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Mental Representations of 14-15 Years Old Students about the Light Propagation Time

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Abstract: Mental representations of 14-15 years old students about the light propagation time. Objectives: The study of students' representations of physics concepts and phenomena constitutes a central part of science education research, as they play a decisive role in teaching. In the study presented here, we investigate the mental representations of 14-15 years old students about the light propagation time, before they were taught about it in school. **Methods:** The empirical data was gathered through an interview using three tasks which involved the evaluation of hypothetical situations. The research data included representations that cause difficulty in the comprehension of the position of a light source in relevance to the light propagation time. **Findings:** Most of students assumed that the identification of the light propagation time is strongly correlated with the large distance between the light source and the receiver. **Conclusion:** This study concluded that the arrangement of objects in space strongly influences the students' thinking.

Keywords: Light propagation time, mental representations, 14-15 years old students.

Abstrak: Representasi mental siswa berusia 14-15 tahun tentang waktu propagasi cahaya. Tujuan: *Studi mengenai representasi siswa terhadap konsep dan fenomena fisika merupakan bagian sentral dari penelitian pendidikan sains, karena hal itu memainkan peran penting dalam kegiatan belajar mengajar. Pada penelitian ini, kami menyelidiki representasi mental siswa berusia 14-15 tahun tentang waktu propagasi cahaya sebelum mereka diajarkan tentang hal itu di sekolah.* ***Metode:*** *Data empiris dikumpulkan melalui wawancara menggunakan tiga penugasan yang melibatkan evaluasi situasi-situasi hipotetis. Data penelitian meliputi representasi-representasi yang menyebabkan kesulitan dalam pemahaman posisi sumber cahaya yang relevan terhadap waktu propagasi cahaya.* ***Temuan:*** *Sebagian besar siswa mengasumsikan bahwa waktu propagasi cahaya berhubungan erat dengan jarak luas antara sumber dan penerima cahaya.* ***Kesimpulan:*** *Penelitian ini menyimpulkan bahwa pengaturan objek di ruang sangat mempengaruhi pemikiran siswa.*

Kata kunci: *Waktu propagasi cahaya, representasi mental, siswa berusia 14-15 tahun.*

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INTRODUCTION

After several decades of relevant research, we know for certain that learning and teaching physics is strongly influenced by the common naive mental representations of the students. In a number of fields such as Physics, Chemistry or Biology (Skoumios & Hatzinikita, 2006; Kampeza & Ravanis, 2009; Ergazaki & Ampatzidis, 2012; Sunyono, Ibrahim, & Yuanita, 2013; Fragkiadaki & Ravanis, 2015; Allen & Kambouri-Danos, 2016; Meli, Koliopoulos, Lavidas & Papalexiou, 2016; Ouasri, 2017; Kalogiannakis, Ampartzaki, Papadakis & Skaraki, 2018), it is firmly established that students' mental representations are incompatible with models drawn from the sciences themselves and are commonly used in school education.

A long tradition of relevant research exists in the field of geometrical optics for concepts and phenomena such as light as entity (Guesne, 1984, 1985; Watts, 1985; Ravanis & Boilevin, 2009; Métioui & Trudel, 2010; Ntalakoura & Ravanis, 2014; Grigorovitch, 2015; Rodriguez & Castro, 2016), light propagation (Ravanis & Papamichael, 1995; Métioui & Trudel, 2012), shadows formation (Ravanis, Zacharos & Vellopoulou, 2010; Herakleioti & Pantidos, 2016; Delserieys, Impedovo, Fragkiadaki & Kampeza, 2017; Pantidos, Herakleioti & Chachlioutaki, 2017; Delserieys, Jegou, Boilevin & Ravanis, 2018), vision (Selley, 1996; Dedes, 2005; Kokologiannaki & Ravanis, 2013; Ravanis 2018) and the image formation (Dedes & Ravanis, 2009; Kaltakci-Gurel1, Eryilmaz & Mc. Dermott, 2017), the reflection and diffraction (Prasetyo, Hindarto & Masturi 2015; Kaltakci-Gurel1, Eryilmaz & McDermott, 2016; Arianti, Yuliati & Sunaryono, 2017, 2018). Nevertheless, only a small number of studies have dealt with the way students conceive time as an important factor of light propagation.

