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ALTERNATIVE IDEAS OF STUDENTS 6-10 YEARS OLD FOR THE FORMATION OF SHADOWS IN THE CONTEXT OF GEOMETRIC OPTICS

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Abstract:
The study of students' alternative ideas of natural science concepts and phenomena is a major objective of Science Education and Pedagogy research. The research presented in this article aims to record the alternative ideas of 6–10-year-old students about the shadow, which is a key phenomenon in Geometric Optics with which we work from Kindergarten to advanced secondary education. Not only for its own understanding, but also because it is the basic introductory phenomenon that underlines the interaction of light with matter. This article presents the results of a study on the understanding of shadow formation by pupils aged 6-10 years, i.e. the first four years of primary education. This is an attempt to understand what the students' misconceptions about the shadow are and how they evolve over time. This research was conducted using a descriptive qualitative design. A total of 402 pupils participated from 19 different primary school classes, divided into four age groups. The survey was conducted through individual semi-directed interviews lasting approximately 11 minutes. The children were asked to answer three tasks, which included different topics related to the formation of shadows. The data analysis was carried out from the transcripts of the interviews using the method of content analysis. Responses were categorised according to their distance from school science knowledge. The results captured significant cognitive barriers to understanding the formation of shadows, and particularly the mechanism of light-opaque barrier interaction. These data show a slight improvement with the age of children, but this is not statistically significant.

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1. Introduction

Within the frameworks of Science Education, Cognitive and Developmental Psychology and the Epistemology of Knowledge, it is absolutely recognized that children approach the physical and social world through certain entities of their thinking called in the international bibliography "*misconceptions*", "*mental representations*", "*naïve* or *spontaneous ideas*", "*alternative conceptions*" (Kontili *et al*., 2025; Rodriguez, 2018; Sotirova, 2024). The question of the nature of these entities of human thought has led to research results that have a strong influence on the teaching of sciences such as chemistry, physics, biology, etc. (Aouad & Andreucci, 2015; Ravanis, 2013; Jégou-Mairone, 2009). This research has produced two powerful and solid results. The alternative conceptions: (a) are the result of the existence of children in their social, natural, cultural and educational environment and have a dynamic, developmental and evolutionary nature, and (b) they are generally at a distance from the natural science models we use in education, which are compatible with those of the pure sciences.

In view of these stable research results, after some fifty years of studies in didactics, the interest of the education and research community in the learning and teaching of natural sciences has been directed towards the design, creation and evaluation of didactic interventions likely to facilitate the construction of ideas compatible with scientific thought. The debates often pit proponents of traditional methods against each other in a sclerotic way, thereby obliterating the need to examine other pedagogical approaches such as those inspired by constructivism, socioconstructivism, or sociocultural approaches (Dean, 1999; Cunningham & Cordeiro, 2003; Fragkiadaki & Ravanis, 2016; Tin, 2016, 2017), i.e. based on exploiting pupils' alternative ideas. Despite this implicit or explicit 'resistance', the need to improve and renew teaching in the natural sciences has led to the development of research in Science Education.

In this theoretical framework, the research that has been carried out extends to a wide range of concepts and phenomena of the natural sciences and, of course, of physics. Indeed, in all fields of Physics (heat, electricity, mechanics, etc.), issues have been studied in all grades that, on the one hand, are related to the discovery of students' alternative conceptions and the difficulties they create in learning, and on the other hand, teaching interventions aimed at addressing the identified difficulties. One of these fields is Geometric Optics, which is a classic topic of study from pre-school to the first cycle of secondary education. Research in Geometric Optics has clarified many elements of students' reasoning, both before and after instruction, about light as a distinct entity (Castro, 2013, 2018, 2019; Castro & Rodriguez, 2014; Grigorovitch, 2014, 2015; Ravanis *et al*., 2002; Rodriguez & Castro, 2016, 2020), the rectilinear propagation of light (Castro, 2018; Yurumezoglu, 2009), the vision (Kokologiannaki & Ravanis, 2013; Selley, 1996), the colors (Hoang, 2020; Keles & Demirel, 2010; Kocakülah, 2006) etc.

