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# Investigating students' mental models about the nature of light in different contexts

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## Abstract

In this study, we investigated pre-service physics teachers' mental models of light in different contexts, such as blackbody radiation, the photoelectric effect and the Compton effect. The data collected through the paper-and-pencil questionnaire (PPQ) were analyzed both quantitatively and qualitatively. Sampling of this study consists of a total of 110 physics education students who were taking a modern physics course at two different state universities in Turkey. As a result, three mental models, which were called the beam ray model (BrM), hybrid model (HM) and particle model (PM), were being used by the students while explaining these phenomena. The most model fluctuation was seen in HM and BrM. In addition, some students were in a mixed-model state where they use multiple mental models in explaining a phenomenon and used these models inconsistently. On the other hand, most of the students who used the particle model can be said to be in a pure model state.

Keywords: photoelectric effect, blackbody radiation, Compton effect, mental models, model states

## 1. Introduction

One of the basic aims of physics education is to enable students to learn about the concepts related to events they experience in daily life and the physical facts underlying the



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relationship between these concepts. Concepts related to events students directly or indirectly experience vary according to their structures and the way they occur. In this process, while it is always possible for some concepts to be experienced in daily life, for some it is impossible to understand without having prior knowledge on the subject. For example, we may experience directly the concept of gravity by the falling of a thrown object; however, it is not possible for us to experience or see the concepts related to atoms or the particulate structure of matter as clearly as we do the former example. We try to teach such concepts by drawing parallelism with daily life or with a known event. Usually, tools that are used to make these abstract and not-directly-observable concepts concrete are called models.

Students come to class with preconceptions that they have acquired through daily life experience (Bransford *et al* 1999). These ideas, which conflict with scientific facts, are known as misconceptions. These misconceptions students have and the new concepts they learn in class should be combined in order to turn them into scientifically-accepted knowledge (Bransford *et al* 1999, Donovan, *et al* 1999). Thus, physics education researchers should define these concepts by focusing on students' intuitive perceptions about the world (Dykstra *et al* 1992).

In addition to the different types of student difficulties, students' cognitive structures and mental model based studies are the topics that physics educators are investigating with high interest. Mental models have formed the focal point for physics education studies that are conducted to lay bare the way students define various scientific concepts and ideas (Hrepic *et al* 2010). Due to the abstract nature of the microscopic world that is formed by subatomic particles, investigating students' mental models and their comprehension level is highly significant in physics education (Ke *et al* 2005, Park and Light 2009). In a study by Park (2006), it was determined that students have different alternative mental models for atomic structure. In another study by the same researcher, students' conceptual development was analyzed using these mental models.

There is no consensus on the exact definition of a mental model; nevertheless, this term usually denotes people's internal representation which they shape via interaction with their environment (Van der Veer 2015). Therefore, in this study, we understand a mental model as 'an internal representation, which acts out as a structural analogue of situations or processes. Its role is to account for the individuals' reasoning both when they try to understand discourse and when they try to explain and predict the physical world behavior' (Greca and Moreiro 2001, p 108). According to Greca and Moreira (2001), in order for a scientific theory to be understood/comprehended, forming mental models is necessary. Norman (1983) indicates that there is a linear and simple relationship between a conceptual model and a mental model. Thus, examining mental models would give useful information about students' sentiment and learning (Park 2006). According to Duit and Glynn (1996), students' mental models are arranged by conceptual models and the changes taking place in mental models due to this arrangement provides meaningful learning. Mental models can also give significant information about students' conceptual frameworks in science education (Coll and Treagust 2003). According to Wittmann (2001), the models students form in their minds give educators information as to how students make sense of concepts. In addition to this, reasoning that the students make concerning the models also gives important clues as to whether these models are scientific or not (Steinberg *et al* 1999). Studies show that the alternative concepts that the students developed for light are different from scientific models (Bendall *et al* 1993, Galili *et al* 1993, Galili and Lavrik 1998, Goldberg and McDermott 1986). In a study (Hubber 2006) with six secondary-grade students, the models students use in explaining various physical phenomena such as color, refraction, diffraction, etc, were determined. Some researchers who study understanding of physical optics (Ambrose *et al* 1999a) determined

that students use a hybrid model in explaining phenomena related to geometric and physical optics. The conceptual variety that the students use in explaining these phenomena prevents them from drawing appropriate connections between physical phenomena and scientific models of light. In other studies about the interference and diffraction of light, it was determined that the models used by students to explain these phenomena do not match the scientific models (Ambrose 1999, Wosilait 1996, Wosilait *et al* 1999). Another finding obtained from these studies is that students do not have a functional understanding of the wave model which they use to explain the interference and diffraction effects of light. In another study by Ambrose (1999a), it was determined that students have many difficulties concerning path difference and phase difference, which are important concepts of physical optics.

