Representations of rectilinear light propagation in the thinking of 12-13 year olds: A transformative teaching intervention

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Article Info	ABSTRACT
	This research investigates the transformation of the seventh-grade students' mental representations of the rectilinear propagation of light. The researcher employed the quasi-experimental method on two groups of students aged 12-13 years. The survey involved 102 students who were divided into two equal groups determined by the stratified sampling technique. The first group participated in a didactic intervention based on the students' representations. The second group of students participated in a traditional school teaching. The Mann–Whitney U test was utilized for calculating the significance of the data. The statistical analysis showed that the pretest and the posttest progress was statistically significant for the first group. It resulted in the mental constitution of a representation that is compatible with the scientific model. The research results allow the design of effective interventions for the teaching of light propagation and geometric optics in general.

INTRODUCTION

In the context of contemporary research in physics learning and teaching, an attempt is often made to systematically identify misconceptions, mental, or alternative representations in students' thinking. Furthermore, it is used to design teaching interventions aimed at overcoming difficulties and transforming misconceptions.

The knowledge to be taught, which is different from scientific knowledge, must consider the level of students' cognitive development. It requires a reorientation and modification of the conceptual formulations according to their level. In reality, students are taught constructs spontaneously, i.e., pre-existing cognitive entities that are resistant to learning (Kaliampos & Ravanis, 2018; Latifah et al., 2018; Sotirova, 2017; Tin, 2018). These representations produced by everyday life and the students' activities often have little to do with the structure of scientific disciplines, such as physics. It is essential to know and explore these representations to understand the effectiveness of teaching.

This article begins with a review of what is known about students' specific representations and obstacles to the rectilinear propagation of light by highlighting the compatibility between these representations and the scientific construct used in teaching. The methodology used is presented, and the quantitative results of the research are discussed. This study argues that a didactic intervention based on students' representations leads better than traditional teaching to the reorganization of representations and the construction of a precursor model compatible with the scientific model (Fratiwi et al., 2019; Ravanis, 2020; Rodriguez, 2018; Saregar et al., 2018). The results of this research could enrich educational practices by proposing an alternative procedure for teaching the

concept of the rectilinear propagation of light within the framework of geometricaloptics.

Students' Representations about Light Propagation

As has been shown by a series of researches focused on 5 to 14-year-olds' representations of light, the difficulties lie in the propagation and interaction of light with different objects (Andersson & Karrqvist, 1983; Dedes, 2005; Dedes&Ravanis, 2009; Grigorovitch, 2015; Grigorovitch & Nertivich, 2017; Kokologiannaki & Ravanis, 2013; Rice & Feher, 1987; Selley, 1996; Voutsinos, 2013; Watts, 1985). The main obstacle is recognizing light as a distinct physical entity, independent from the sources that produce it and the effects it causes in a certain region of space. The origin of this difficulty is the subjects' tendency to associate light exclusively with its source or the visible effects it produces (Castro & Rodriguez, 2014; Grigorovitch, 2014; Ravanis, 1999; Ravanis, 2018; Rodriguez & Castro, 2016; Sotirova, 2018).

Among the properties of light that are important for its interaction with the objects it encounters, the rectilinear propagation of light is an interesting topic for research in teaching geometrical optics. Feher and Rice (1988) asked students aged 9 to 13 to draw images and shadows from several sources and found that the shadows were not related to the proposed light sources in these drawings. Thus, even when a set of diagonal rays coming from the source appears in these iconic representations. The equivalence of the various directions is not often perceived because the subjects seem to privilege certain directions according to the spatial arrangement of the objects proposed in the given physical problem. Guesne (1984) reached similar conclusions with 13-14-year-old subjects. She found that only 30% of the subjects mentioned rectilinear propagation, while many recognized this quality of light when only its horizontal direction was involved.

Ramadas & Driver (1989) identified the representations of secondary school students regarding the rectilinear propagation of light. The data analysis showed that the majority had alternative mental representations about the rectilinear propagation of light. It seemed that most secondary school students did not recognize the linear propagation of the light or restrict it to the horizontal direction.

In research on the role of teaching aimed at the transformation of primary school students' mental representations of the rectilinear propagation of light, two different didactic interventions were studied (Castro, 2018). The first teaching intervention was based on the students' mental representations based on cognitive conflicts on simple experiments. The second teaching intervention followed the traditional school teaching approach. The progress between the pretest and the posttest was statistically significant for the subjects in the representations-based group in explaining phenomena related to the rectilinear propagation of light.

