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A COMPARATIVE APPROACH TO THE REPRESENTATION OF LIGHT FOR FIVE-, EIGHT- AND TEN-YEAR-OLD CHILDREN: DIDACTICAL PERSPECTIVES

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Abstract. *Chidren's mental representations of physical concepts and phenomena are often different from those of scientists. In this paper we investigate the issue of understanding light in space as an entity by schoolchildren aged 5 (127 subjects), 8 (142 subjects) and 10 (132 subjects), before they receive any systematic teaching in school. This research was conducted through individual interviews in which the children were asked to talk about light and its results and to locate it in various experimental situations. The results of this study show that even though all the children of all ages have difficulty understanding light as an entity in space, as they grow older they make significant progress in disconnecting light from light sources. These findings allow us to seek out educational perspectives on the understanding of the concept of light in organised scholastic environments.*

Key words: *children's representations, didactics of physics, the concept of light.*

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Theoretical Framework

The question of representations in the minds of children of all ages of concepts of the natural sciences has been studied extensively over the past decades (Gilbert & Watts, 1983; Johsua & Dupin, 1993). The knowledge produced by related research is considered important because it allows us to monitor how a child approaches a certain concept, the main obstacles to its comprehension, the possible influences of teaching interventions in school, and the way a child's thought process develops up until adulthood (Ergazaki, Komis & Zogza, 2005). In the paper presented here, we have attempted to study the representations of light as a natural entity by children of various ages before they receive any kind of systematic teaching in school, with an aim to define the main axes of future teaching interventions.

Understanding light as an entity in space has previously been identified in a series of studies of 5- to 18-year-old schoolchildren. These studies have showcased a series of issues regarding children's thought processes that are related to the diffusion of light and its interaction with other forms of matter. An important finding of these studies is the way in which several children's thinking becomes locked into linking the concept of light exclusively to the light sources themselves (Tiberghien, Delacote, Ghiglione & Matalon, 1980; Anderson & Kärrqvist, 1983; Guesne, 1985; Fleer, 1996; Selley, 1996; Toh, Boo & Woon, 1999; Gallegos Cázares, Flores Camacho & Calderón Canales, 2008). Because of this problem, we have particularly emphasised the importance of expressing thoughts in which light is located outside light sources, even if this is done based

on perception, i.e. in areas where there are visible bright spots (Ravanis, 1999, 2008).

However, the major obstacle in understanding light as a concept is the acknowledgment of its diffuse presence in space, i.e. its existence as an entity, independent of its sources and the results it causes. Indeed, when presented with various experimental situations, children of a broad range of ages and often regardless of conventional teaching in school are not successful in indicating the presence of light in space, while the pupils' thought process concentrates more on the sources of the light or on visible bright areas (Stead & Osborne, 1980; Osborne, Black, Meadows, & Smith, 1993; Ravanis & Papamichael, 1995; Galili, 1996; Langley, Ronen & Eylon, 1997; Galili & Hazan, 2001; Dedes & Ravanis, 2008, 2009).

But how can this obstacle be explained? Piaget and Garcia (1971) explained that transitive thought (if A→B and B→C, then A➔C), although logico-mathematical in nature, can nevertheless be expanded so as to be applicable to entities like power, heat or light as an indirect natural transition. Indeed, for a child at the stage of pre-operational thought, the approach to light as a concept centres on light sources (LS) and visible lighted areas (VLA) or a combination thereof via a thought of direct transition of the following form: LS→VLA. As a result, children at this stage ignore the space in which light bundles propagate, that is to say, the space of light's propagation (SPL). In contrast, a particular form of mathematical transition characterises operational thought: LS→SPL and SPL→VLA then LS➔VLA.

Therefore, according to Piaget and Garcia (1971), in the case of natural transition the correlation among the elements of the problem of propagation of light operates as a general model of representation of light. The representation of light based on transition is important because, as a two-step procedure, it imposes the identification of the presence of light in space. The acceptance of light as an entity that is transmitted independently of the light source and the final receiver constitutes the necessary convention and beginning of the construction of other associated phenomena of light. For example, without the identification of light as an entity it would be impossible to understand the process of the notion of a straight path of light, the formation of shadows or images.