### 1.1. Context dependence of mental models

Students' mental models might be context dependent (Didiş *et al* 2014, Wittmann, *et al* 2003, Schecker and Gerdes 1999, Bao and Redish 2006). In other words, students may use different, stable, and coherent explanatory schemas when they explain a phenomenon related to the same concept, but they put it forth via different contextual settings. In order to examine the context dependency of such reasoning, it is necessary, first of all, to have a clearly defined context boundary. An important question at this point is when two situations would be thought in sufficiently different contexts. In the literature, problem situations which are considered to be different by non-experts and equivalent by experts are usually thought to be different contexts. Or, the difference between variable and situations should be expressed conceptually or verbally. Accordingly, situations differently represented to students (pictorially or otherwise) were also considered different contexts (Didiş *et al* 2014, Hrepic *et al* 2010).

## 2. Research focus

So far, studies on light have been conducted on students' mental models and conceptual difficulties concerning such phenomena as reflection, refraction, diffraction, and interference. The motivation behind this study is to disperse the lack of studies on different physical phenomena related to light, because blackbody radiation, the photoelectric effect and the Compton effect, which are the subjects of this work, are the other important physical phenomena apart from diffraction and interference of light in modern physics. In this sense, the diffraction of light and the interference of light are explained by the wave model of light. The other phenomena mentioned above are explained by the particle model of light. Taking its cue from these ideas, the purpose of this study is to understand primarily the students' mental models of light to explain blackbody radiation, the photoelectric effect, and the Compton effect. Additionally, the aim was also to reveal how students use light-related models in explaining physical phenomena. To this end, questions used as data gathering tools were prepared for each context in accordance with the nature of the study.

As such, this study puts forth in detail the different forms of models used by students related to physical phenomena which have not been studied previously in the literature.

Thus, this study attempted to answer following questions.

1. What mental models do students have about the nature of light to explain various phenomena?
2. Do students' mental models about light change with context?

### 3. Methodology of research

#### 3.1. Sample of research and description of the course setting

In this study, a purposeful sampling method was used. The use of a purposeful sampling method makes possible an in-depth study of situations that are rich in information; thus, the questions this study focuses on will be clarified better (Patton 2002). Sampling of this study consists of a total of 110 (77 female and 33 male) physics education students who were taking a modern physics course at two different state universities in Turkey. All students participating in the study graduated from high schools that have similar curricula. The students, aged between 20 and 23, had taken university level courses covering the topics of modern physics, quantum physics, or any other topic related to other aspects of light. The modern physics and the quantum physics courses were taught using traditional teaching methods. The instructional methodology of these courses was mainly instructor-centered. Instructional techniques such as analogy, questioning, and examples from daily life were not employed to enrich these lessons. Modern physics is a three-hour a week course in the spring semester, and quantum physics is a four-hour a week course in the fall semester; both of them are 14-weeks long in total.

#### 3.2. Instrument and procedures

The survey method was used in this study. It was conducted by surveying 110 third year university students to determine their mental models of light in different contexts, such as blackbody radiation, the photoelectric effect and the Compton effect. A paper-and-pencil questionnaire (PPQ) was prepared after a literature review and using related textbooks (Bernstein *et al* 2000, Dereli and Verçin 2000). The difficulty level of the questions, which were prepared by the researcher and their appropriateness for students' level, was checked by two experts who have worked in physics and physics education. These two experts evaluated several proposed questions for their content validity. So five open-ended questions were selected for inclusion in the survey. With the first question of the study, the aim was to determine student awareness related to scientific theories of light. In the other four questions, students were asked to explain different light-related phenomena by way of drawing, because student drawing and explanations give thorough information about their mental models and learning difficulties (Ambrose *et al* 1999a, Çepni and Keleş 2006, Wosilait *et al* 1999). The students completed the PPQ under examination conditions during a class lasting 40 min.

