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## High School Students’ Misconceptions and Conceptual Difficulties Regarding the Nature of Light<sup>1</sup>

Ali Kaya

### Abstract

This study investigates high school students' perceptions and misconceptions regarding the concept of light. Employing a phenomenological design within the qualitative research framework, the study was conducted with 125 students enrolled in the 9th, 10th, 11th, and 12th grades of an Anatolian high school in Gümüşhane province, Türkiye. Data were collected using a diagnostic test comprising ten open-ended questions and were analyzed using qualitative data analysis techniques.

The findings reveal that a significant majority of students lack sufficient understanding of how light is formed and structured. Furthermore, students were found to have difficulty grasping the relationship between matter and light, holding scientifically inaccurate ideas such as "light is formed as a result of a chemical reaction" or "light requires a material medium to propagate." The results also indicate that students predominantly conceptualize light through everyday light sources and its practical functions—such as illumination, heating, and energy provision—rather than through scientific principles.

In conclusion, students' cognitive structures concerning the concept of light remain far from scientifically grounded. Accordingly, science curricula from primary school onward should emphasize that light is a form of energy and explain its formation mechanisms in ways that are appropriate to students' developmental levels. Additionally, introducing abstract topics such as the nature of light, the electromagnetic spectrum, and photons—currently reserved for the 12th grade—at earlier grade levels may significantly support students' conceptual development.

**Keywords:** Light concept, misconceptions, phenomenology, qualitative research, science education, high school students, diagnostic test

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## Lise Öğrencilerinin Işığın Doğası Hakkındaki Yanlış Anlamaları ve Kavramsal Zorlukları

### Özet

Bu çalışma, lise öğrencilerinin ışık kavramına ilişkin algılarını ve kavram yanlışlarını araştırmaktadır. Nitel araştırma kapsamında fenomenolojik desen kullanılarak gerçekleştirilen çalışma, Türkiye'nin Gümüşhane ilindeki bir Anadolu Lisesi'nin 9, 10, 11 ve 12. sınıflarında öğrenim gören 125 öğrenci ile yürütülmüştür. Veriler, on açık uçlu sorudan oluşan bir tanı testi aracılığıyla toplanmış ve nitel veri analizi teknikleri ile analiz edilmiştir.

Bulgular, öğrencilerin büyük çoğunluğunun ışığın oluşumu ve yapısını açıklamada yetersiz kaldığını göstermektedir. Ayrıca, öğrencilerin madde ile ışık arasındaki ilişkiyi kavrayamadıkları; "ışık kimyasal bir tepkime sonucu oluşur" veya "ışığın yayılması için maddesel bir ortama ihtiyaç vardır" gibi bilimsel olarak hatalı düşüncelere sahip oldukları tespit edilmiştir. Sonuçlar ayrıca, öğrencilerin ışık kavramını çoğunlukla günlük hayattaki ışık kaynakları ve aydınlatma, ısıtma, enerji sağlama gibi işlevsel kullanımları üzerinden anlamlandırdıklarını ortaya koymaktadır.

Sonuç olarak, öğrencilerin ışık kavramına ilişkin bilişsel yapılarının bilimsel temelden uzak olduğu belirlenmiştir. Bu doğrultuda, ilköğretimden itibaren fen bilimleri derslerinde ışığın bir enerji türü olduğu ve oluşum mekanizmasının öğrencilerin gelişim düzeylerine uygun biçimde açıklanması gerekmektedir. Ayrıca, uygulamada 12. sınıf müfredatında yer alan ışığın doğası, elektromanyetik spektrum ve fotonlar gibi soyut konuların daha alt sınıflara kaydırılması, öğrencilerin kavramsal gelişimini önemli ölçüde destekleyebilir.

**Anahtar Kelimeler:** Işık kavramı, yanlış anlamalar, fenomenoloji, nitel araştırma, fen eğitimi, lise öğrencileri, tanı testi

### 1. Introduction

The structure of light, the source of life, has long been a subject of human curiosity. Light illuminates and warms our world, enables natural phenomena to occur, and provides the essential energy for photosynthesis, the fundamental process by which plants produce food. The history of science reveals that understanding light has been a centuries-long endeavor. Although many scholars contributed to this journey, prominent figures include Aristotle, Plato, Ibn al-Haytham, Newton, and Einstein. Owing to its nature, which differs from material structures encountered in daily life, light only attained its modern scientific meaning in the 20th century, largely due to Einstein's unique perspective (Aygün et al., 2015). Considering the challenges





faced throughout the historical development of the concept of light, identifying the relationship and differences between students’ answers to the question “What is light?” and the scientific explanation is of great importance.