In this field of research, Ravanis & Papamichael (1995), who comparatively studied two teaching interventions, outlined two difficulties for students: a) The difficulty in identifying the general rectilinear propagation of light and; b) The difficulty in recognizing the propagation of light in all directions.

The research mentioned above is designed to ascertain students' representations and create teaching interventions that can help reconstruct these alternative mental representations.

This article presents research on the comparison of two teaching interventions for the rectilinear propagation of light. The hypothesis is that students who are taught based on their representations and their identified difficulties with rectilinear light propagation will have better results than those taught based on traditional teaching.

This research attempts for the first time to transform the representations of 12-13-year-old students with simple teaching tools that can be easily used in a regular classroom.

METHODS

A quasi-experimental method was used in this research.Two independent samples were used, drawn from the same population.

Sample

With stratified sampling, the research involved 102 students aged 12-13 years (average age 12 years and ten months) selected from 12 different classes. The classrooms in which the students attended belonged to schools located on the eastern outskirts of Moscow. These students were randomly divided into two groups of 51. The research subjects were those who provided correct answers to questions about light as an autonomous entity (Ntalakoura & Ravanis, 2014; Rodriguez & Castro, 2016, 2020), and they were selected after an individual interview on a larger sample.

The Research Procedure

The research was carried out in three stages. (a) In the first stage, all subjects were given a pretest to allow the students to express their alternative mental representations about light propagation based on the questions asked. (b) One month after the pretest, the two groups participated in two different teaching interventions in a two-group design research procedure. In group 1, the teaching was based on the students' mental representations. In group 2, the teaching was based on a traditional model. (c) One month after the didactic interventions to the two groups, all the students underwent the posttest to identify the changes in their alternative mental representations noted in the pretest (Figure 1).
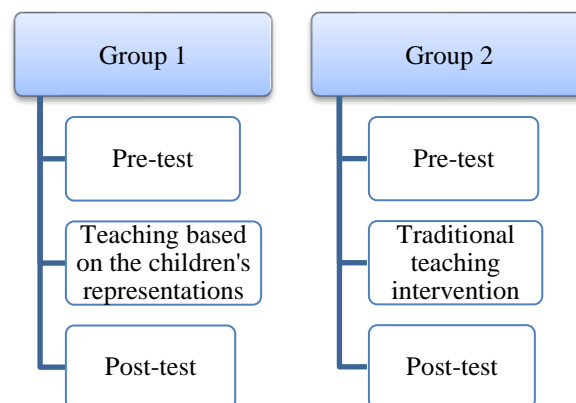

Figure 1. The Experimental Design

The Tasks

In the pretest and the posttest, the students were asked to answer questions based on two tasks:

- *Task 1:* The students construct shadows on the wall using a portable lamp and their hands (Figure 2). Then, the students were asked to explain the mechanism of shadow formation through the following questions: "How does a shadow form?", "When does a shadow form?" (Nertivich, 2016; Ravanis, Zacharos &Vellopoulou, 2010).

Figure 2. The Formation of the Shadow

- *Task 2:* Two 17cm x 25cm cardboardsare placed vertically on stable horizontal supports to be 12cm apart (Figure 3). The first of these cardboardshas a 0.5cm circular hole at the height of 17cm from its support point. At a distance of 8cm diagonally and below the hole, a light source was located. Before turning on the lamp, the students were asked to predict whether the second box would be

illuminated when the lamp was turned on. Positive answers led to the interview by asking for clarification ("where will it light up?", "how will the light go?"). In case of negative answers, the students were asked to describe what he/she thought the trajectory of the light would be (Ravanis & Papamichael, 1995).

Figure 3. The Arrangement of the Objects in Task 2

Didactic Interventions to Both Groups

After the pretest, the students from both groups participated in teaching procedures. Group 1 aimed to transform their alternative mental representations, and group 2 participated in a traditional approach according to the school curriculum. Each didactic session, for teams of 3-4 students, lasted 14-18 minutes. These lessons took place in the school laboratories.