But what is the cause of this solid finding? It's the difficulty young children have in associating different entities with each other, and therefore in dealing with these isolated entities. In this context, the explanations given by the pupils focus solely on the shadows, obstacles or light, and do not build the necessary links between the shadow and light mediated by the obstacle (Impedovo *et al.*, 2017; Parker, 2006; Ravanis, 1998; Resta-Schweitzer & Weil-Barais, 2007; Segal & Cosgrove, 1993; Voutsinos, 2013). In addition to research into the question of understanding the formation of shadows in the minds of young children, some constant difficulties have been found, such as recognising the correct plan for projecting a shadow, the positions of shadows in relation to light sources and obstacles, the correspondence between the number of lamps and the number of shadows, etc. (Chen, 2009; Grigorovitch, 2015; Grigorovitch & Nertivich, 2017; Herakleioti & Pantidos, 2016; Kampeza & Delserieys, 2020, 2024; Nertivich, 2016; Ravanis *et al.*, 2005).

An interesting research topic is whether the biological maturation of children helps them cope with the difficulties arising from alternative conceptions. That is, whether, prior to any organized classroom instruction, as children are growing up, they can reorganize their initial alternative conceptions. In this direction, this study presents the results of qualitative research into the alternative conceptions of pupils aged 6-10 about the phenomenon of shadow formation. Therefore, our research questions concern the study and identification of alternative conceptions of shadow formation in different contexts. Thus, alternative conceptions and their evolution with the age of the children were recorded for the following situations:

1) The interaction between light and objects is the physical cause of shadow formation.
2) The prevention of light creating a shadow field in space, and not just on the projection surfaces of the object that has acted as an obstacle to the formation of the shadow.
3) The correspondence between the number of light sources and the number of shadows caused.

2. Methodology

2.1. Research Design and Procedures

This research was qualitative and was implemented through semi-structured interviews. The interviews were conducted prior to any systematic teaching intervention on shadow formation in their classroom in order to record the students' alternative conceptions as they are formed in their everyday lives. The discussions with the children were individual, lasted about ten minutes and took place in the school laboratory or in specially secluded areas of their schools. We had the agreement of the schools, the students' teachers and their parents, who were informed by the school. (Cohen *et al.*, 2018; Creswell *et al.*, 2018; Fraenkel *et al.*, 2019).

2.2. Participants

The research involved 402 pupils from 19 different primary school classes, divided into four age groups [6-7 years group: 97 pupils (49 boys and 48 girls, mean age: 6 years and 4 months, S. D. 3 months), 7-8 years group: 105 pupils (54 boys and 51 girls, mean age: 7 years and 5 months, S. D. 4 months), 8-9 years group: 95 pupils (46 boys and 49 girls, mean age: 8 years and 7 months, S. D. 2 months), 9-10 years group: 105 pupils (52 boys and 53 girls, mean age: 9 years and 6 months, S. D. 3 months). These students agreed to discuss with us, and therefore, this sample was convenient. These are pupils whose parents have no particular knowledge of the physical sciences. The schools are located in an urban area, and the children's families have an average socio-economic status.

2.3. Instruments

The study of the children's alternative conceptions of the three research questions was carried out using 3 specific tasks (Ravanis *et al.*, 2005, 2010). The first task was based on a simple discussion between the researcher and the child, while the second and third included the necessary experimental support. For all the tasks, we asked the initial question and, based on each child's response, we continued the dialogue until each child's representation was clearly identified.

Task 1: In the first task, a flashlight and various opaque objects are used. We ask the children to think about and explain the process of shadow formation through the following questions: "What is a shadow?", "How is a shadow formed?", "When is a shadow formed?" or "Under what conditions is a shadow created?".