Light holds a significant place in human life. By harnessing it, people have developed tools and devices that facilitate daily living, thereby laying the groundwork for scientific progress. Consequently, light has become highly important in the field of science education. For scientific advancement to continue, a sound understanding of this concept is essential. Recognizing this, many researchers have conducted studies on the teaching of light (Anderson & Karrquist, 1983; Guesne et al., 1985; Galili et al., 1991; Feher & Meyer, 1992; Büyükkasap & Samancı, 1998; Yıldız, 2000; Galili & Hazan, 2000; Cansüngü, 2000; Akdeniz, 2001; Epik et al., 2001; Gemici et al., 2002; Kara, 2002; Şen, 2003; Kara et al., 2008; Kaya, 2010; Aygün et al., 2015; Değirmenci et al., 2019; Dai et al., 2019). These studies generally focus on students’ understanding of the concept, its structure, and its properties. This highlights both the difficulty and the importance of teaching the concept of light.

Anderson and Karrquist (1983) revealed in their study that students’ knowledge of the concept of light was influenced by everyday experiences and inconsistent with scientific models. This finding marked an important turning point in science education research, demonstrating that misconceptions must be directly addressed in teaching. A study conducted with university students in China showed that their understanding of light interference was inadequate and that they experienced significant difficulties in grasping the dual particle–wave nature of light (Dai et al., 2019). In the work of Aygün et al. (2015), it was found that students attempted to explain the concept of light by making associations with its function, motion, and structure. The same study also reported that students did not provide direct explanations of what light is, but rather attributed emotional meanings to the concept instead of scientific ones. Furthermore, alternative conceptions were identified, such as equating light with its function, perceiving energy and photons as phenomena separate from light, attributing reflection and infinity properties to light, and interpreting light as a material entity. Kara et al. (2008) determined that the majority of preservice science teachers possessed highly incomplete knowledge of the concept of light, with 38% having insufficient, incorrect, or no knowledge at all, and holding misconceptions. Similarly, Kaya (2010) found that students failed to understand the concept of light and held misconceptions such as





“Light is the substance that illuminates the surface it reaches” and “Light is a collection of rays emanating from a source and extending infinitely.” Overall, these studies demonstrate that students’ level of understanding of the concept of light is low, that they struggle to comprehend it, and that they hold misconceptions related to it.

The position of the concept of light within the teaching system can itself create learning difficulties. According to the curriculum implemented in Turkey since 2018, the treatment of the concept of light during the first eight years of education is as follows (MEB, 1; MEB, 2): In Grade 3, science lessons introduce light sources and the role of light in vision; in Grade 4, the illuminating effect of light and light pollution; in Grade 5, reflection and shadows; and in Grade 7, absorption, colors, mirrors, refraction, and lenses, though without detailed elaboration (MEB, 1). In high school, the concept of light is not included in Grades 9 and 11. In Grade 10, topics such as reflection, shadows, refraction, mirrors, colors, and lenses are covered, while in Grade 12, the nature of light, the electromagnetic spectrum, photons, and quantum physics are addressed (MEB, 2). Although curricular changes occur, the topics related to light remain largely unchanged. High school students typically learn about light through textbooks, teacher explanations, and laboratory experiments. A review of the curriculum shows that until Grade 12, the question “What is light?” is not explicitly addressed. Instead, instruction focuses on light sources and their properties. This situation may negatively affect students’ learning of the concept and the mental representations they form about it.

Research conducted both in Turkey and abroad indicates that students struggle to understand the concept of light and hold misconceptions about it. Investigating the reasons behind these difficulties and developing solutions is crucial. Identifying students’ perceptions of light and the factors shaping them will contribute to resolving these issues. Light is one of the most fundamental and striking phenomena of nature. Moving at an invisible speed, creating colors and shadows, light is a core concept of physics. For high school students, the topic of light is of great importance in developing scientific thinking and observational skills. To contribute to this aim, the present study seeks to determine high school students’ perceptions of the concept of light.