The concept of time has a particular difficulty due to the fact that while time has primarily a logical meaning, it becomes a concept of physics when it is connected with the propagation of a physical entity. Therefore, as the speed of light propagation is very big, it seems that the time does not play any role in the light propagation for distances encountered in the school lab or in everyday phenomena. Thus, as everyday experience does not provide any kind of valuable data, logical processes that a typical developing child can achieve with difficulty are required for the understanding of the role of time in light propagation.

Stead & Osborne (1980) first linked light propagation phenomena with the power of source as they noticed that the stronger a light source was, the more powerful properties were attributed to it by pupils aged 7-11 years. In addition, Guesne (1984) found out that the vast majority of students aged between 13-14 years recognize time as a factor of light propagation only for long enough distances. In another study it was found that pupils up to 10 years old seems to consider the spread of light to be instantaneous for cases where the receiver stands near the light source or the power of the source is too strong. (Ravanis, 1991). Meanwhile another research stream, though different to ours, deals with the notion of understanding the role of time in the framework of Classical Physics and Special Theory of Relativity (Villani & Pacca, 1987; Otero, Arlego & Prodanoff, 2016; Otero & Arlego, 2018). In this context, issues concerning the difficulties encountered with the relativistic nature of time are mainly discussed. The current research investigates mental representations on the time of light propagation of students aged between 14-15 years old.

METHOD

Sample and procedure

The research of the children's representations was carried out through individual directive interviews which were about 20 minutes long. The interviews took place in the school laboratory. The research sample was 109 students, aged 14-15 years (grade 9), who had chosen courses covering the fundamentals of Optics in grades 5, 6 and 8. However, these lessons did not include any systematic reference to the time of propagation of light. All the students participated in the research live in an urban area of Greece. Each child was presented with three different Tasks; each one deals with the issue of time of light propagation from a different point of view. All the approaches are presented below. Every student's answer was followed up with a dialogue with the researcher in order to get a deeper understanding of the way students hold and use their mental representations.

Tasks

Task 1. In the first Task we tried to check whether and how students' mental representations on a fixed light source are influenced when the distance of the receiver of the light from the source is changed. For this purpose a table lamp (220 V, 80 W) which remained off during the entire experiment were used. In particular, we placed the light source consecutively in positions spaced from the student 30 cm (Task 1a), 2 m (Task 1b) and 10 m (Task 1c). For each different location of the source we asked '*If we light up the light, its light comes straight into our eyes or does it take time until it reaches us?*'.

Task 2. In the second Task we tried to study the effect of a strong light source, such as the sun, on children's representations of light propagation time. The children were asked to answer the following question '*Does the Sunlight immediately comes to our eyes on earth or does it take time to reach us?*'.

Task 3. In the third Task, which included two different experimental situations, we tried to study whether phenomena of successive events in the propagation of light are strictly dealt by the students on the basis of estimation of propagation time. For each experimental setup, it was used a device aparted from: an improvised light source (no function) which we called 'the lighthouse', two human dummies (child soldiers), a carton box of 16 cm high, which we called 'the mountain', and a paper tape 16cm width and 55cm length, of which 42cm were blue and 13cm were brown in color representing sea and land respectively.

Special arrangements of the objects were used for each setup. Therefore, in the first setup (Task 3a), person A and B are standing on land at distances of 42 cm and 50 cm from the lighthouse respectively (Figure 1). In the second setup (Task 3b), one person (A) is located 42 cm on land and the other person (C) is located on a mountain behind A, 50 cm length and 16 cm height from the lighthouse (Figure 2).

Having explained in detail the characteristics of the objects and the setup of Tasks 3a and 3b, we asked each child to answer the following question: '*If the lighthouse lights up, who will see its light first, A, B (or C) or both at the same time. Explain your answer?*'.

Figure 1. Person A and B are standing on land at distances of 42 cm and 50 cm from the lighthouse respectively.