#### 3.3. Data analysis

The data obtained from the PPQ were analyzed quantitatively and qualitatively by the researcher. As the aim in this study was to determine students' mental models about different light-related phenomena, during the analysis process four different contexts were analyzed among themselves, and no generalization was made in students' reasoning with other contexts. Therefore, students' mental models for each context were determined and as such whether models are context-dependent or not was easily determined. First of all, frequently used drawings and descriptions were gathered under three different mental models. Light-related models used in Smit and Finegold (1995), Hubber (2006) and Şengören (2010) inspired the decision as to which mental model the explanations of students fit. The descriptions as to which drawings and explanations were collected under which mental models were given in table 1. If there is no consistency between the students' explanation and drawings, then the drawings were taken into consideration. For instance, if the student uses

**Table 1.** Scheme for analyzing students' mental models of light and descriptions of the models.

Light models	Descriptions of the models
Hybrid model (HM) incorporating wave-particle model	(a) Light as wave packets, (b) light as a transverse wave motion where the motion propagated in particles, and (c) light as consisting of photons (particles) whose trajectory mapped out a transverse wave.
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 stream of particles.

**Table 2.** Pre-service physics teachers' answers about theories of light.

Question 1. Which of the following expression or expressions explain the behavior of light? Explain your selected answer by drawing.	Distribution of responses ( <i>N</i> )
A. Light behaves both like particle and wave <sup>a</sup> .	80
B. Light behaves like a particle.	3
C. Light behaves either like wave or particle.	11
D. Light behaves like wave.	7
E. Light behaves neither like wave nor particle.	4
Blank	5
Total	110

<sup>a</sup> We used hybrid model instead of wave-particle model in the last four contexts.

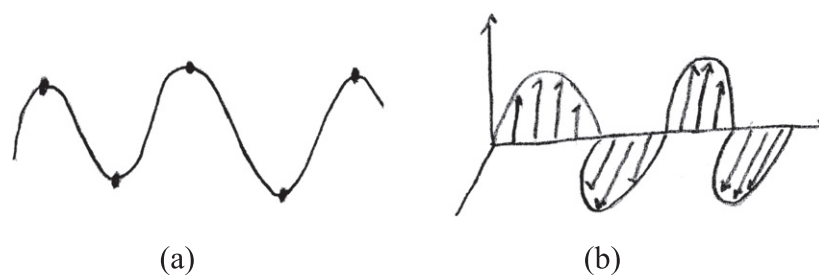
the hybrid model in the drawings while preferring the particle model in his or her explanations, the mental model of this student was coded as a hybrid model.

#### 4. Results of research

In this section, the data collected through the PPQ were analyzed quantitatively and qualitatively. Based on the light-related scientific models given in table 1, students' answers and drawings for the five different questions were analyzed and mental models for each context were determined. First of all, answers given to the first question by 110 students were analyzed. Then, in light of the model students have selected for the first question, their answers related to three different contexts (black body radiation, the photoelectric effect and the Compton effect) were analyzed.

##### 4.1. Students' mental models about the concept of light

With the first question given below, students' mental models of light were determined. In determining these models, both students' descriptions and their drawings were taken into consideration. The distribution of students' answers related to the theories that best explains the behavior of light is given in table 2.



**Figure 1.** Diagrammatic descriptions drawn by the students while trying to account for the light theories: (a) wave-particle model (hybrid model), (b) wave model.

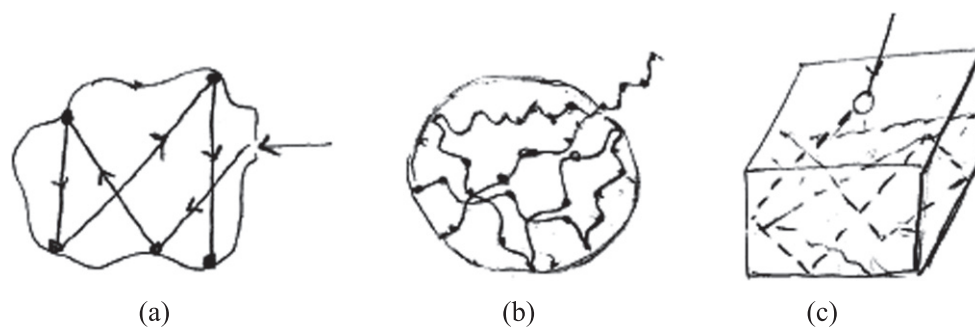
**Table 3.** Students' preferred model(s) for various light phenomena.

