

# Teaching Image Formation by Extended Light Sources: The Use of a Model Derived from the History of Science

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Published online: 22 December 2007  
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**Abstract** This research, carried out in Greece on pupils aged 12–16, focuses on the transformation of their representations concerning light emission and image formation by extended light sources. The instructive process was carried out in two stages, each one having a different, distinct target set. During the first stage, the appropriate conflict conditions were created by contrasting the subjects' predictions with the results of experimental situations inspired by the History of Science, with a view to destabilizing the pupils' alternative representations. During the second stage, the experimental teaching intervention was carried out; it was based on the geometrical optics model and its parameters were derived from Kepler's relevant historic experiment. For the duration of this process and within the framework of didactical interactions, an effort was made to reorganize initial limited representations and restructure them at the level of the accepted scientific model. The effectiveness of the intervention was evaluated two weeks later, using experimental tasks which had the same cognitive yet different empirical content with respect to the tasks conducted during the intervention. The results of the study showed that the majority of the subjects accepted the model of geometrical optics, that is, the pupils were able to correctly predict and adequately justify the experimental results based on the principle of punctiform light emission. Educational and research implications are discussed.

**Keywords** Destabilisation-restructuring of pupils' representations · Didactics of physics · Geometrical optics · History of science

## Introduction

### Light Emission by Extended Light Sources

In the research field of Science Education and in the domain of optics in particular, the vast majority of studies conducted on children's representations concerning light phenomena

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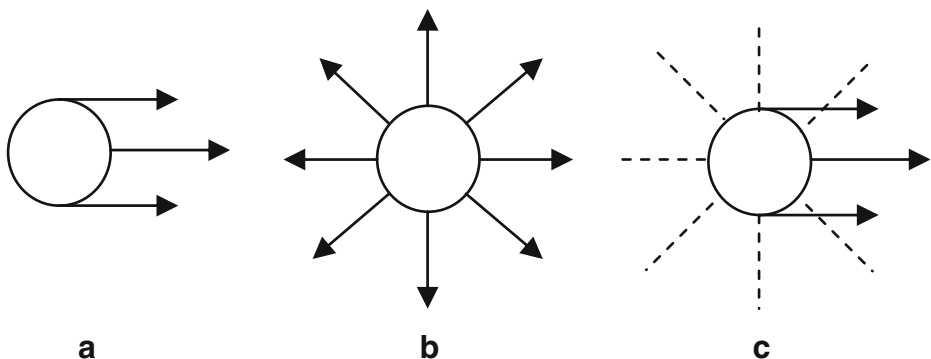
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assumes dimensionless light sources, that is, point sources (Andersson and Kärrqvist 1983; Boyes and Stanisstreet 1991; Eaton et al. 1984; Guesne 1978; Hosson and Kaminski 2002; Langley et al. 1997; Palacios et al. 1989; Ramadas and Driver 1989; Selley 1996). However, since the chapters taught on optics include topics whose understanding requires the use of extended light sources (that is, pinhole images, shadow formation, mirror images, mechanism of vision, lens and prism images), this has led to the development of a (limited) number of research initiatives based on this latter assumption. The findings of these studies prove that – even following school instruction – pupils still approach such phenomena through representations which deviate, more or less, from the accepted scientific models. In other words, it is established that school didactics does not always lead to acceptance and adoption of formal knowledge. The interaction between the initial representations and the knowledge offered through teaching formulates particular meanings in the pupils' minds. This interaction often leads to the construction of new representations, which are again incompatible with scientific concepts and which are constructed by pupils through teaching. In searching for the interpretations that these new representations lead to, as these are documented in the relevant literature and confirmed by our own preliminary research (pre-test), we discover that pupils' interpretative schemata are largely dependent on the way in which children perceive light emission when coming from extended light sources (Galili 1996; Galili et al. 1993; Goldberg and McDermott 1987; Fawaz and Viennot 1986; Rice and Feher 1987). After codifying the pupils' alternative approaches, three representation categories emerge:

1. Representations of a holistic mode of light emission and propagation in a preferential direction (that is, the source emits light as a whole and the light rays carry its shape in the direction that 'matters' to the problem at hand, which is in our case the horizontal direction; see Fig. 1a)
2. Representations of a radial mode of emission (that is, irrespective of its shape, the source emits light as if it were a spherical surface whose every point emits a single ray of light perpendicular to its surface; see Fig. 1b)
3. Representations of a combinative mode of emission (that is, simultaneous emission in both the aforementioned ways; see Fig. 1c)

The aim of this paper is to present the results of a teaching intervention based on the involvement of the subjects in experimental activities with a view to restructuring their intellectual tools concerning image formation by extended light sources. The theoretical background of this project is the view of social constructivism, meaning the view which accentuates the role of social mediation in children's cognitive development. In their