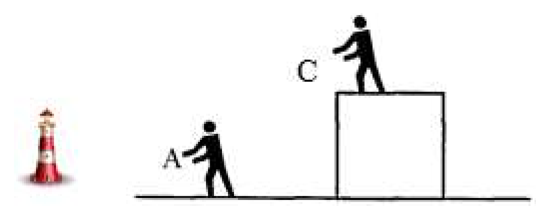

Figure 2. Person A is located 42 cm on land and person C is located on a mountain behind A, 50 cm length and 16 cm height from the lighthouse.

Data analysis

The interviews were recorded and the transcripts of students' answers were used for the categorization process. Field notes have also been kept to accurately capture non-verbal behaviors of children.

■ RESULTS AND DISCUSSION

In this section the results of each Task are presented and properly discussed. Hence, categories of responses, typical examples of each response as well as frequency tables of the responses are given below.

Task 1. For all distances (Task 1a, 1b, 1c) the answers of the students are based on the same mental representations and are therefore classified in the following two categories:

Á) Answers of children who clearly recognize that the spread of light in space takes time. For example, *'... it takes time to make some distance (1a) ... .. now it needs more (1b) ... .. and now even more (1c)*' (Subject 69).

Â) Answers of children who believe that light does not need time to propagate. For example, '*It immediately reaches our eyes (1a) ... it will arrive immediately (1b) ... it will arrive immediately ...... always arrives immediately ... (1c)*' (Subject 42).

However, many children claimed that while light travels immediately over short distances, it takes time when the distance increases. To quote a students' response '*... it arrives immediately (1a) ... now takes a little time, not much ... but it needs ... before ... when it was close it did not need (1b) ... now it will do ... far enough ... (1c)*' (Subject 21).

Table 1 are listed the frequencies of students' responses concerning the three different distances of the recipient of the light.

Answers to T1a, T1b and T1c show that for a large number of students the identification of the light propagation time is strongly correlated with the large distance between the light source and the receiver. As it is clearly showed in Table 1, while only 35,8% of students responses support the idea that light travels immediately when it has to cover a short distance (Task 1a), the percentage of answers increases immediately to 90,8% when the distance that has to be covered becomes larger (Task 3c). The above mentioned data underlines the fact that in the mind of these children the light has no fixed properties as an autonomous physical entity, and that these properties are mainly correlated with the arrangement of the objects of the examined state.

Table 1. Answers of subjects on the first Task (T1a, T1b, T1c)

Person	Frequencies			Percentages %		
	T1a	T1b	T1c	T1a	T1b	T1c
A	39	81	99	35,8	74,3	90,8
B	70	28	10	64,2	25,7	9,2
	109	109	109	100	100	100

Task 2. In this task, students' answers are divided into three categories.

A) Answers that recognizes the fact that light needs time to propagate. For example, '*It takes time ... ..the sun is far away from the earth ... e ... and until the light comes ...*' (Subject 32).

B) Answers that support the idea that light propagation is instantaneous.. For example, '*... (the light of the sun comes) immediately ...... as soon as it rises .... it does not take time .... I believe immediately ...*' (Subject 101).

C) Answers that supports the idea that light propagation is instantaneous due to the high power of the light source from which it is derived. For example, '*The sunlight comes immediately to our eyes because ... because the sun has very strong light and thousands of degrees of temperature ...*' (Subject 44).

In Table 2 are listed the frequencies of students responses in Task 2.

Table 2. Answers of subjects on the second Task (T2)

	Frequencies	Percentages %
	T2	T2
A	71	65,1
B	28	25,7
C	10	9,2
	109	100

The answers we got here largely confirm the findings of Task 1.

The distance factor leads 2/3 of students to recognize that it needs time for the light in order to propagate, while 1/4 of students insist on instantaneous light propagation even if a large distance has to be covered. Nevertheless, it should be noted that the power of the source played a key role for the instantaneous light propagation for 1/10 of students' responses. This fact underlines the intuitive correlation which seems to exist in students mind between the characteristics of 'light' as an entity and the source from which the light derives.