Task 2: With a torch that we place in front of a matchbox supported in an appropriate way (Figure 1), we form a shadow on a screen that is at a distance from the box. We ask the children to show us three places in the space between the box and the screen where a match that we were supposed to be placed will not be directly illuminated by the lamp. This question is asked with the aim of checking whether the children recognize that the shadow is created not only at the points in space where they can perceive it directly (such as on the screen or just behind the box), but also at the space in between.

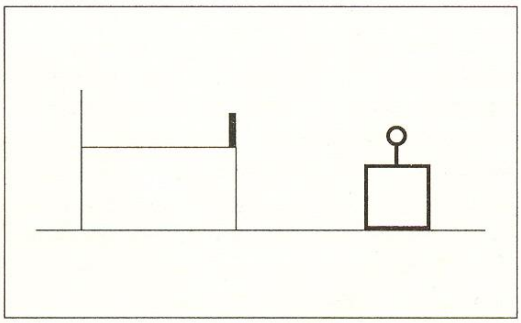

Figure 1: The Task 2 configuration

Task 3: We showed the children a photo (Figure 2) showing a football player and his two shadows on a horizontal plane. The shadows are formed by two headlights and

the player, who is visible in the figure and stands as an obstacle between the headlights and the horizontal plane. We ask the children to show us the place from which "the player is lit", in other words, the position and number of the light sources.

Figure 2: The photo of the footballer for Task 3

2.4. Analysis of data

The interviews with the children were recorded. The texts of the transcribed interviews were approached by content analysis (Patton, 2014). This analysis identified the students' alternative conceptions of shadow formation. The coding of the children's answers was based on their relation to school scientific knowledge, i.e. the qualitative interpretation of the formation of shadows in the context of Geometric Optics. The data were analysed by two researchers, and when there was a discrepancy, they discussed to resolve it. For all three tasks, three major categories of ideas were identified in the discussions with children.

1) "Sufficient" answers were those in which students identified the mechanism of shadow formation, i.e. the obstruction of light propagation from opaque objects. The obstacle is always between the light source and the shadow. That is, the reasoning is compatible with the model of geometric optics.
2) In the category of “intermediate”, responses were those in which students referred to the basic elements of the layout, but without consistently identifying their interactions leading to the formation of the shadows.
3) “Insufficient" responses were defined as those which simply stated the elements of the situation without correlating them. These are answers that are not related to the geometric optics model.

3. Results

When analyzing the results, we classified the responses we received during the interviews into three categories, which we mentioned above. We present below typical examples of responses for each category in all three projects, and also a table with the frequencies of responses. Each student is given a number with the following distribution:

6-7 years from 1 to 97, 7-8 years from 98 to 202, 8-9 years from 203 to 297, 9-10 years 298-402.

a) Sufficient answers. These are answers which offer a satisfactory explanation from the point of view of the scientific model of geometrical optics.

- **Task 1.** In the first task the students clearly refer to the mechanism for forming shadows [e.g. *"…. the light does not pass through the chair ….. it forms a black chair on the floor…."* (Student 124), " *….. this shadow… is the shadow that makes the light and the curtain. (Researcher: But how?) It is the light that is prevented from passing…."* (S. 166)].
- **Task 2.** In the second Task the children can explain sufficiently that the shadow exists, on the cardboard and/or just behind the box, but also in the space between the cardboard and the box [e.g. *"… (the shadow) is there….. between the cardboard and the box…" (S. 130), "….. there's a shadow in the air… you can't see it…"* (S. 195)].
- **Task 3.** In the third task, the students correctly predict the correspondence between the number of light sources and the number of shadows, but also the correspondence of each source with each shadow [e.g. "*The two lamps will make two shadows……", "…. we have two shadows….. by two lamps*" (S. 41)].

b) Intermediate answers. In these answers, while recognizing the factors that cause the formation of shadows, there is instability in reasoning, backtracking or contradictions.