**Fig. 1** Schematisation of children's representations concerning light emission by extended light sources

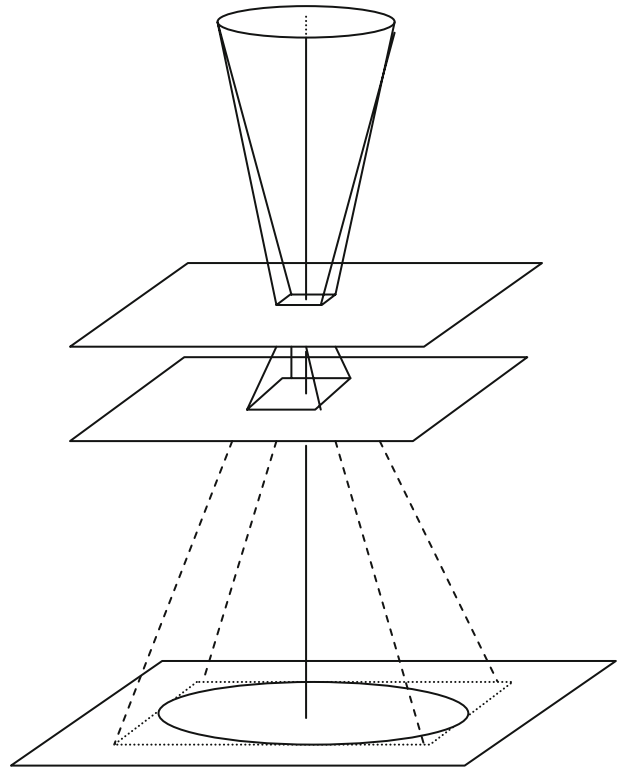
studies, representatives of this movement analyse the social dynamics that mediate in the relationship of the child with the cognitive object, suggesting active contribution of the teacher in creating situations capable of producing derangement and discordance of the subject's cognitive structure (Gilly and Roux 1988; Perret-Clermont et al. 2004; Ravanis et al. 2004). The teacher thus functions as a source of social contrast directly linked to the interactive dynamics of an experimental situation (Weil-Barais 1994). Researchers moving in this direction postulate that the construction of 'difficult' scientific concepts "is not a procedure that can arise ex-abrupto, through attending a lecture, studying definitions in school textbooks or figures and symbols referring to experimental situations" (Weil-Barais and Lemeignan 1990, p. 393). What is more, nor can it be realised in a spontaneous manner. The transformation of representations demands and presupposes the destabilisation of cognitive structures, which can be achieved through social interaction of the subject with other children as well as the teacher, through conflict of opinion and verbal communication (Ravanis et al. 2002; Vergnaud 1988). With respect to restructuring children's representations, some productive speculation has developed over the past few decades. According to Vosniadou and Brewer (1987) the term 'restructuring' means the creation of new cognitive structures on the subject's part, which are devised so as either to reinterpret previous information or to explain new information. In an epistemological approach of the issue, the authors point out the difference between theory change in science and conceptual development in childhood, stressing that "... (whilst) restructuring in the case of the scientist requires the discovery of an internally consistent new paradigm ... the problem for the developing child is not to independently discover a new paradigm, but to integrate current scientific views (coming from the adult world) with theories derived from his/her phenomenal experience" (p. 55). Thus, the mediating role of the teacher consists, on the one hand, in becoming actively involved in diagnosing the students' contradictions and, on the other hand, in responding to these contradictions. This can be achieved by presenting and developing a model that is understandable, renders the children interested and leads them to change their contradictory notions and adopt scientific concepts (Roth et al. 1987). In other words, when following the phase of cognitive destabilization, the children's involvement in elaborating the correct scientific model may prove beneficial to learning inasmuch as it favours the development of representations and the logical systematization of the pupils' notions (Ravanis 2005).

The History of Science is used in this effort as a tool for creating teaching–learning situations. Experimental settings whose cognitive content is derived from the History of optics are thus utilized in teaching. This is attempted in the destabilization of the subjects' representations as much as it is in their restructuring. Thus, during the first stage of the procedure, appropriate conflict conditions are created during experimental situations inspired by the History of optics, by confronting the subjects' predictions and the results of these situations, with an aim to imbalance the spontaneously formatted representations. During the second stage, the use of historical data and their didactic transformation form the basis for constructing the experimental situations as well as the intervention strategy: through organizing and rearranging the same materials based on Kepler's relevant historic experiment and through appropriate guidance on the researcher's part, it is attempted to reorganize representations and construct a scientific model.