Task 3. In both experimental setups (Task 3a, 3b) students' mental representations were mainly influenced by the arrangement of the objects of the examined state. In Task 3a we categorized the following answers:

Á) Answers in which it is clearly stated that the light will be seen firstly by the one who is closest to the light source, due to time of light propagation time. For example, '*... A will see it first ... because the light comes faster to the one on the front and later to the one who stands below'* (Subject 9).

Â) Students' answers who recognize that the one who stands closer to the light source will see the light first, thought they seem unable to explain it. To quote a student response, '*A will see the light first because he stands closer… B will see it later… because… because the lighthouse is farther away* (Researcher: '*So, what happens to the light since the lighthouse stands farther away?*') *It will ... It will be more difficult for B to see it… A can see it faster'* (Subject 17).

C) Students' answers that hold the view that both persons will see the light simultaneously, regardless their distance from the light source. For example, '*They will both see it at the same time... they are on the same level and at the same distance from the lighthouse*' (Subject 94).

D) For a small number of students, the light arrives firstly at the receiver who stands further away from the lighthouse. For example, '*... the one who stands behind can see the light clearly ... it has a better view of the sea.* (Researcher: '*We are interested, however, for the person who sees it firstly… not for the one who sees it more clear*'*). ... Person B… he can see the lighthouse first*' (Subject 79).

On Task 3b we have the following categories of responses

Á) Answers that recognize that the light will be seen firstly by the one who stands closest to the light source. For example '*A (will see the light first)… he is much closer than C and therefore the light will reach him faster*' (Subject 54).

Â) Students' answers who recognize that the one who stands closer to the light source will see the light first, but are unable to give explanations. For example '*A (will see the light first) who stands lower… C will see it later as he is being above*. (Researcher: '*Why is this happening?*') *Because ...... he is probably at the same line with the lighthouse ...... while the other stands above ... I'm sure A will see it first...*' (Subject 62).

C) Students' answers that hold the view that both persons will see the light simultaneously, regardless their distance from the light source. For example '*I think both will see the light simultaneously… they can both see the lighthouse clearly*' (Subject 127).

D) Students' answers who state that the light will be seen firstly by the person who is located on place C. For example, '*He (C) will see the light first as he stands higher… the higher one stands, the more capable he becomes to see …*' (Subject 87).

In Table 2 are listed the frequencies of students responses in Tasks 3a and 3b.

Table 3. Answers of subjects on the third Task (Ô3a, T3b)

	Frequencies		Percentages %	
	T3a	**T3b**	**T3a**	**T3b**
A	44	15	40,4	13,8
B	17	12	15,6	11
C	46	47	42,2	43,1
D	2	35	1,8	32,1
	109	109	100	100

The percentages presented in Table 3 clearly confirm the findings of previous Tasks, as they solidly show the degree to which the arrangement of objects of an experimental situation can affect students' responses. Indeed, while Task 3a results are quite similar to those of the previous Tasks, that is 40.4% recognize that time propagation takes time, an arrangement of the objects which were in line with students daily experience in Task 3b immediately reduced the corresponding percentage to only 13.8% of students.

CONCLUSION

In the current research we tried to investigate mental representations on the time of light propagation of students aged between 14-15 years old. Three Tasks were used to examine the stability and the degree of which these representations are influenced by the arrangements of objects in space. Judging from the above, it can be concluded that students' thinking is strongly influenced by the arrangement of objects in space, as the proportion of responses which takes into account the time of light propagation range from 13.8% (Task 3b) to 90.8% (Task 1c). This finding, which is consistent with findings of other studies conducted with younger children (Stead & Osborne, 1980; Guesne, 1984; Ravanis, 1991), shows that students even at the age of 14-15 years do not deal with light as an autonomous entity being propagated in space, and therefore cannot attribute to it the properties that a moving object is likely to have.

In this respect, future research should be turned into two directions. On the one hand, emphasis should be placed on the psychologically-developmental exploration of interpretations at the level of cognitive formation of children in order to gain a deeper understanding on how pupils conceptualize natural entities having energy such as light. On the other hand, from a didactic point of view, it is of great interest to study the design and implementation of teaching plans that will allow the light propagation time to be recognized. Thus, children's thinking may approach the subject with a reasoning that correlates the time of propagation of light with the distance traveled.

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