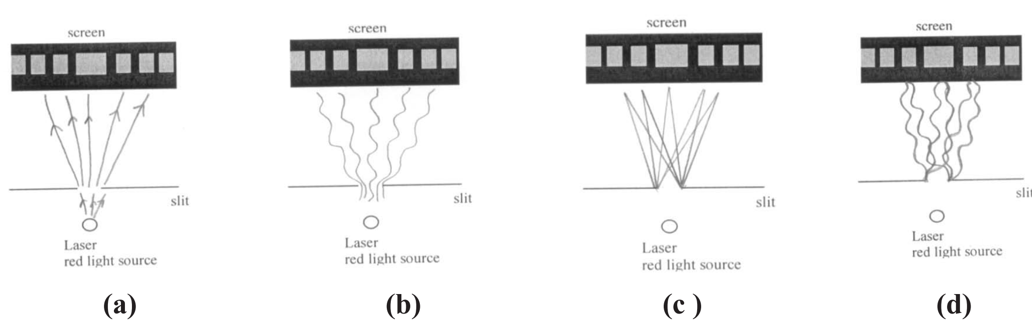

Figure 2. Diagrammatic descriptions of a beam ray model used by students to describe single slit diffraction.

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The students' alternative ideas categorised by taking into consideration their explanations about their drawings was presented in Table 4. Also, which figures the introductory and advanced level students drew to exspress the pattern was showed with frequency distrubition. While the students showed rays as straight lines in the figure (a), they showed them as sinus waves in the figure (b). Interpretation showed that these two drawings were used in the same way.

Table 4. The students' alternative ideas about their drawings in Figure 2.

Students' Alternative Ideas	f_{IL}	f_{AL}
Fig 2a / 2b	**45/22**	**20/15**
The rays represent brightness and the places in between two rays are darkness.		
Wave crests represent the bright area; wave troughs represent the dark area.		
Fig 2c / 2d	**7/8**	**12/16**
Overlapping of waves can only form bright area.		
Overlapping of two wave crests forms bright area and overlapping of two wave troughs forms dark area.		

In order to explain diffraction, the students used the particle model in two different ways (Figure 3).

(a) (n_{IL}= 7 ; n_{AL}= -)   (b) (n_{IL}= 11; n_{AL}= -)

Figure 3. Diagrammatic descriptions of a particle model used by students to describe single slit diffraction.

As seen from Figure 3, none of the advanced level students used PM model. The alternative ideas of introductory students who make explanations about Figure 3 could be summarized in words; "the regions where particles hit the screen are brightness.".

Mental Models of Light Used by Students to Explain Double – Slit Interference Phenomenon of Light

Question: The pattern, with a red laser source and a double- slit, is shown in the figure below. a) Could you remember this pattern? b) how does the pattern on the screen occur? Explain the reasons for your answer and demonstrate your answer with drawings by using propagation of light between slits and screen.

At first stage of this question (Question 2a); 157 out of 175 introductory level and 116 out of 119 advanced level students stated that they remembered the pattern. Finally, those student answers to Question 2b were analyzed.

Which models were used by introductory and advanced level students while explaining the double –slit interference were given in Table 5. This table also gives the understanding level of these students with the percentages.

Table 5. Students' mental models and understanding levels about double- slit interference.

	Students' level	
	Introductory level (f_{IL}=157) %	Advanced level (f_{AL}=119)
Understanding		
Wave model	16	48
Beam ray model	14	20
Misunderstanding		
Wave model	20	18
Beam Ray model	36	10
Particle model	8	-
No understanding	6	3

As seen from Table 5, the some usages of wave and beam ray model were indicated as "understanding". Alternative ideas were intensified in beam ray model, wave model and particle model, respectively. Although, in advanced level, most of the students (% 66) used the wave model to explain interference, in introductory level, most of the students (50%) used beam ray model. The advanced level students used wave model with 66%, while the introductory level students used same model with 36%.

In order to explain double slit interference, the students used the wave model in a single way (Figure 4).

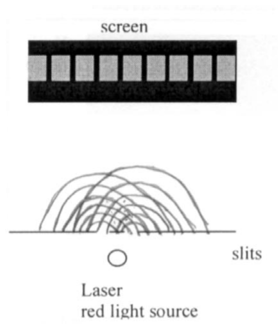

Figure 4. Diagrammatic description of a wave model to explain interference.