- **Task 1.** In the first task the students refer to the factors that create the shadow without being able to suggest the exact mechanism [e.g. *"…. (the shadow) is made from light….. (R: Can you tell me how exactly?)…. We turn on the light and it becomes…. but there must be things….. the shadow is made from light and things*" (S. 12), *" ….. On one side there is the lamp with the light it gives off. On the other side are the…. objects such as, say, this box. When these are present, it becomes the shadow. (Researcher: But how?) …. After we turned on the light, it became the shadow…*" (S. 166)].
- **Task 2.** In the second task, several children refer to the shadow that will form on the cardboard, sometimes just behind the box, but do not refer to the space between the cardboard and the box [e.g. *"… there will be a black box (points to the cardboard)*" (S. 88), "*On the cardboard across the way it will definitely be….. and just behind the box and there's the shadow…. (R: In the air between the box and the cardboard?). No there's the air of the atmosphere, it's not a shadow…. the shadow appears somewhere*" (S. 395)].
- **Task 3.** In the third task, sometimes students correctly predict the correspondence between the number of light sources and the number of shadows. However, in the case of intermediate answers, sometimes they express doubts and/or sometimes they cannot explain which shadow corresponds to which light source and how this happens. [e.g. "*It's two shadows….. will be lit by two lamps….. not sure…. Maybe one lamp can do that….*" (S. 47), "*Every shadow is created by a lamp….. The right shadow is made by the right lamp which cannot be seen, and the left shadow is made by the left*

lamp.... which cannot be seen either. (R. How is that possible? Can you explain?). I think by reflection.... It hits the light on the man and makes the shadow" (S. 338)].

c) Insufficient responses. This category includes answers that do not use the main elements of the shadow formation process that are compatible with the geometric optics model. The following responses are classified in this category.

Task 1. In the first task, the pupils give answers without reference to the relationship between the light and/or the object for the formation of the shadow. [*"I can see it on the wall*" (S. 174), "*When there is light, the shadows become..... (R: but how do they form?). It's the light that makes the shadows.... (R: and the objects do something?). The objects stay as they are*" (S. 198)].

Task 2. In the second task, the students do not recognise that the shadow is not on the cardboard and/or the box, but also in the space in between. [e.g. "*The shadow..... is there... (he shows on the card). (R. Is there a shadow elsewhere? Behind the box? Between the box and the cardboard?)*". *I don't see anything.... (R. You don't see or it doesn't exist?). But..... if you don't see it black..... there is no shadow.... (S. 108), "... no, there's no shadow there (in the space)..... it's on the cardboard*" (S. 186)].

Task 3. In the third task, the children cannot match the number of shadows with the number of light sources for a given obstacle both quantitatively and qualitatively since they cannot explain how the two shadows are made [e.g. "*I saw this picture on the football pitch.... but I don't know why it's on the ground... is it not a real photo?" (S. 106), "I think there's a big headlamp at one end of the stadium....*" (S. 174)].

The frequencies of the responses of the students in the four groups who answered the three tasks are presented in table 1 below.

Table 1: The frequencies of the responses of the students in the four groups

		Frequencies							
	Answer	**Age 6-7**		**Age 7-8**		**Age 8-9**		**Age 9-10**	
Task 1	Sufficient	4	4.12%	4	3.81%	6	6.32%	8	7.62%
	Intermediate	43	44.33%	56	53.33%	47	49.47%	53	50.48%
	Insufficient	50	51.55%	45	42.86%	42	44,21%	44	41.90%
Task 2	Sufficient	5	5.16%	7	6.66%,	12	12.63%	13	12.38%
	Intermediate	21	21.65%	32	30.48%	22	23.16%	33	31.43%
	Insufficient	71	73.19%	66	62.86%	61	64.21%	59	56.19%
Task 3	Sufficient	3	3.09%	2	1.90%	7	7.36%	9	8.57%
	Intermediate	31	31.96%	40	38.10%	34	35.79%	38	36.19%
	Sufficient	63	64.95	63	60%	54	56.85%	58	55.24%

Statistical analysis of the results (χ^2 test) found no statistically significant differences between the four groups. Also, the comparison of performance between boys and girls in each of the 4 groups did not give a statistically significant result.

