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THE FORMATION OF SHADOWS: THE CASE OF THE POSITION OF A LIGHT SOURCE IN RELEVANCE TO THE SHADOW

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Abstract: The study of pupils' 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 212 fifth grade pupils' mental representations of the formation of shadows, before they were taught about it in school. The empirical data was gathered through an interview using four 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 shadow.

Key words: Formation of shadows, light source, pupils' mental representations

1. The Theoretical Framework

The study of representations of pupils of all ages and school levels within the context of Physics Education points to the need for the creation of special teaching interventions in a wide spectrum of subjects in the teaching of the Natural Sciences (Ravanis, 1999; Ergazaki, Komis & Zogza, 2005; Kampeza, 2006; Koliopoulos et al., 2009). These representations, which are often in contradiction to the explanations given by Physics in regard to these phenomena, are referred to in literature as ideas, misconceptions, preconceptions or alternative conceptions. The problem of the formation of shadows is critical in the learning and teaching of Geometrical Optics because "*developing a qualitative explanation of shadow formation requires a complex synthesis of knowledge including:*

- *light as an entity produced by a light source;*
- *light as an entity propagated in space;*
- *reflection and absorption of light as it interacts with an object;*
- *shadow formation as an area of darkness that varies in intensity according to how much light is reflected from the area into the eye; and*
- *the role of the eye as a receptor*" (Parker, 2006, p. 1551) .

In this paper we will study the mental representations of ten-year-old children about the formation of shadows by point light sources and an object in the shape of a stick.

The children's explanations of the natural phenomena are neither arbitrary nor casual estimations; they result from a series of intellectual achievements of a psychological nature, which we must become aware of in order to predict and interpret correctly the alternative conceptions and also for reasons concerning teaching methods. As a theoretical framework we will use the Piagetian theory because we believe that its codifications can also explain, from a psychological point of view, children's difficulties regarding the formation of shadows.

There are important differences between pre-operational thinking and concrete operations in the case of the formation of shadows. Jean Piaget and Bärbel Inhelder (1981, pp. 181-225) have shown that the elementary topological relations change into projections as soon as the child is able to decenter his

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point of view, i.e., to differentiate his own point of view from all the others and, at the same time, to coordinate it with the others. According to Piaget and Inhelder, two questions can be posed regarding the formation of shadows (op.cit., p. 227).

1. One question referring to the understanding of the natural cause of the shadow.
2. The second question referring to the anticipation of the shadow in relevance to the object.

In this paper we will only address one aspect of the last question. Pre-operational thought, dominated by egocentrism, does not allow the child to differentiate his/her views and thus the only possible view is a result of the restrictions imposed by the conceptual centrations of the objects forming the problem in question. Gradual decentration removes initial egocentrism from the thought of the child and thus, during the stage of concrete operations, the child becomes capable of coordinating perspectives by means of logical thinking, thus establishing groups of relations between the dimensions of the projective space. The procedure of the understanding of the formation of shadows presupposes the ability to coordinate the light source, the object casting the shadow and the planes on which the shadow is projected.

Data taken from relevant research agree that 5- to 12-year-old children face the problem of the shaping of shadows by a pre-operational way of thinking. "Some of the earliest accounts of children's ideas about shadows can be found in Piaget's *Conception of Physical Causality* (Piaget, 1930) and *Conception of Space* (Piaget & Inheler, 1967). In both books, Piaget identified four different stages or levels of concept development for children aged five and over. The four stages of physical explanations of shadows are as follows: The shadow of an object is regarded as emanating from both internal (the shadow emanates from the object) and external sources; the shadow emanates from the object; the shadow emanates from the object but the emanation drives away the light; and the formation of shadows is due to the light being blocked by the objects" (Chen, 2009). Other researchers have found that shadows as reflections of objects, the prediction of the shape of a shadow, the explanation of how the shadow was formed, the relation of the light source(s) to the shadow and the size or the orientation of the corresponding shadows can pose problems in understanding and learning (Tiberghien et al., 1980; Guesne, 1985; Feher & Rice, 1988; Fleer, 1996; Ravanis, 1996; Ravanis et al., 2005; Ravanis & Koliopoulos, 2007; Resta-Schweizer & Weil-Barais, 2007, 2009; Dedes & Ravanis, 2007, 2009; Chen, 2009; Gallegos Cázares et al., 2009).

Our hypothesis is that, in the event that the shadow and the object making it are visible, ten-year-old children make evaluations regarding the position of the light source which are influenced by conceptual centrations, i.e., are not based on the model of Geometrical Optics. The observed difficulties of the children increase when the design of the experimental condition requires more complex coordination.