The students' alternative ideas about Figure 4 were presented in Table 6.

Table 6. The students' alternative ideas about their drawing in Figure 4.

Students' Alternative Ideas	f_{IL}	f_{AL}
Fig. 4	**57**	**79**
Overlapping of two wave crests forms bright area and overlapping of two wave troughs forms dark area.		
Overlapping waves cancel each other.		
The areas between the spherical surfaces are darkness.		

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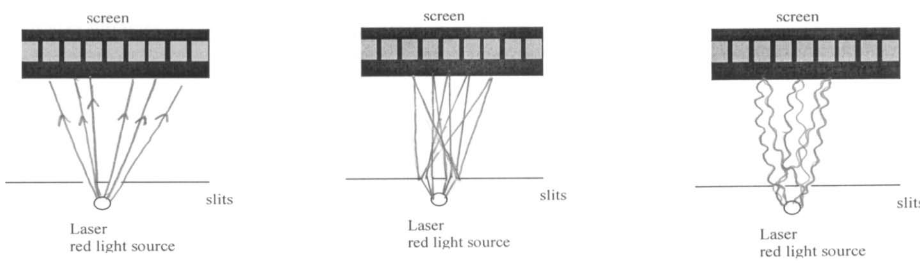
The students, who had utilized the 'ray model' along the limitations given in Table 1, used the 'ray model' in three different ways as shown in Figure 5.



(a) **(b)** **(c)**

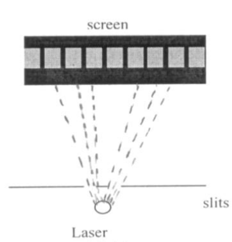
Figure 5. Diagrammatic description of a beam ray model used by students to explain interference.

The students' alternative ideas about Figure 5 were presented in Table 7. Some students using figure 5a reflected rays; some used rays as sinus waves. These were not shown on the figures but they were included in the alternative ideas.

Table 7. The students' alternative ideas about their drawings in Figure 5.

Students' alternative ideas	f_{IL}	f_{AL}
Figure 5a	**55**	**3**
The rays represent brightness and the places in between two rays are darkness.		
Light rays can not form the central bright area.		
The rays reflected from the screen form the pattern.		
Wave crests represent the bright area; wave troughs represent the dark area.		
Figure 5b/ 5c	**15/8**	**14/19**
Overlapping of waves can only form bright area.		
Overlapping of two wave crests forms bright area and overlapping of two wave troughs forms dark area.		

The students, who had utilized the 'Particle model' used only one drawing as shown in Figure 6.



(n_{IL}= 13; nAL= -)

Figure 6. Diagrammatic description of a particle model used by students to explain interference.

None of the advanced level students used PM model and the introductory students used the expressions of places bright where photons hitting the screen and the places dark in between photons in their explanations as in diffraction.

Discussion

In this study, it is investigated which mental models toward the nature of light introductory and advanced level university students had developed while trying to explain the effects of diffraction from single-slit and interference from double-slit, and how they formed and interpreted them.

As a result, the students were used three mental models of light while explaining the double slit interference and single slit diffraction. However, the advanced level students used the wave model more extensively than the introductory level students. So, the advanced students performed higher than the introductory students in terms of the understanding level. However, the findings indicate that the interpretations of these models by the students are quite different from the real scientific expressions and students used the models in a number of different forms. So, it was observed that the students had serious alternative ideas towards the nature of light. These ideas were intensified in the explanations of beam ray model for the both phenomena. At the end as it would be explained below, the very interesting results were observed and some of these results could contribute to the related literature.

From the analysis it was observed that the students preferred using the ray model during the explanations of single-slit diffraction phenomenon and in the phenomenon of double-slit interference mainly used the wave model. The very important reason of this is that the students did not explain single-slit diffraction phenomenon with the Huygens principle. As stated by Romdhane and Maurines (2003) students could not be divided a wide slit into point sources. This situation was the reason for many of the students using the wave model as in Figure 1a to consider single wide slit to behave like single point source, and it prevented them to explain the pattern by recognizing the effect of interference. Besides of this, while the certain part of the students was trying to explain diffraction pattern with the wave model, as it was shown in the work of Ambrose, et al. (1999b) they thought that waves come out of the sides of slits only (Figure 1b). Whereas the double-slit interference experiment contains directly the Huygens point sources, circler waves emitted from two point slits were permitted students to explain the pattern by putting forward the effect of interference without remembering the Huygens principle.