## **2. Aim of Study and Expected Benefits**

This study is designed to identify high school students’ perceptions of the concept of light and the difficulties they encounter in comprehending this topic. In doing so, the existing level of knowledge and the deficiencies of the students regarding this subject will be determined. It is anticipated that these findings will contribute to taking necessary measures in the education provided to them. Furthermore, this research is significant in that it will offer fundamental insights for researchers conducting studies on the topic of light.

## **3. Methodology**

In this research, we employed the phenomenology design, which is part of qualitative research. This approach is effective in revealing students’ personal experiences, thoughts, and interpretations regarding light. In this way, instead of superficial knowledge, students’ mental models and misconceptions can be uncovered (Yalçın, 2022).

### **Samble**

The sample for this study consisted of 125 students in total, comprising 40, 19, 30, and 36 students from the 1st, 2nd, 3rd, and 4th grades respectively, attending an Anatolian High School in Gümüşhane province. Purposeful sampling was preferred in determining the study group. This method allows for the selection of participants most suitable for the aim of the research. Students were randomly selected from each grade level. Participation was carried out on a voluntary basis.

### **Data Collection Tool**

A diagnostic test consisting of ten open-ended questions was used to collect data in the study. These tests are administered as two-stage tests (answer + reasoning) to assess concept perception and reveal misconceptions. The questions were prepared using research conducted in the literature on the subject (Kaya, 2010). The questions prepared by the researchers were examined for face and construct validity by a group consisting of three physicists and one physics educator. Then, the questions were evaluated for comprehensibility, scientific accuracy, and test face validity by a physics teacher at the relevant Anatolian high school. The questions were administered to ten ninth-grade students, who were excluded from the main application, and their comprehensibility and readability were tested in a pilot





study. The open-ended questions were placed on a single page, leaving blank spaces for answers. The top of the page contained questions about the participants' names, surnames, and classes.

### **Data Analysis**

Qualitative data analysis techniques were used to analyze the open-ended questions. The first stage of qualitative data analysis is data reduction (Miles and Huberman, 1994). In data reduction, statements unrelated to light were separated from the main data. Then, the data were separated and interpreted according to their similarities and differences.

### **4. Findings**

The students' answers to the questions are presented in separate tables.

The students' answers to the first question, "How is light formed? Explain the light formation process to the best of your knowledge," are given in Table 1 below, along with their frequencies.

According to the table, 59 students did not answer this question and said "I don't know," which is a percentage of 47%.

The students' answers to the second question, "Is light an energy or a substance? Explain with your reasoning," are given in Table 2 below along with their frequencies.





**Table 1.** Answers to the question, "How is light formed? Explain the light formation process to the best of your knowledge."

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	22	11	14	12	59
By an explosion between two atoms	2	0	0	0	2
By interaction between atoms	1	0	0	0	1
Formed by heat	3	0	2	0	5
By the release of energy accumulation in matter	1	0	0	0	1
Formed from the sun and electricity	1	0	0	0	1
Light is formed as a result of a chemical reaction	1	0	0	0	1
By the reflection of rays from the sun	1	0	0	0	1
Formed as a result of refraction (colors)	0	7	5	0	12
Formed from waves and particles emanating from a source	0	3	0	0	3
It is energy emanating from a source	0	3	0	0	3
By the vibration of atoms	0	0	1	0	1
Formed by energy transformation	0	0	7	0	7
By the combination of different energies	0	0	2	0	2
Formed by fission	0	0	1	0	1
Matters	0	0	2	0	2
Light is an energy-carrying electromagnetic field	0	0	1	0	1
By the movement of photons	0	0	0	4	4
Light is formed as a result of the interaction of electrons with each other	0	0	0	4	4
It is formed by the transitions of electrons in the energy levels of atoms	0	0	0	2	2
It is released in the form of photons as a result of the radiation of energy in matter	0	0	0	2	2





**Table 2.** The students' answers to the question "Is light an energy or a substance? Explain with your reasoning."

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	17	2	13	10	42
It is energy	18	17	17	17	69
It is used in electricity production	8	2	0	0	10
It has a temperature	1	0	0	0	1
It generates heat	1	3	0	0	4
We use the light from the sun as energy in different places	0	0	0	3	3
Matter cannot exist at the speed of light	0	0	0	2	2
Photons have no mass	0	0	0	2	2
It is matter	2		1	0	3
Light occupies space and we see it	0	0	1	0	1
It is both matter and energy	0	0	4	3	7

According to the table, 53 students did not answer this question and said "I don't know," which is a percentage of 42%. The number of students who stated that light is energy is 69, which is seen to be 55 percent.