However, the representations do not remain fixed and unchanged in children's minds but evolve along with their biological maturation as well as with the work the children do in organised Physics courses, though we know very well that neither the one factor nor the other are sufficient to transform their thinking towards schemata that are compatible with the models of Physics. But if we exclude the teaching factor, i.e. we study the children's representations before they are taught issues related to light and Geometrical Optics, then we can follow their thought process as it takes shape during their biological maturation within their social and natural environment. Thus, in this paper we have tried to study the representations of children aged 5, 8 and 10, before they take part in organised courses on light and its interactions with matter, so as to locate the difficulties and obstacles we will come across during teaching.

Methodology of Research

Sample

The sample of the study consisted of 127 subjects from 10 kindergarten classes (Group 5: S_1 – S_{127}), 64 boys and 63 girls (ages 4.5–5.5; average age 5.10 years), 142 subjects from 10 primary school classes (Group 8: S_{128} – S_{269}), 70 boys and 72 girls (ages 7.5–8.5; average age 7.88 years) and 132 subjects from 11 primary school classes (Group 10: S_{270} – S_{401}), 66 boys and 66 girls (ages 9.5–10.5; average age 9.94 years). The selection of the subjects was made by random sampling from among those who had agreed to "have a discussion" with us. The schools and the kindergartens were in an urban area with a population of middle socio-economic status.

Having observed, in earlier analyses, that there were no differences between boys and girls in understanding light as an entity in space (Ravanis, 1999, 2008), we will not be studying differences in terms of gender. Besides, on the whole, research into children's ideas concerning the concepts

and phenomena of the Natural Sciences does not indicate any significant differences in terms of gender (Wandersee, Mintzes & Novak, 1994; Skoumios, 2008).

Design

The study of the children's representations was carried out through individual interviews which were 15-18 minutes long, in a space with natural and artificial lighting. The interviews were carried out by a researcher and were analysed independently by two researchers. During these interviews the children were presented with five consecutive tasks, were asked certain questions and then had a discussion with the researchers based on the thoughts they expressed. In all five tasks, the subjects were able to locate light as an entity in space, on certain surfaces or in the light sources themselves.

In the pre-research carried out on all subject categories, we discovered that the children understand the questions and are able to formulate verbal answers and interact with the objects we suggested to them. Sixty subjects participated in the pre-research, 20 out of each group.

We then presented the tasks, the categories of the children's answers in certain typical examples and the analysis of the frequency of their answers in the various categories. The eventual differences were examined for statistical significance with a chi-square test.

Results of Research

In order to gather different kinds of information, we used different kinds of tasks:

a) Tasks/open questions that allow us to understand which aspects of light the children are verbally referring to when asked directly about it (Tasks 1 & 2).
b) Tasks/experimental situations that are put forth in the form of open questions and are not closely connected to the children's verbal expression (Tasks 3, 4 & 5).

In all these tasks we posed an initial question and then, based on each subject's answer, a dialogue ensued which was completed when we had a clear picture of each child's representation.

Task 1

Each child is asked the question: "What is light to you?" Through this question we are trying to explore whether and how children spontaneously distinguish a) light as a separate entity which is independent of light sources, and b) the visible results, such as, for example, the strong lighting on certain surfaces, i.e., whether children use operational thought by which they attribute to light certain autonomous properties. The answers we received were classified into four categories.

1. Answers that recognise light as an entity in space. For example, "It is something that is all around us and comes from the sun... (Question: Does it come from somewhere else?) … And from lamps" (S_{147}), "Light is beams… bright beams" (S_{273}).
2. Answers in which light is connected to its visible results or to bright spots. For example, "Light helps us see… it helps us walk at night" (S_{87}), "Light shines on us" (S_{210}), "light comes from the sun so we can see things... like on the wall over there..." (S_{362}).
3. Answers that focus on light sources. For example, "It's a thing that shines on us when there's no sun" (S_{102}), "Light is... the sun" (S_{202}), "It's a lamp that gives out light" (S_{280}).
4. The fourth category comprises answers given by children that cannot express a specific representation or the answer "I don't know," after we have insisted and given them plenty of time to think.