2. Methodology

2.1. Sample

The sample consisted of 212 subjects (106 boys and 106 girls), aged 10 years and 1 month (S.D. 2 months), from 17 different school classes. 132 interviews were made in 1989 (S_1-S_{132}) and 80 in 2009 (S_{133}-S_{212}). The pupils who took part in the research had not yet been taught the relevant subject by their teachers. The children's parents' level of education ranged from a total of 12 to 24 years for each set of parents, none of whom had attended university. All socio-economic levels (low, middle, high) and all levels of pupils' performance (low, middle, high) were represented equivalently in the sample.

2.2. Design and tasks

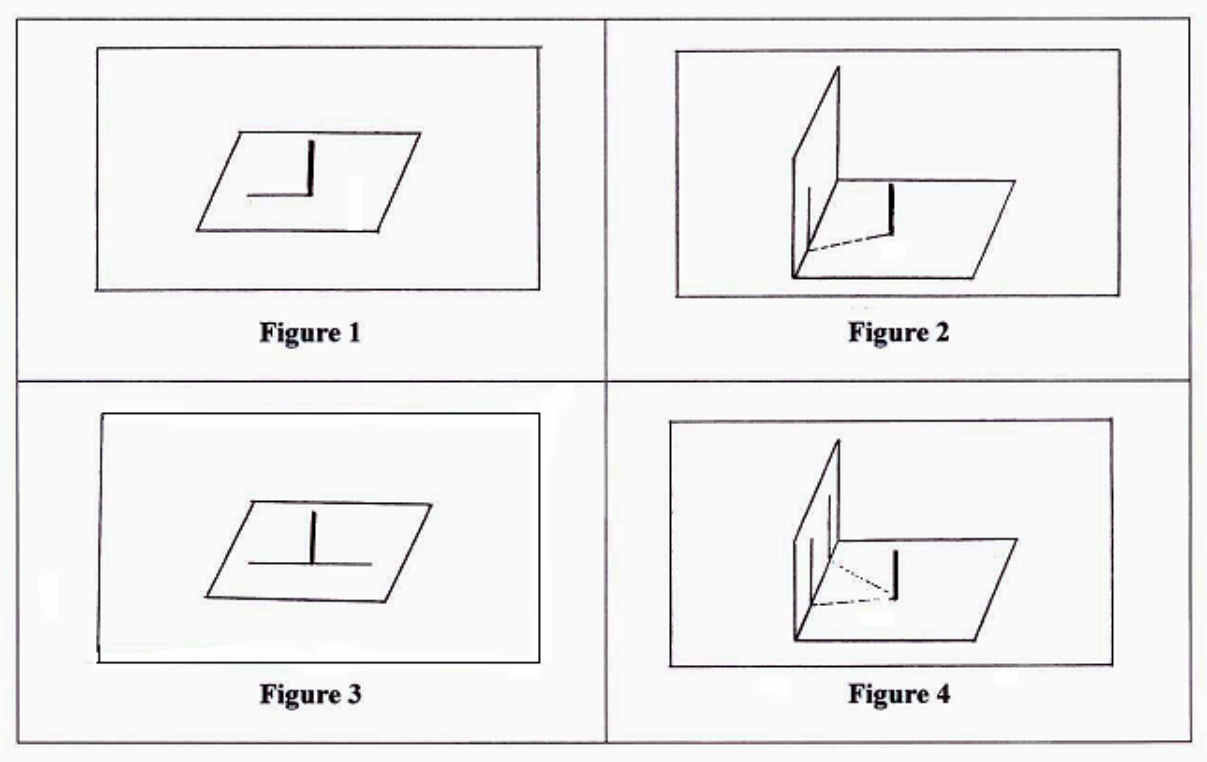
The technique we used in our research was the directive individual interview. Each interview lasted approximately 15 minutes and was held in the schools' laboratories.

We presented successively to the children four figures in which one can observe a shadow on a horizontal plane (Figure 1), a shadow on a vertical plane (Figure 2), two shadows on a horizontal plane (Figure 3) and two shadows on a vertical plane (Figure 4). All the shadows are formed by a

torch and a baton made of cardboard, 13.5cm in height, which is visible in all figures and is placed as an obstacle between the torch and the plane. In each case we ask the children to show us the place from which the torch is lighted, i.e., the position and the number of the light sources. 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.