The students' answers to the third question, "Can we see without light? Explain based on your observations," are given in Table 3 below along with their frequencies.

According to the table, 58 students did not answer this question and said "I don't know," which is a percentage of 46%. The number of students who said they cannot see without light is 63, which is 51 percent. Seventeen students gave the correct answer, "For us to see, light must reflect off objects and reach our eyes," which is 27 percent.





**Tablo 3.** The students' answers to the question "Can we see without light? Explain based on your observations"

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	20	3	19	16	58
We cannot see.	20	16	20	17	63
The environment would be dark 9(majority)	0	2	0	0	0
For us to see, light must reflect off objects and reach our eyes	1	3	7	6	17
We can see	2	2	0	0	4
Some living things have night vision abilities	1	0	0	0	0
After a while, our eyes get used to the darkness	0	1	2	0	3

The students' answers to the fourth question, "Give examples of light emission from daily life. How might these events occur?", are given in Table 4 below along with their frequencies.

According to the table, 29 students did not answer this question and said "I don't know," which is a percentage of 23%. It was observed that 62% of the students answered this question with "Rays from the sun".





**Table 4.** The students' answers to the question "Give examples of light emission from everyday life. How might these events occur?"

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	9	7	6	7	29
Rays from the sun	46	2	14	12	78
Flashlight	0	2	1	3	6
Mirrors	0	3	0	0	3
Rainbow	0	4	0	0	4
Stadium light	0	1	0	0	1
Street lamps	0	1	1	0	2
Moon	0	0	1	0	1
Star	0	0	1	0	1
Bulb	0	0	5	3	8
LED light	0	0	0	1	1

The students' answers to the fifth question, "Can an object emit light when its temperature increases? Explain," are given in Table 5 below along with their frequencies.

According to the table, 48 students did not answer this question and said "I don't know," which is a percentage of 38%. More than half of the students answered "Yes" to this question, indicating that heated objects can emit light. Twelve students (9.6%) stated that light cannot be emitted from heated materials.





**Table 5.** The students' answers to the question "Can an object emit light when its temperature increases? Explain."

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	16	6	14	12	48
Yes.	20	13	19	13	65
Heat energy is converted into light energy	1	0	2	0	3
Light needs temperature to propagate	1	0	0	0	1
As temperature increases, brightness increases and the object emits light	0	4	4	0	8
A burning light bulb gets hot	0	1	1	0	2
Iron turns red when heated	0	0	0	1	1
Objects above absolute zero emit light	0	0	0	1	1
According to the black body theory, it emits light	0	0	0	4	4
As temperature increases, the light spectrum shifts to the visible region	0	0	0	1	1
No	4	4	3	1	12
Light has no relation to heat	3	0	0	0	3
Black bodies absorb light	1	0	0	0	2
Not all emit light	0	0	2	0	2
Water boils but does not emit light	0	0	1	0	1
Increased temperature does not affect light	0	0	1	0	1

The students' answers to the sixth question, "Can light travel in a vacuum? Explain your answer," are given in Table 6 below along with their frequencies.





**Table 6.** The students' answers to the question "Can light propagate in a vacuum? Explain your answer."

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	15	9	7	6	37
Yes	10	5	16	19	50
We see the stars thanks to the rays from the sun reaching the earth	1	3	6	6	16
Light does not need a material medium to propagate	0	1	4	0	5
Light does not need a medium because it is an electromagnetic wave (EMD)	0	0	0	3	3
No	20	12	5	1	38
Light needs a material medium to propagate	1	7	1	0	9
Light needs to hit an object to be seen	1	0	0	0	1
There is no light in an environment without air	0	2	0	0	2
Vacuum draws light into itself	0	0	1	0	1

According to the table, 37 students did not answer this question and said "I don't know," which corresponds to 29.6%. 50 students (40%) answered "Yes" to this question, indicating that light can travel in a vacuum. 38 students (30%) answered "No" to this question, indicating that light cannot travel in a vacuum.