As it could be seen in Tables 2 and 5, the most important reason of the number of advanced level students being more compared with the introductory level students utilizing the wave model in order to explain both interference and diffraction phenomena and while the introductory level usually utilizing the ray model to explain both phenomena, is that the Huygens principle was not thought to them in the high school and it is because not considering circler waves formed by point sources.

However, explanations made for Figure 4 indicate that the students have serious reasonable difficulties with respect to explain interference with the wave model. At the students' explanations, it was observed that they did not realize wave troughs and wave crests in the used wavefronts and they only attached wave concept to their continuous lines drawn on wavefronts, and thought the places between the continuous lines are dark.

However, the drawings in Figures 2 and 5 indicate that the students from both groups had unscientific reasons in order to explain interference and diffraction with the ray model. The students made the similar drawings to explain both of two situations. The students, who had used this mental model to explain these phenomena, considered the space in between rays as dark since they had given the role of light to light rays. However some students considered as wave troughs are dark. The explanations of students indicate that sinus waves were assigned the same duty as rays. In these drawings while the introductory level students were drawing rays as in Figures 2a and 5a without thinking overlapping effects, the advanced level students often used Figures 2c, d and 5 b, c considering overlapping effects. Overlapping effects in Figures 2 c, d and Figure 5 b, c could mainly remembered by the students, but it was considered extensively that overlapping effects could only be for bright fringes and the places in between rays were thought to be naturally stayed dark through thinking of only drawn rays and sinus waves representing light. Also, some students thought overlapping of the wave throughs create darkness.

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Besides, it was observed that in order to explain interference and diffraction phenomena the particle model was a mental model which was preferred very little by the students and at all by the advanced level students. The reason of the advanced level students not utilizing this model may be that they have had modern physics courses and could understand the particle model explaining different light phenomena. Besides of this, the introductory level students, who had used the particle method, developed this model by drawing the rays (Figure 3 a and 6) and sinus waves (Figure 3b) with dashed lines, and they thought in a similar way as to the ray model. Since it is similar to the ray model, in reality as in the work of Hubber (2006), it could be named as the 'particle ray model'.

Conclusions and Implications

In general, the results of this research indicate that the students in both level while trying to explain the phenomena of interference and diffraction of light have developed very different mental models of light and in order to explain the phenomena they haven't got a functional wave model. This situation would prevent them to sense the nature of wave of the matter (Steinberg et al., 1996; Vokos et al., 2000). Students' mental model changes serve as the most important source covering learning processes and conceptual changes of them (Park 2006). For this reason, it is required to revise the fundamental optics teaching in order to realize the students to learn the light models effectively.

Although interference and diffraction phenomena have continuously been explained in terms of the wave model of light both at university and high school as well as in the source books, because during the explanations of these topics, rays have been used continuously without realizing that these would be just geometrical representations, these results are naturally not unexpected situation. This shortage appearing very simple pushes students to very mistakes with respect the conception of light and wave model. Several studies (Galili 1996; Galili & Hazan 2000) have shown that many difficulties may occur when using the ray model of light in teaching. Spherical wave surfaces should be used instead of light beams or sinusoidal waves to describe light propagation from source. Also, the wave fronts between slit(s) and pattern should be drawn and the interference should be shown while teaching the interference and diffraction subjects. This usage would prevent students from thinking geometrical optic laws in the physical optics subjects. Also, the water waves in ripple tank would be useful to describe the wave surface as a model for the light wave.

However, the educators should investigate students' understanding level about the light models in their optics instruction. In addition, they should use the proper instructional materials to overcome the alternative ideas of the students. It is hoped that the results of this study will help the educatiors to recognize the students' difficulties in both introductory and advanced levels. Besides, the studies about how students use the light models for explaining the other subjects in optics should be conducted.

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