Group 1. The students were given a device shown in Figure 4 (three cardboard boxes placed vertically, a candle, and a man doing experiments). Each of these boxes has a 0.5cm circular hole at the same height as its support point.
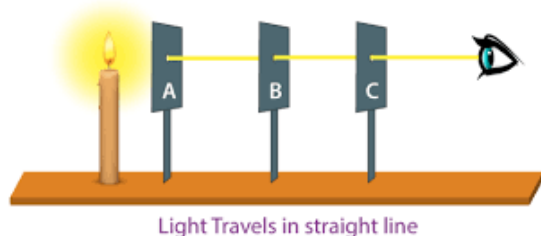

Light Travels in straight line

Figure 4. The Arrangement of the Objects in Task 2

The researcher started with a question, "Under what conditions could the human eye see the light of the candle? Starting with this question, the researcher continued with a discussion while constantly moving one, two, or three cards and changing their positions. During this teaching, the researchers asked the students to predict whether the light

reaches the eye and occurs only horizontally or in diagonal directions. After listening to their predictions based on their mental representations, the researcher confirmed whether they were correct or wrong.

By comparing the students' predictions and the experiment's results, the researcher tried to discuss with the students in each group to formalize the rectilinear propagation of light in all directions. The researcher tried to connect the light with everyday life by working with students on a picture and a sketch showing visibly accented light beams. The researcher systematically discusses the propagation of light in all directions by contrasting the propagation in the horizontal or vertical direction with all other possible orientations.

Group 2. The students in Group 2 were taught the same subject based on the curriculum guidelines and corresponding textbooks. The teachers did not use an experimental set-up based on the research results in the school-type activity, but they did some demonstrations with flashlights and opaque objects. They proposed some pictures with different situations (see Figures 5 and 6) and discussed the creation of phenomena based on the linear propagation of light. Throughout the teaching process, the teaching materials, such as photographs, images, and three-dimensional objects (the sun and the planets, small light sources sometimes in operation, and sometimes not) were used systematically.
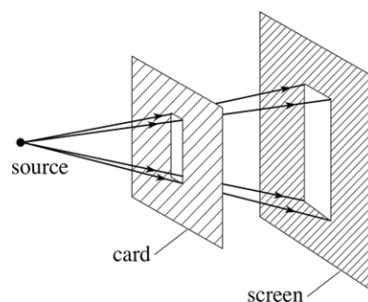

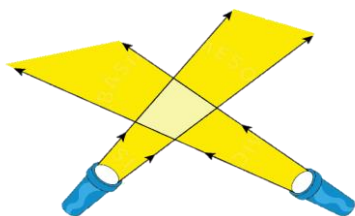**Figure 5**. Linear Propagation from a Point Source

Figure 6. Linear Propagation from Extended Sources

Data Collection and Criteria of Evaluation

In the pretest and posttest, individual interviews with the students lasted between 7 to 11 minutes. The interviews took place in a specially designed room in the school.

The interviews were recorded to obtain an accurate record of the student's speech, and the analysis of the responses was based on the transcript.

The data analysis was performed in two phases. In the first phase, a descriptive categorization of the students' representations of linear light propagation was performed. In the second phase, a comparison of the student's answers to the pretest and posttest and statistical control of the change was carried out. Differences in students' responses between pretest and posttests were classified into two levels (Castro, 2018; Ravanis & Papamichael, 1995; Ravanis et al., 2013). (1) The progress was identified when a student answered the posttest, then the student recognized the linear propagation of light, whereas, on the pretest, the student did not recognize it. (2) Stability was recognized when a student gave the same answer level on the pretest and posttest.

The Mann-Whitney test was used for statistical testing since two separate students randomly selected from the same group sample were used. The differences in the responses of the two groups were considered statistically significant at a level of $p \leq 0.05$.

RESULTS AND DISCUSSION

In both tests, students' responses were categorized into two levels related to the type of representation they used. In both tasks, the first category (A) classified responses in which students used the rectilinear propagation of light to explain phenomena.

The second category (B) of responses ranked the responses of students who explained that there was difficulty in using linear propagation of light correctly. In these answers, the students were often influenced by the characteristics of the experimental situation. For example, in Task 2, students in the second category were often influenced by the hole's position in the second cardboard box and claimed that after the light had passed through the hole, it would move horizontally.

Table 1 shows the responses of students in both groups in the pretest and posttest.

Table 1. Frequences of Answers of Students in Both Groups in the Pretest and Posttest.