The responses of the students to the seventh question, "Do you think life would be possible on Earth without light? Share your thoughts," are given in Table 7 below, along with their frequencies.





**Table 7.** The students' answers to the question "Do you think life on Earth would be possible without light? Share your thoughts."

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	16	13	12	10	51
Yes	2	0	6	2	10
Blind people can live	1	0	3	0	4
It would be difficult but it would be possible	0	3	0	0	3
Living things that can obtain their food and oxygen would survive	0	1	0	0	1
They would adapt to the environment	0	0	2	0	2
There are living things that live in lightless environments	0	0	0	1	1
There are living things that live underground	0	0	0	1	1
No	22	13	15	14	64
Because life is impossible in the dark	1	0	0	0	1
The sun provides heat and light, only then can we live	1	0	0	0	1
We cannot survive without sight	1	2	0	2	5
The ecosystem collapses without light	1	0	0	0	1
Living things need light	0	4	7	3	14

According to the table, 51 students did not answer this question and said "I don't know," which corresponds to 41%. Ten students answered "Yes" to this question, indicating that life would exist on Earth even without light. Half of the students answered "No" to this question, stating that life on Earth would be impossible without light.

The responses of students to the eighth question, "Is there a relationship between light and matter? If your answer is 'Yes,' explain," are given in Table 8 below along with their frequencies.





**Tablo 8.** Bulunan "Işık ve madde arasında bir ilişki var mı? Cevabınız "Evet" ise, açıklayınız." sorularına verdikleri yanıtlar.

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	19	5	15	15	54
Yes	15	14	17	10	56
Light reaches us through matter	1	0	0	0	1
Matter is needed for light to propagate	1	0	3	0	4
Light is matter	1	0	0	0	1
Light is formed as a result of a certain event in matter	1	0	0	0	1
There is no light without matter	1	0	0	0	1
Light spreads by hitting matter	0	5	0	0	5
Colors are formed by the absorption of light by matter	0	2	0	0	2
Light is also matter	0	1	0	0	1
Light is formed as a result of the interaction of matter	0	0	2	0	2
Matters either absorb or reflect light	0	0	2	1	3
Everything that emits light is matter	0	0	1		1
Every substance reflects light to some extent	0	0		1	1
Reflection-absorption-refraction occurs between matter and light	0	0	0	1	1
No	7	1	3	4	15
Those below absolute zero do not emit	0	0	0	1	1

According to the table, 54 students did not answer this question and said "I don't know," which corresponds to 43.2%. Nearly half of the students (56) answered "Yes" to the question, indicating that there is a relationship between light and matter. Fifteen of the students answered "No" to the question, indicating that there is no relationship between light and matter.

The students' answers to the ninth question, "Can light be emitted from every substance? If your answer is 'Yes,' explain," are given in Table 9 below along with their frequencies.





**Table 9.** Students' answers to the question, "Can light be emitted from any substance? If your answer is 'Yes,' explain your reasoning."

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	15	9	9	6	39
Yes	6	1	8	6	21
It emits light if an external influence is applied	0	0	1	0	1
It emits light as the temperature of the substance increases	0	0	1	0	1
It emits light unless there is a substance that completely absorbs light	0	0	0	1	1
Every object with a temperature emits light	0	0	0	1	1
No	22	18	15	9	64
Light does not emit from wood and plastic	1	0	0	0	1
Matter cannot emit light without a light source	1	0	0	0	1
Dark materials absorb light	1	0	0	0	1
Matter reflects light	1	0	0	0	1
Matters that absorb light prevent us from seeing light	0	2	0	0	2
It must be above absolute temperature	0	0	0	1	1
It must have energy	0	0	0	1	1

According to the table, 39 students did not answer this question and said "I don't know," which corresponds to 31%. Seventeen percent of the students answered "Yes" to the question, indicating that not all substances can emit light. It appears that 64 students stated that light cannot be emitted from every substance.