In Table 1 we present the frequency of answers by children of all three age groups for Tasks 1 and 2.

Table 1. Frequency of the answers of the children of all three groups to Tasks 1 & 2.

	Representations	Group 5	Group 8	Group 10	Total
Task 1	Light-entity	6	10	12	28
	Light-noticeable result	11	27	61	99
	Light-light source	91	77	35	203
	No representation	19	28	24	71
	Total	127	142	132	401
Task 2	Light-entity	2	7	9	18
	Light-noticeable result	17	35	63	115
	Light-light source	97	84	58	239
	No representation	11	16	2	29
	Total	127	142	132	401

These results show, first of all, that when we ask of children to express their thoughts on light in the form of an open question, they have difficulty recognising it as an entity in space. The problem remains a significant one as the children grow older, in spite of the small improvement that is observed from ages 5 to 10 (5 % at around 5 years old, 7 % at 8 and 9 % at 10 years old). However, the increase in age seems to correspond to an improvement in the recognition of light independently of its sources (9 % at around 5 years old, 19 % at 8 and 46 % at 10 years old), i.e., children's thought processes shift from the exclusive association between light sources and light itself. We also observed a respective decrease in age in the answers that remained focused on light sources (72 % at 5 years old, 54 % at 8, and 26 % at 10 years old). It is precisely these results, in the second and third answer categories that lead us to a statistically significant progression in terms of age ($\chi^2 = 67.55$, df = 6, $p < 0.01$). The improvement that comes with the increase in age is as significant statistically between 5- and 8-year-olds ($\chi^2 = 10.16$, df = 3, $p < 0.02$) as it is between 8- and 10-year-olds ($\chi^2 = 29.04$, df = 3, $p < 0.01$).

Task 2

In the second task we talked with the children based on the initial question "What do you think light does?" Through this question we tried to determine how children associate light with its results, given that pre-operational and operational thought leads to different kinds of reasoning. Results that can be traced through direct sensory perception, such as heating or lighting, display persistence in intuitive reasoning. By contrast, reasoning that goes beyond pre-operational thought recognises light as an independent entity associated to phenomena such as life and the growth of organisms. The answers we received in this task were classified into four categories:

1. Answers in which results caused by light as an entity are generally recognised. For example, "… (light) gives us life" (S_{96}), "…makes the day" (S_{386}).
2. Answers that focus on the noticeable results caused by light. For example, "It shines on the table and the blackboard" (S_{102}), "Light shines on us…" (S_{251}).
3. Answers that focus on the presence of light sources. For example, "…we turn on the lamp and it shines on things" (S_{101}), "Light is in the sun that shines on us" (S_{265}).
4. The fourth category comprises answers given by children that cannot express a specific representation or the answer "I don't know," after we have insisted and given them plenty of time to think.

In this task too, the results, as presented in Table 1, confirm the difficulties that children of all three groups have in recognizing light as an independent entity when they are called upon to think within the framework of an open question. Here again we observe a small improvement in regard to recognising

light as an entity, but in terms of quantity this improvement is extremely limited (2 % at 5 years, 5 % at 8 and 7 % at 10 years). However, just as in Task 1, we observe that as the children grow older there is a significant increase in the percentage of the answers in which it is recognised that light exists outside the light sources (9 % at 5.19 % at 8 and 46 % at 10 years). A respective decrease is observed in answers that associate light exclusively with light sources (72 % at 5. 54 % at 8 and 27 % at 10 years). Thus, by studying all the changes in the sample, there emerges a statistically significant improvement in the children's answers ($\chi^2 = 52.83$, df = 6, $p < 0.01$). And in Task 2, the improvement with age is statistically significant between 5 and 8 years ($\chi^2 = 10.06$, df = 3, $p < 0.02$) as well as between 8 and 10 years ($\chi^2 = 23.82$, df = 3, $p < 0.01$).