The choice of these four tasks serves two purposes. The distinction between the horizontal and the vertical plane is made because the shaping of the shadow on the two planes requires projective coordinates of a different kind. Being able to change the topological relations into projective ones constructs a representation which has to correspond to this change, regardless of the kind of projection, since it is formed during the stage of concrete operations.

The first distinction aims to locate the functional use of the projective activity of the child's thought process in regard to the formation of shadows, in order for us to draw conclusions regarding the integration and stability of the conception. The second distinction, i.e., the repetition of the questions about figures with two shadows, aims at the same purpose mentioned above. We can locate a factor which might lead to the revelation of difficulties of a functional nature, since our task does not allow any other possibility but the corresponding light sources and shadows, one-to-one; this factor is the number of shadows and consequently the number of light sources.



Figures. *The four tasks*

If reversibility has already been achieved, the children will have no difficulty is discerning the number of light sources, since the number of shadows has already been discerned. If the mechanism forming the shadow is recognized, an estimation of the exact position of the light source is also possible.

3. Results

In regard to the first and second task (Task 1 & 2), during which the children are asked to comment on the figures showing one shadow, the answers given by the children can be classified into two categories (Table 1):

1. Answers showing that the child correctly locates the position of the light source in relevance to the obstacle and the shadow. For example: "It's here … on the right" (Subject 6, Task 1). "The light leaves the lamp … striking the stick …and the shadow goes back… Appears on the floor and the wall because the lamp is low… (*shows the path by hand*)" (S. 96, Task 2).
2. Answers showing that the child does not correctly locate the position of the light source. For example: "This way … exactly … (*Researcher: From the middle?*) … Yes, from the middle…" (S. 182, Task 1). "The light must come from the top … so that the shadow falls on the wall… (*shows a lamp over the baton*)" (S. 201, Task 2).

Table 1. Results of locating the position of the light sources causing the formation of the shadows in the Tasks 1& 2

Task	Answer	N	%
1. One shadow horizontal plane	Correct position of the light source	167	78.8
	Incorrect position of the light source	45	21.2
2. One shadow vertical plane	Correct position of the light source	156	73.6
	Incorrect position of the light source	56	26.4

During the next two tasks (Task 3 & 4), the children see figures showing two shadows. In this case the answers given are classified into three categories (Table 2):

1. Answers showing that the child correctly locates the position of the light sources. For example, "I think they have put two torches … because there are two shadows (*the child shows the positions correctly*)" (S. 49, Task 3). "Since we have two shadows, we will have two torches. This lamp make this shadow... (*correctly*)" (S. 114, Task 4).
2. Answers showing that the child correctly locates only one of the two light sources. For example, "From here (*from the left*) … Because in this way … there is more light here … and when the light comes from both sides it makes two shadows because it has a round shape" (S. 3, Task 3). "The light falls on the baton and creates the shadows" (S. 69, Task 4).
3. Answers showing that the child incorrectly locates the position of the light source as being between the two light sources. For example, "From the middle … because if the lamp was on the right or on the left, it could not be lighted here…." (S. 27, Task 3). "The torch is between the two shadows …in front of the baton…" (S. 111, Task 4).

Table 2. Results of locating the position of the light sources causing the formation of the shadows in Tasks 3 &4

Task	Answer	N	%
3. Two shadows horizontal plane	The light comes from two correct positions	33	15.5
	The light comes from one side-position	40	18.9
	The light comes from a middle position	132	62.3
	No answer	7	3.3
4. Two shadows vertical plane	The light comes from the correct position	22	10.4
	The light comes from one side-position	36	17
	The light comes from a middle position	140	66
	No answer	14	6.6

In terms of gender, we did not find any statistically significant differences between boys and girls. Also, we did not find significant differences between the pupils of 1989 and 2009.

4. Conclusions

Results show that our hypothesis is confirmed. As for the first two tasks which represent common images of everyday life, the majority of the answers corresponds to the model of Geometrical Optics (78.8 % and 73.6 %); however, the percentages of correct answers in the first and fourth task are very low (15.5 % and 10.4 %). Because of incomplete construction of reversibility, children of this age can not put shadows and light sources into a one-to-one correspondence. As a result, children face great difficulties in trying to understand the mechanism which causes shadows. This fact influences procedure, since teaching the formation of shadows must not only lead to the understanding of the relation: light source ==➔ obstacle ==➔ shadow, but also to the understanding of the relation shadow ==➔ obstacle ==➔ light source.

Finally, there is not only a special interest in the absence of differences between boys' and girls' representations, but also between the representations of those who were pupils twenty years ago and those who are pupils today. These results show the strong psychological background of the representations which the children use in the question of the formation of shadows.

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