The answers given by students to the tenth question, "If light is emitted from a substance, what kind of event might be occurring inside the substance? Explain," are given in Table 10 below along with their frequencies..





**Table 10.** Answers to the question: If light is emitted from a substance, what kind of event is occurring inside that substance?

Answers	Classes				Total
	9	10	11	12	
No answer and I don't know	27	12	17	31	87
It is formed from the energy within it	1	0	0	0	1
The substance reflects the energy it receives	1	0	0	0	1
A chemical reaction occurs	1	0	2	2	5
It is formed by refraction and reflection	0	6	0	0	6
The temperature may be increasing	0	2	5	3	10
There may be energetic reactions at a certain level	0	1	0	0	1
Electrons in the atom emit energy as they fall from a higher energy level to a lower energy level	0	0	2	4	6
By the movement of electric charges	0	0	1		1
By the acceleration of molecules within the substance	0	0	1	0	1
By the interaction between electrons	0	0	2	0	2
By energy conversion	0	0	2	0	2
As a result of fission	0	0	0	2	2

According to the table, 87 students did not answer this question and said "I don't know," which corresponds to 69.6%. As you can see, six students gave the correct answer to this question.

## 5. Conclusion and Discussion

The results obtained from the research findings are given below.

Approximately two percent of the students gave the correct answer to the question of how light is formed (Table 1). It was determined that students did not know how light is formed and its structure. This situation may be due to the fact that the structure of light is different from other substances and that the topic is included in the curriculum at the end of the second semester of the final year of high school.

While 55% of students stated that light is energy, 42% did not answer the





question (Table 2). This indicates that approximately half of the students did not know that light is energy.

Nearly half of the students either didn't answer the question about the effect of light on our ability to see objects or said they didn't know the answer. While most of those who answered gave the correct answer, only 27% were able to explain why (Table 3).

It was determined that the students were unable to give examples of light reflection. They were observed trying to explain light reflection by giving examples of light sources (Table 4).

Half of the students stated that objects whose temperature increases can emit light, but they could not scientifically explain how this occurs. 38% of the students did not express an opinion on this matter (Table 5). This indicates that students lack sufficient knowledge about how thermal energy can be converted into light energy.

40% of the students stated that light can propagate in a vacuum, while 30% stated that it cannot (Table 6). This indicates a lack of knowledge among the students on this subject. Furthermore, some students were found to have the misconception that "light needs a material medium to propagate."

While 51% of students stated that life is impossible without light on Earth, 8% said it is possible (Table 7). Approximately 40% of students did not answer this question. This is significant because it shows that some of them did not perceive that light is essential for human life.

As shown in Table 8, although 44% of the students stated that there is a relationship between light and matter, they could not explain this relationship. Furthermore, 12% of them stated that there is no relationship between light and matter. This indicates that the majority of students did not explain the relationship between matter and light.

As shown in Table 9, one-third of the students did not answer the question "Can light be emitted from every substance?", and more than half answered "No". This indicates that most students have insufficient knowledge about the formation of light.

Seventy percent of students either did not answer the question of how light is formed or said they did not know. Only six percent of students (5%) were able to explain the formation of light scientifically (Table 10).





In conclusion, it was determined that students lacked sufficient understanding of fundamental aspects of light, such as its formation, relationship with matter, its role in vision, and its propagation in space. These findings are consistent with the results obtained by Kaya (2010), Kara et al. (2008), Yeşilyurt et al. (2005), Cansüngü (2000), and Yıldızbaş and Güzel (2020) at different educational levels. The fact that light has a different nature from matter and that the subject is presented in curricula based on its properties without answering the question "What is light?" is considered among the main reasons for these conceptual difficulties. Therefore, it is understood that students from primary school to university have difficulty understanding fundamental aspects such as the formation of light, its nature as a form of energy, and its effects on living beings.

## **6. Suggestions**

To help students overcome the difficulties they face in understanding the concept of light, the following measures are strongly recommended:

Introduce the structure and formation of light during primary and secondary education to foster a scientific understanding from an early stage.

Advance the teaching of fundamental topics—such as the nature of light, the electromagnetic spectrum, and photons—currently included in the 12th grade curriculum, to earlier grades.





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