Phenomenon	Students' preferred model			Total ( <i>N</i> )
	Hybrid model	Beam ray model	Particle model/Particle ray model	
Blackbody radiation	34	7 + 6	46 + 3 + 5	101
Photoelectric effect	34	7 + 6	46 + 3 + 5	101
Compton effect	34	7 + 6	46 + 3 + 5	101
Blank				9

According to this table, seven students used the wave model to explain the concept of light (figure 1(b)). Moreover, three students used the particle model, and 80 students used the wave-particle model (figure 1(a)). On the other hand, 11 students indicated that light will act either as a wave or a particle; in other words, they indicated that these two characteristics of light will vary according to the content of the experiment. Four students indicated that light will act neither as a wave nor as a particle, thus they selected option E. These four students explained that they have selected option E because light should be thought of as a quantum object. Students who selected option A and D used two different pictorial representations (figures 1(a) and (b)). Only two of these representations were given as examples below. Students who selected other options did not provide any drawings in this question. These drawings by students give information about the structure they have in mind about light.

*Question 2. Which one of the theory (theories) of light theory that you preferred in the first question could be used to explain the physical phenomenon like blackbody radiation, photoelectric effect and Compton effect?*

The distribution of answers regarding light models students used to explain different light-related phenomena were given in table 3. Some of the students changed the model they used in the first question and tried to select models that are appropriate to physical phenomenon. 46 of the 80 students who selected the hybrid model indicated that particle model would be appropriate for three different contexts (blackbody, photoelectric and Compton), 34 students continued to use the hybrid model for these contexts. A detailed evaluation of this will be done when we examine the models students formed in their minds for each context. All students who selected the option 'light behaves like a particle' in the first question used the particle models again for three different contexts. Seven students who selected only the wave model used the beam ray model for the contexts given in this question. Six of the 11 students who selected the option 'light behaves either like wave or particle' selected the beam



**Figure 2.** Diagrammatic descriptions drawn by the students while trying to account for blackbody radiation: (a) beam ray model, (b) hybrid model, (c) particle model.

ray model for the three contexts, and five students selected the particle model. Nine students did not select a model for the given physical phenomenon (see table 3).

#### 4.2. Students' mental model of light to explain blackbody radiation

*Question 3.* A cave with a sinuous interior that has a small hole whose walls are kept at a thermal equilibrium at absolute temperature  $T$  behaves like an ideal blackbody. With the light that goes inside this small hole which is reflected and absorbed multiple times from the interior of the cave, so the blackbody radiation occurs. Explain this event with drawings by using propagation of light in the cavity? Explain the reasons for your answer?

98 of the 110 students answered this question with drawings and explanations. According to the descriptions given in table 1, students tried to explain blackbody radiation with the help of three different models. Three different representations from drawing samples were given in figure 2. The model drawings given in figure 2 are the (a) beam ray model, (b) hybrid model, and (c) particle model, respectively.

The beam ray model is the most frequently used by the students. 55 out of 98 students preferred this model to explain blackbody radiation, 23 students preferred the hybrid model, and 20 students preferred the particle model. Students' alternative conceptions were categorized by taking into consideration the explanations they give for their drawings. The students who showed rays as straight lines have usually the following alternative conceptions (AC).

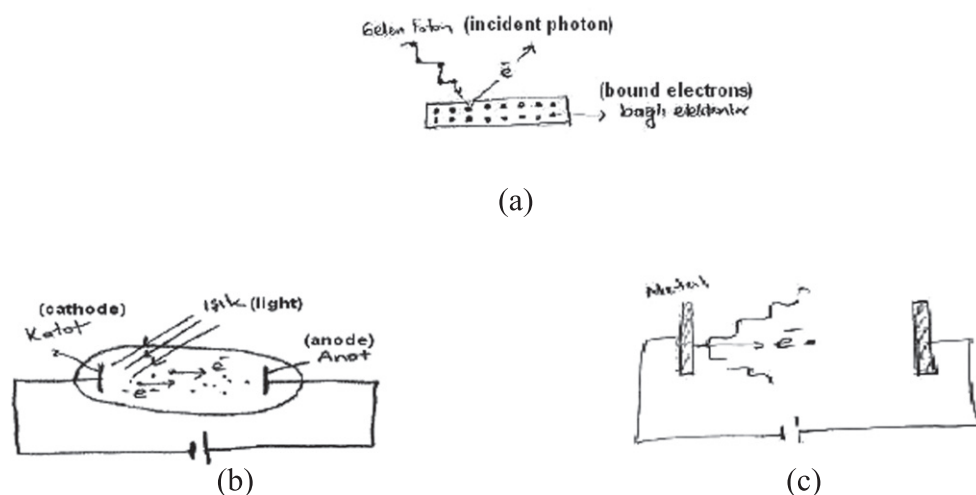
- Light that goes into the cave acts like a particle when it reflects from the cave wall.
- Each reflection reflects as light beam.