4. Discussion, implications, limitations, suggestions

In this article, we studied the ideas of children aged 6 to 10 regarding the phenomenon of shadow formation. The data collected described the most important difficulties of the subjects in our sample. In the first task, we saw that most children have difficulties with the physical cause of shadow formation. In fact, only 4.12% (group aged 6-7), 3.81% (group aged 7-8), 6.32% (group aged 8-9), and 7.62% (group aged 9-10) of pupils can explain how a shadow is formed in relation to light and an object. Based on these data, we can assume that the overwhelmingly large proportion of students either give intermediate or insufficient answers based on what we might call intuitive or spontaneous reasoning.

For the second task, the sufficient responses were 5.15%, 6.66%, 12.63% and 12.38% for the 6-7, 7-8, 8-9 and 9-10 age groups, respectively. This may mean that the thinking of the vast majority of children is dominated by the sensory effect because their reasoning is trapped in places where the shadow is visible.

Finally, the results in the third task show that very few children are able to make complete reasoning about the appearance of multiple shadows (3.09% in the 6-7 years old group, 1.90% for the 7-8 years old group, 7.36% for the 8-9 years old group and 8.75% for the 9-10 years old group). Here, dominant responses are those in which the shadow is more a product of light and object as separate entities than a logical construction based on the interactions of opaque objects with light coming from light sources.

These findings are consistent with those in international literature, as difficulties in learning and teaching the formation of shadows are found in the 6-10 age group (Delserieys *et al.*, 2022; Grigorovitch, 2015; Ravanis *et al.*, 2005, 2010). In this context, a particular finding in this research is the great importance of all tasks of the cognitive obstacle of understanding the exact mechanism of shadow formation, i.e. its creation as a product of the obstruction of transmitted light. However, the most important new finding is the stability of the difficulties in understanding shadow formation across a wide age range, covering the 6–10-year age period. The findings showing minimal improvement in children's responses with increasing age highlight the importance of tailored teaching interventions, as biological maturation does not seem to allow children to reconstruct alternative ideas about shadow.

Despite having a relatively large sample for its qualitative nature, this survey needs a quantitative extension to a larger sample to control other variables such as the social origin and place of residence of the children, their performance either in science or in all their subjects. It would also be interesting to extend this research to other national or cultural contexts to allow for comparative studies.

In such oriented research, an important issue is always the relation of the results to the curricula, teaching materials and textbooks. In this respect, the data from this research can be useful at all these levels, as they highlight some critical issues for learning and teaching the phenomenon of shadow formation in young children. Another

interesting research topic is the correlation of the formation of the shadow with concepts such as light as an entity or transparent and opaque objects.

5. Conclusions

As discussed in "Introduction", the issue of students' alternative ideas, especially at young ages, despite many years of research in this field, is always important (Grigorovitch, 2018; Ravanis, 2020; Rodriguez, 2025; Zulkipli & Surat, 2022). Indeed, the findings of the research presented here show that despite the increase in children's age from 6 to 10 years, the difficulties in developing reasoning about shadow formation remain constant and systematic. In this sense, it is of particular importance both to conduct research that identifies difficulties such as the one presented here and to conduct research that tests the effectiveness of teaching interventions based on identified difficulties rather than on simple empirical designs and estimates. This direction of research is of particular interest for pre-school and primary education in the concepts and phenomena of geometric optics, since for secondary education, it is a research field that has been quite developed in the last decades.

Conflict of Interest Statement
The authors declare no conflicts of interest.

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