Task 3

In the room where the interview took place there was natural light, a light source in operation, and visible spots of light on walls, on the floor and on certain objects. Each child was asked to: "Tell me and show me three places in this room where you know light exists." When the children showed us only light sources and/or lighted surfaces, we would ask them to show us other places in the room so as to see whether they would refer to the light in space, i.e. whether they would use operational rather than pre-operational thought. In this task we received answers which we classified into four categories:

1. Answers in which light is recognised as an independent entity in space or on surfaces where there is no discernible bright spot. For example, "Light is all around us... it fills the air... " (S_{147}), "…it's above…below, to the right, to the left… everywhere" (S_{239}), "…it's all over the wall but some places we can see it and other places we can't…" (S_{380}).
2. Answers that focus on the surfaces where there are bright spots. For example, "I see the light of the sun on the window and on the floor… and the light of the lamp on the table, on the book…" (S_{65}), "The light is everywhere where it can be seen… on the wall, on the table, on the book…" (S_{302}).
3. Answers that focus on the light sources. For example, "When we turn on the electric lamp… there's light (*touches the lamp*) … now it's not turned on and it's hiding the light inside it" (S_{221}), "In this lamp… in the other one on the ceiling and… in the sun… (*Question*: Anywhere else?)… I don't see any anywhere else" (S_{388}).
4. The fourth category comprises answers given by children that cannot express a specific representation or the answer "I don't know," after we have insisted and given them plenty of time to think.

In Table 2 we present the frequency of answers by children of all three age groups for Tasks 3, 4 and 5.

Table 2. Frequency of the answers of the children of all three groups to Tasks 3, 4 & 5.

	Representations	Group 5	Group 8	Group 10	Total
Task 3	Light-entity	5	18	20	43
	Light-noticeable result	10	64	85	159
	Light-light source	112	58	26	196
	No representation		2	1	3
	Total	127	142	132	401
Task 4	Light-entity	9	28	64	101
	Light-noticeable result	65	68	50	183
	Light-light source	53	46	18	117
	Total	127	142	132	401

	Representations	Group 5	Group 8	Group 10	Total
Task 5	Light-entity	2	32	41	75
	Light-noticeable result	64	75	75	214
	Light-light source	61	35	16	112
	Total	127	142	132	401

In the third task, in which children are asked to locate light in different parts of the room, we observe a slight increase in the answers given by subjects of Groups 8 and 10 recognising light in space (4 % in Group 5.13 % in Group 8 and 15 % in Group 10). Moreover, we observe a significant increase in the number of subjects of the same groups that locate light away from light sources, albeit including areas of bright spots (8 % in Group 5.45% in Group 8 and 64 % in Group 10). At the same time, as the children grow older, there is a significant reduction in the subjects that focus on light sources (88 % in Group 5.41 % in Group 8 and 20 % in Group 10) and thus the processing of all the results leads to a statistically significant progression ($\chi^2 = 128.09$, df = 6, $p < 0.01$). The improvement of the subjects' answers with age is statistically significant between 5 and 8 years ($\chi^2 = 65.06$, df = 3, $p < 0.01$) as well as between 8 and 10 years ($\chi^2 = 14.86$, df = 3, $p < 0.01$).

Task 4

We turn on a flashlight (3V, 1.5W), turn its beam to a wall at a distance of 3m creating a bright spot, and ask the children: "Where is there light produced by the lamp?" If the children locate the light at the light bulb or on the wall, we ask them to show us "if there is light between the light bulb and the wall." Moreover, the children that refer to the wall are asked to show us where exactly on the wall do they recognise that there is light. Through this task, carried out in a familiar situation, we can explore whether the children recognise light in space or not, and where exactly they locate it. In this task, we received answers that we classified into three categories.