The common alternative conceptions of the students who explained blackbody radiation by using the hybrid model can be given as follows.

- Blackbody radiation can be explained by both wave and particle nature of light.
- Photons reflect from cave walls as sinus waves.

As can be seen in figure 2(c), according to students who selected the particle model, light is composed of dashed lines that follow each other. An alternative conception frequently used by students who provide explanations for this figure is 'photons are composed of little particles that carry energy and these particles propagate as a straight line'. This statement might be denoted as follows: 'because these particles move in speed of light we see them as a straight line'.





**Figure 3.** Diagrammatic descriptions drawn by the students while trying to account for the photoelectric effect: (a) hybrid model, (b) and (c) beam ray model.

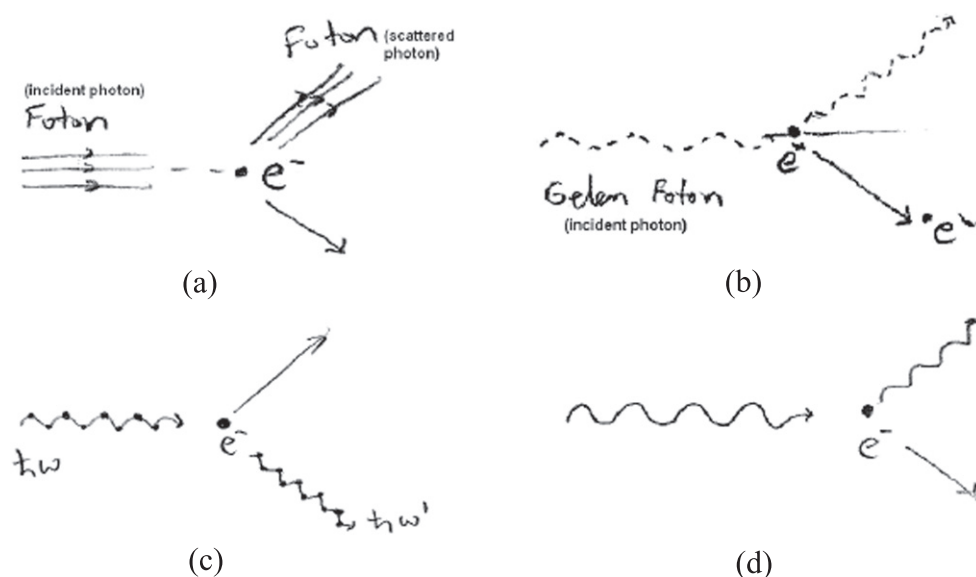
#### 4.3. Students' mental model of light to explain the photoelectric effect

*Question 4. In a photoelectric effect, light that hits a metal surface breaks off electrons from the surface and makes them become free. Explain this event with drawings by using propagation of light between the metal surface and light source?*

92 of 110 pre-service teachers explain this question about the photoelectric effect by drawings and by supporting these drawings with explanations. The three different models used, selected from students' drawings, can be seen in figure 3. According to the model descriptions given in table 1, students tried to explain the photoelectric effect with the help of two different models. These models, which were given in figure 3, are the hybrid model and the beam ray model, respectively. Here, students used the beam ray model in two different ways (figures 3(b), (c)).

The hybrid model was the most frequently used by the students. 42 out of 92 students preferred this model to explain the photoelectric effect, 27 students preferred the beam ray model. The other 23 students preferred the particle model; however, none of the students who preferred the particle model provided any drawings related to their answers. Students' alternative conceptions were determined by taking into consideration their explanations about their model drawings. Alternative conceptions mostly used by students who described the behavior of light between the source of light and the metal surface as sinus waves of the particles can be summarized as follows.

- Light behaves as a wave until it hits the metal anode. However, during its interaction with the plaque, it would behave as a particle. That is to say, it can be said that during this process light is composed of particles that move as a wave.
- Waves that are composed of  $h\nu$ -energy photons create waves at certain frequencies by hitting the metal surface.
- In photoelectric effect, light behaves like particles that move as a wave. Energy carried by the waves which.
- Photon transfers its energy to the electron by absorption. During this transfer, photon acts like a wave packet.