		PRETEST		POSTTEST	
		G1	G2	G1	G2
Task 1	Cat. A	10	10	42	17
	Cat. B	41	41	9	34
Task 2	Cat. A	8	10	39	18
	Cat. B	43	41	12	33

Below are typical examples of students' responses from both groups for the two tasks:

A) These are the answers of students who made satisfactory use of the linear propagation of light. For example, "If I take the rays coming out of the lamp and take them straight up to the outline of my hand…… and ….. then to the wall, we understand why the shadow becomes like this" (Task 1, student 39, pretest). "The shadow is made by light going straight... straight.... straight.... (pointing with hand) and then it can't pass through the hand which is opaque.... the other rays continue straight, and we see the light on the board." (Task 1, subject 66, post-test). "The light will go everywhere. A few rays go up to the hole, through it, and intersect diagonally upwards" (Task 2, student 69, posttest). "If we turned on the lamp, the light would go everywhere. That's why it would go diagonally across the cardboard and through the hole. (Researcher. After the lamp, it will continue?). After the hole, it will continue diagonally as it was going..." (Task 2, subject 71, posttest).

B) The second category included answers in which students made insufficient or no use of the linear propagation of light. "The light falls on the hand, and that's how the shadow becomes..... (Researcher: Can you tell me exactly how that happens?). The rays go to the hand, and it makes a shadow on the wall. (Researcher: How do the rays from the shadow? Can you show me?). This is the lamp, and this is the hand. Only the hand makes the shadow... not the rays....." (Task 1, student 55). "The light will not pass through the hole. It will leave the lamp and go across.... far below the hole" (Task 2, student 43, pretest). "The light will go in the hole.... and go across.... (Researcher. So we'll see it on the cardboard?). We will see it across the hole. (Researcher. Can you show me where? Here (points directly across the hole)" (Task 2, subject 101, posttest).

Before they participated in the teaching interventions, about 20% could not solve problems using rectilinear light propagation. However, after the lesson 8/10, the students in group 1 could use linear propagation satisfactorily, while only 3/10 students in group 2 achieved the same.

Table 2 presents the students' responses changes before and after the teaching interventions in which they participated. The analysis of the differences in students' responses between the two groups showed that in both tasks, the changes were statistically significant for group 1 (task 1: U=1632, p<0.001, task 2: U=1701, p<0.01).

Table 2. Frequencies of Changes in Students' Responses between the Two Tests (Pre and Posttest)

		PRETEST / POSTTEST	
		EG	CG
Task 1	Progress	32	7
	Stability	19	44
Task 2	Progress	31	8
	Stability	20	43

These results confirmed the research hypothesis. They showed that after the two instructional interventions, the students in group 1 were much more able than those in

group 2 to operate a rectilinear light propagation representation. The instructional intervention aimed at transforming students' representations addressed their actual difficulties and barriers, rather than what we empirically assume in traditional instructional interventions and related curricula.

In the first task, the rectilinear propagation of light was combined with the production of the shadow, i.e., the most every day and perceptible event. The success of the teaching intervention could lead to considerations about the simultaneous teaching of both phenomena, as it is well known from relevant research that primary and secondary school students face the problem of alternative mental representations also in the issue of shadow formation (Nertivich, 2016; Voutsinos, 2013).

In the second task, the progress of students in the group that received instruction based on alternative mental representations was much greater than that of students who received traditional instruction. This task was more closely related to light itself, i.e., the properties of the light ray as identified in geometricoptics.

From this point of view, it might be interesting to integrate the issue of the linear propagation of light rays into a teaching approach on the light itself, since the problems of understanding light as an independent entity in space from a very early age are already established.

The results of this study are consistent with those of other studies conducted on younger students aged 9-12 years (Castro, 2018; Ravanis & Papamichael, 1995). In these studies, the specific teaching interventions based on representations lead to an understanding of linear light propagation. However, the research results presented here are better. Also, a peculiarity of the design is that it includes simple experiments that can be easily used in any classroom.

CONCLUSIONS

In this research, the possibility of transforming a representation of 12-13 years old students about the linear propagation of light, i.e., one of the issues of light propagation in space, was studied. These data are sensitive as they could affect the general issue of learning and teaching geometricoptics. It is almost impossible without understanding a basic assumption about the concept of the light ray. As shown by the procedure followed, this transformation is possible but requires a teaching intervention that relies on the alternative mental representations of the students. This finding exactly confirms the hypothesis that was formulated.

This perspective places this research in the spectrum of constructivist approaches, i.e., in a framework that aims at what is generally recognized in the literature as a transformation of students' representations of their thinking or as a conceptual change.

In such a context, it is obvious that two factors are important: (1) the study and identification of students' alternative mental representations as this allows us to understand the distance from the scientific model we use in education and (2) the construction and testing of teaching interventions that enable the transformation of representations in a direction compatible with the scientific model.

Such a direction for research is of general interest for teaching as it allows an effective approach to the issues of science learning. In this view, wider use of such research data in curriculum development and basic education, and continuing teacher education is particularly important.

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