1. Answers in which light is recognised as an entity in space or on surfaces on which there is no distinct bright spot. For example, "It's everywhere in the air... all the way to the wall (*points at the trajectory from the light bulb to the wall*) … but we can't always see it" (S_{147}), "The rays leave the flashlight and go to the wall... between them there is always light" (S_{304}).
2. Answers that focus on the surfaces upon which there are bright spots. For example, "It's over there, on the white wall... There it is... The round spot that's lighted" (S_{233}), "The light of the light bulb is only on the wall… we don't see any in between… (*Question:* We don't see any or there isn't any?) Since it doesn't exist... we don't see it... it's only on the wall... over there" (S_{346}).
3. Answers that focus on light sources. For example, "Light is the flashlight you're holding… there isn't any anywhere else…" (S_{82}), "Light is in the lamp… it doesn't exist in the air, unless you shine the flashlight on a certain point" (S_{186}).

Here, the progress in recognising light as an independent entity is even greater than in the third task for the groups of subjects aged 8 and 10 (7% at 5 years, 20% at 8 and 48% at 10 years). However, it seems that a simple experimental circumstance helps the subjects of all groups to recognise light away from the light source (51% at 5 years, 48% at 8 and 38% at 10 years). This improvement, together with the concurrent decrease in the answers focusing exclusively on a light source (42% at 5 years, 32% at 8 and 14% at 10 years), leads to a statistically significant progression following the processing of the results in their entirety ($\chi^2 = 68.48$, df = 4, $p < 0.01$). In task 4 also, the improvement of the subjects' answers with age is statistically significant between 5 and 8 years ($\chi^2 = 9.50$, df = 2, $p < 0.01$), as well as between 8 and 10 years ($\chi^2 = 28.74$, df = 2, $p < 0.01$).

Task 5

Two pieces of cardboard (A and B), 17cm x 25cm, are placed perpendicularly to a horizontal surface and at a distance of 12cm from each other (Figure 1). Cardboard A has a hole in it, 0.5cm in diameter at a height of 17cm from the horizontal surface. At a distance of 10cm and exactly at the height of the hole, a light source L (4.8V, 2.4W) is placed.

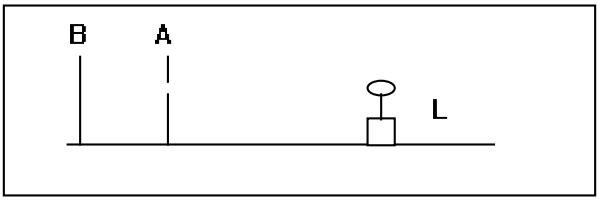

Figure 1. Schematic representation of the Task 5.

The lamp is turned on without the light beam being visible, and we ask the children whether "there is light in the space between the two pieces of cardboard." Our aim here is to explore where the children recognise the presence of light in a situation that is not familiar but artificially constructed. In this task we receive questions that we classify into three categories:

1. Answers in which light is recognised as an independent entity in space or on the surfaces on which there is no discernible light spot. For example, "The light goes as far as the hole… then it goes through the hole, continues between the two pieces of cardboard... and comes to here, on cardboard (B) " (S_{194}), "since the light reaches the second piece of cardboard, then it is everywhere in the air… both before and after the hole" (S_{325}).
2. Answers that focus on the surfaces upon which there are bright spots. For example, "Not between them… there is light only on cardboard (B) " (S_{185}), "There is some light on cardboard (A) and then after the hole there is some more light on cardboard (B) " (S_{336}).
3. Answers that focus on light sources. For example, "the light is in the lamp… I don't think there's any in the air…" (S_{220}), "The lamp… the lamp… not between the pieces of cardboard" (S_{399}).

In this task we see that, unlike the subjects in Group 5, several children from Groups 8 and 10 achieve a representation in which light in space is recognised (2% in Group 5, 22% in Group 8 and 31% in Group 10). Furthermore, over half the children in each group recognise the existence of light in the bright spot on the piece of cardboard B (50% in Group 5, 53% in Group 8 and 57% in Group 10). Respectively, a small number of subjects, mainly from Groups 8 and 10, refer exclusively to the light sources (48% in Group 5, 25% in Group 8 and 12% in Group 10). The processing of all these results gives a statistically significant progression for the entire sample ($\chi^2 = 63.52$, df = 4, $p < 0.01$). Finally, in Task 5 too, the improvement of the answers with age is as significant statistically between 5 and 8 year olds ($\chi^2 = 33.65$, df = 2, $p < 0.01$) as it is between 8 and 10 year olds ($\chi^2 = 7.83$, df = 2, $p < 0.025$).