**Figure 4.** Diagrammatic descriptions drawn by the students while trying to account for the Compton effect: (a) and (d) beam ray model, (b) particle model, (c) hybrid model.

As can be seen in figures 3(b) and (c), according to students who preferred the beam ray model, light moves as a straight line or continuous sinus waves. Within the frame of model descriptions given in table 1, students who preferred the beam ray model used it in two different ways as shown in figures 3(b) and (c). The alternative conceptions of the students who used the beam ray model in their drawings can be mainly expressed as follows.

- Light rays remove the electrons away from the metal by hitting the metal surface. An electron is removed from the place hit by each light wave.
- After the light ray hits the metal surface, some of it is reflected back and some of it removes electron from the metal. In this event, because light scatters as continuous sinus waves, some of the wave is absorbed and some of it is reflected back from the metal.

#### 4.4. Students' mental model of light to explain the Compton effect

*Question 5. In Compton effect, a photon collides with an electron that initially at rest and is scattered. In this event, wave length of the photon was measured to be bigger than it was before the collision. Explain this process by drawings.*

93 of 110 pre-service teachers answered this question about the Compton effect with drawings and backing up these drawings with explanations. According to the model descriptions given in table 1, students tried to explain the Compton effect with the help of three different models they used. Only the beam ray model among these three models was used in two different ways (figures 4(a) and (b)). Four different uses selected from students' drawings were given in figure 4. The models given respectively in figure 4 are (a) and (d) the beam ray model, (b) the particle model, and (c) the hybrid model.

Some of the students (14 students) represented rays as straight lines as shown in figure 4(a), and some of them (38 students) represented rays as sinusoidal waves as shown in

figure 4(d). It can be seen that these drawings are two different representations of the beam ray model. On the other hand, 26 students preferred the particle model (figure 4(b)), and 15 students tried to explain the Compton effect using the hybrid model (figure 4(c)). From the explanations students gave about their drawings, it was seen that students have some alternative conceptions. The students' alternative conceptions obtained from their explanations regarding the drawings about the Compton effect can be given as follows.

- *In this event, because the photon transfers some of its energy to the electron, its wave length increases. This change in the wave length shows that the photon moves as sinus waves in this event.*
- *This shows that light rays behave as waves because there is a change in the wave length of the photon.*

Students used the beam ray model more frequently than other models when they tried to explain the Compton effect. Possible reasons for this were mentioned in the discussion section of the study. The use of the hybrid model types of students show similarities with the types with which this model was used in other contexts. Pictorial representations of this model that simultaneously includes both the wave and the particle characteristic of light are completely the same with the other three contexts. Alternative conceptions of students who preferred the hybrid model in explaining the Compton effect can be summarized as follows.

- *In the Compton effect, light displays both the wave and the particle characteristic because energy and the momentum are preserved. The change in the wave length of light shows that it has a wave-like structure.*
- *Photon behaves like a particle only when it collides with the electron. It scatters as wave before and after the collision. Thus, the Compton effect shows that the light behaves both as a wave and a particle.*

#### 4.5. Model states: context dependency of mental models

Examining the change of mental models in different contexts is highly important in order to determine whether models are context dependent or not. Just as stated in previous studies (Bao and Redish 2006, Hrepic 2002, 2004, Hrepic *et al* 2010, Wittmann *et al* 2003), this study also indicated that students' mental models are context dependent. In other words, a student can use different models for the same phenomenon in different contexts. For example, while one student used the hybrid model in the first context, it was seen that he/she used the particle model for the blackbody or Compton effect.

We know for a fact that students use two or more models inconsistently to explain the same concept (Gentner 2002). In other words, a student may use different models for the same phenomenon in different contexts. In this study, we called such usage 'mixed state' as also used in the literature (Hrepic 2002, 2004, Hrepic *et al* 2010). If a student uses the same model across contexts, it is called a 'pure state' (Bao and Redish 2006, Hrepic 2002, Hrepic *et al* 2010.). Also in this study, students used different models in different contexts. Because the number of participants is very high, it is rather difficult to show the models for each student. As such, we will merely provide the number of students (see table 4).

For example, in context 1, 80 students preferred the hybrid model, and this model was used in other contexts by 23, 42, and 15 students, respectively. As can be seen in table 4, the most 'model fluctuation' was seen in HM and BrM. Diversity in the particle model is relatively low. In other words, most of the students who used the particle model can be said to

**Table 4.** Diversity of mental models across contexts.

Contexts	HM	BrM	PM/PrM	Total number of students
Context 1	80	—	3	83
Context 2 (blackbody radiation)	23	55	20	98
Context 3 (photoelectric effect)	42	27	23	92
Context 4 (Compton effect)	15	52	26	93

HM: hybrid model, BrM: beam ray model, PM: particle model.

be in a pure model state. On the other hand, students' model state in the other two models (HM and BrM) is mostly the mixed model state.

## 5. Discussion

In this study, which mental models about the nature of light the pre-service physics teachers had developed while trying to explain blackbody radiation, the photoelectric effect, and the Compton effect, and how they interpreted them, were investigated. With the help of the first question used in the study, it was aimed to determine students' awareness about the wave and particle theories of light. Answers given to this question revealed that students have knowledge about the wave and particle theories of light. In the drawings made for the wave model of light, some of the students used sinusoidal waves and plane wave representations. This result is compatible with the result of the study conducted by Şengören (2010) in which different physical contexts were used for light. The reason why students preferred the sinusoidal wave and plane wave drawings may be that these drawings are mainly used in textbooks in explaining phenomena related to light. On the other hand, the majority of students used the hybrid model which consists of both the wave and the particle characteristics of light. In the drawings, images that are formed in students' minds clearly put forth that photons move as waves, as shown in figure 1(a). Another finding that is parallel to the use of the hybrid model in our study can be seen in the drawings students made for electrons in Olsen (2002). The mental models of students may originate from a variety of sources, such as their preconceptions and textbooks used for the modern physics and quantum physics courses (Aygün and Zengin 1998, Dereli and Verçin 2000) or that they got from their instruction. Examining students' mental model characteristics, we found that the thin beams (we coded as the beam ray model) and rays constitute stream of particles (we coded as the particle model) were the main used ones in these textbooks. In this respect, it can be claimed that there is a strong relationship between students' mental models and textbooks. In other words, the reason why students prefer especially the beam ray model and particle model can be the pictorial representations in these textbooks. In Aygün and Zengin's book (1998), in the drawings representing these three phenomena, the particle model was used for blackbody radiation (p 25), and the beam ray model was used for the photoelectric effect (p 30) and the Compton effect (p 37). In Dereli and Verçin's book (2000), no drawing was used for blackbody radiation or the photoelectric effect, but continuous sinus waves (beam ray model) were used for the Compton effect. Undoubtedly, these textbooks are not the unique reason for students' preferences for these models. Indeed, some students have the hybrid model although neither of these textbooks used the hybrid model for each context. Thus, textbooks may be

accepted as the origin of the mental models, but they cannot be claimed to be the only source. The students' prior knowledge of these phenomena, instructors, or students' own daily experiences can be also taken as various parameters for constructing their mental models.

With the second question used in the study, students were asked to indicate which theory of light they have selected in the first question could explain blackbody radiation, the photoelectric effect and the Compton effect. As can be seen in the results given in table 3, 54 students used the appropriate scientific model in explaining these phenomena. In other words, it was seen that the particle model is predominantly used in explaining these three phenomena. Students who used the hybrid and the beam ray model to explain these three phenomena made wrong comments and explanations that conflict with scientific models and facts when they tried to explain the concepts. Different names are used for these non-scientific explanations. There have been many studies about students' conceptions and ideas of scientific phenomena based on this type of explanations (Nakhleh 1992, Novak 1987, Yeziarski and Birk 2006). In these studies, although students' explanations and comments regarding the concepts basically denote the same thing, different names are used. Students' conceptions that conflict with scientific facts accepted by the scientific community are called alternative frameworks (Driver and Easley 1978), conceptual stumbling blocks (Clement 1981), children's science (Osborne *et al* 1983), intuitive beliefs (McCloskey 1983), students' ideas (Eylon and Linn 1988), misconceptions (Griffiths and Preston 1992), alternative conceptions (Clement 1983, Garnett and Hackling 1995, Gilbert 1995), and alternative models (Park 2006). In our study, we used alternative conceptions to denote students' non-scientific explanations for each context. Thus, it was established that students have important alternative conceptions that would contribute to the literature in terms of the nature of light. Moreover, within the framework of this study, the way students used these models in different physical contexts was thoroughly examined. The findings show that the models used and comments made by students in explaining physical phenomena are rather different from scientific expressions. In relation to this, models related to light were used in various different forms by the students (see figures 2–4).