Discussion

First of all, the research results show that recognising light as an entity in space is, broadly speaking, an important problem in children's thought process, as has been pointed out in the related bibliography regarding different ages. It seems, then, that an obstacle of a psychological nature keeps interfering with the thought process of children who have not yet been taught Optics in school. This obstacle cannot merely be an adherence to the givens of perception, since the children could easily locate light on the various lighted surfaces they see and yet a large number of them focus exclusively on the light sources. The transitivity hypothesis proposed by Piaget and Garcia (1971) gives an adequate psychological explanation of the difficulty of understanding not only light, but also other natural entities that entail a transmitter, a field of propagation and a receiver. It also points to the direction in which researchers should move when exploring children's difficulty in recognizing light as an autonomous entity and addressing the question

of a conceptual change (Stead & Osborne, 1980; Guesne, 1985; Osborne, Black, Meadows, & Smith, 1993; Langley, Ronen & Eylon, 1997; Galili & Hazan, 2001).

However, in terms of teaching, we cannot ignore the qualitative superiority of the answers that recognise the existence of light outside light sources, albeit in the form of bright spots, compared to other answers that stress that light exists only in the light sources or is identified with them. For, indeed, when children recognise light independently of its sources, we are able, through special teaching interventions, to lead their thought to formulate the necessary reasoning which will conclude with the construction of light as a material entity that exists everywhere in space.

From the point of view of methodology, we came across big differences between the answers between the tasks/open questions and the tasks/experimental situations. It appears that, as the open questions require more developed verbal abilities, established representations in the selection of examples and, primarily, the ability to tackle, process and understand abstract questions, the majority of the children and almost all the children aged 5 were not in a position to discuss light in space in terms of its autonomous presence. This specific dimension of the matter is also evident in the 'lost' questions to which the children either do not answer at all, or answer in a way that does not allow us to give form to a representation. Indeed, as we saw, while in the tasks/open questions we had several lost answers from subjects belonging to all the groups, in the tasks/experimental situations, in which all questions address specific problems, there were very few lost answers.

By studying the results in their entirety, we can observe that, starting with children aged 5 and shifting towards children aged 10, there is systematic improvement in the matter of recognizing light as an entity in space, independent of light sources and the results it causes. Furthermore, there is great progress in the matter of locating light outside light sources. These observations are also statistically confirmed in all tasks. It is also interesting to note that the statistically significant progression is observed between 5- and 8-years-olds as well as between 8- and 10-year-olds.

This general improvement can be expected with the increase in age, since, as the children grow older, they reorganise and improve their representations of natural entities. However, in the matter of understanding light as an independent entity in space, the results show that the progress made before any kind of systematic teaching intervention is limited and concerns only older children. Nevertheless, given that in many international curricula children's exposure to the concepts and phenomena of Optics is carried out as early as kindergarten, addressing the concept of light as an entity in space is necessary, since all the optical phenomena require and presuppose the construction of the concept of light.

From a didactic aspect, therefore, it is both useful and effective to lead the children as early as possible to the construction of the concept of light. This might involve efforts to approach light through activities that aim at the formation of images (Gallegos Cázares, Flores Camacho & Calderón Canales, 2009) or at the comprehension of the mechanism of vision (Osborne, Black, Meadows, & Smith, 1993).

In other studies, researchers have directly attempted to transform children's representations of light. The results of a previous study (Ravanis, Papamichaël and Koulaidis, 2002) showed that, through processes of cognitive destabilization and reconstruction of their representations, children aged 10 are able to effectively construct a concept regarding light that is compatible with the model of Geometrical Optics. The study carried out here moves in the same direction but involves 5- as well as 8-year-olds.

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