Mental models preferred by students in the context related to blackbody radiation were mostly the hybrid model (23 students) and the beam ray model (55 students). The reason for this was that they misinterpreted the Planck postulate, which indicates that light is composed of photons and has discrete energy values, in order to explain blackbody radiation. In other words, the reason may be the fact that students have difficulty in understanding the quantization of light. Students' drawings for blackbody radiation were shown in three different ways in figure 2. Students who used the hybrid model tried to explain blackbody radiation using classical electromagnetic theory. The explanations that were written down by the students indicated that the light that goes into the cave would have multiple reflections from the cave walls and thus these reflections would create standing waves that have discrete wavelength.

As with the previous context, in the context related to the photoelectric effect, students preferred the hybrid model (42 students) and the beam ray model (27 students). Students who used the wave model to explain this phenomenon thought that electromagnetic waves that hit the metal surface vibrate the electrons on the surface and thus transfer their energies to the electrons and enable them to become free. Moreover, in their explanations, students indicated that the increase of light intensity causes the increase of the wave fronts, thus the wavefronts carry more energy to the metal surface thereby causing the vibration and liberation of many electrons. In other words, these students who have a wrong mental model used the hybrid model instead of the particle model to explain the photoelectric effect. Thus, the wrong mental model usage of the students triggered vreation of alternative conceptions. The findings we obtained in this study overlap with the findings in Şengören's study (2010). In that study,

which focused on diffraction and interference phenomena, the researcher determined that students use wrong mental models for these two phenomena. In the same study, students interpreted the space between consecutive wavefronts as dark regions. That is to say, findings in these studies which were conducted by using different physical contexts show that students' mental models might be context dependent (Steinberg *et al* 1999, Hrepic *et al* 2010) and can also be context independent (Hrepic *et al* 2010).

On the other hand, in the question about the Compton effect, students mostly preferred the beam ray model (52 students) (figure 4). Although it may seem surprising initially, in fact, the frequent use of this model is not a surprise. When high school and college textbooks are examined, it can be seen that in many of the drawings related to the Compton effect, the beam ray model is used. The way students use this model also brought forth many interesting results. Some students showed the incident and scattered photon as sinus waves that are composed of dashed lines (figure 4(b)) and as rays (figure 2(c)). Because it is similar to the ray model, such use of the particle model was called 'the particle ray model' in studies conducted by Hubber (2006) and Şengören (2010). In other words, this model, which we could call an alternative mental model related to the scattering of light, comes into being as a similar model to both the particle model and the beam ray model. However, we cannot call this a hybrid model because in studies, hybrid model (Galili *et al* 1993, Greca and Moreira 2001) or blend model (Brookes and Etkina 2007, Podolefsky and Finkelstein 2006, 2007) is rather different from each model that constitutes it. The use of the hybrid model within the Compton effect context is rather rare. The reason for this may be that in order to find the Compton wavelength shift of the photon students use the energy momentum conservation law, because in textbooks, the photon and electron interaction process is likened to the collision of billiard balls. As such, by using the energy momentum conservation law, the shift in wavelength of the photon is calculated.

## 6. Conclusion and implications

According to this study, students use usually non-scientific knowledge fragments along with scientific ones when developing mental models related to light. They come up with explanations by drawing connections between these two types of knowledge fragments. This result supports Norman's (1983) result as well. According to Norman (1983), 'individuals' mental models might contain contradictory, erroneous, and unnecessary concepts'. Why students preferred to use the hybrid model in this study can be explained as such because all of the students who used the hybrid model used the scientific and non-scientific knowledge fragments together. Students could not use the wave and particle characteristics of light appropriately. Thus, an inappropriate use resulted in a non-scientific model.

The findings obtained at the end of this study show that teachers and instructors at high school and university levels, respectively, should pay specific attention to certain points when teaching light-related topics. As such, contexts and contents that would form connections between different physical concepts should be prepared both in class and in textbooks. At this point, advance organizers should be used such as a concept map or conceptual frameworks so that these advance organizers encourage students to form connections between concepts. Moreover, determining students' pre-knowledge is highly important as well. To this end, students' pre-knowledge should be determined using concept maps at the beginning of the course. Important concepts should be given as a list in textbooks at the end of each topic, and a sample concept map that includes these concepts should be added at the end of the topics. Moreover, students should be presented with opportunities to develop their own mental

models in class. In order to do this, emphasis should be put in courses or in textbooks on the connections between concepts. This would enable students to form connections in a coherent way and thus help them organize their knowledge. The fact that individuals have mental models concerning concepts would promote the development of complex organized knowledge about phenomena.

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