### Image Formation through Holes in the Evolution of Scientific Thought

It is often the case in the History of Science that facts of immediate sensory experience cannot be interpreted based on the prevalent framework of principles and convictions of the

**Fig. 2** Schematic representation of Aristotle's 'optical puzzle'

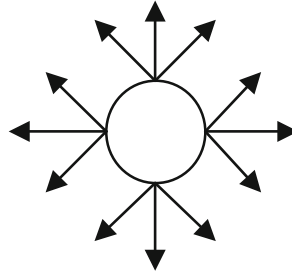


time. Such facts constitute problems which are either solved within the existing conceptual network of values, laws and techniques (through the discovery of 'hidden' parameters initially not accounted for), or which lead to the overall abandonment of the system's basic assumptions and methods and to the establishment of a new 'paradigm,' radically different than its precedent. In either case, maintaining a problematic situation over a prolonged period of time usually renders such a phenomenon somewhat of a 'puzzle' (Kuhn 1996, pp. 43–51). The present study is based on the educational exploitation of such an 'historical puzzle.' In his work *Problems*, considered by many as a pseudepigraph,<sup>1</sup> Aristotle ascertains a strange optical phenomenon: when sunlight passes through random-shaped apertures created by tree foliage, it produces an image on the ground which changes shape according to the aperture's distance from the ground. Thus, while at a short distance the image bears the shape of the aperture, as is expected according to the rectilinear propagation of sunrays, nonetheless at greater distances the image assumes the seeming shape of the sun, that is, it becomes circular (Fig. 2).

The scientific community has unsuccessfully puzzled over the explanation of this phenomenon over some 2,000 years, revealing not only a large number of alternative interpretative approaches, but also a series of theoretical schematizations exceeding the scope of the particular problem and verging on fundamental principles and axioms of optics (Lindberg 1968, 1970). At the turn of the seventeenth century, Johannes Kepler adopted the principle of punctiform analysis, as formulated by the Arab Al Haytham in his work *On the*

<sup>1</sup>Aristotle: *Problems*. Trans. W.S. Hett (1952) and E.S. Forster (1963). Hett places the author within the second century B.C., as a later representative of the Peripatetic School.

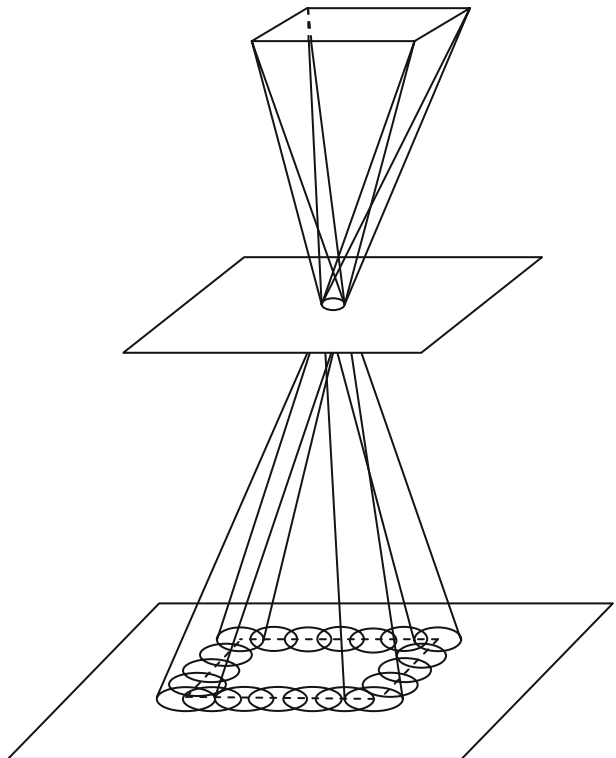
**Fig. 3** Al Haytham's principle of punctiform analysis



*Shape of the Eclipse* (Straker 1971, p. 555), and performed a mechanistic representation of the phenomenon in three dimensions, thus providing the definitive solution to the 'mystery' (Kepler 2000, p. 56). Kepler considered the luminous body as the composition of an infinite number of luminous point-elements, each of which radiates independently, rectilinearly and isotropically in all directions (Fig. 3).

According to this view, each luminous point produces an image that, due to the rectilinear propagation of light, will bear the shape of the aperture. If one attempts a dynamic depiction and supposes that a luminous point-element travels the circumference of a luminous object, then the respective images of the aperture partially overlap and are distributed along the circumference of a shape corresponding to the luminous object and located on the ground (Fig. 4).

**Fig. 4** Kepler's crucial experiment



As the distance between the aperture and the ground lessens, the degree of overlap of the hole images becomes larger than the degree of decrease in their size, so that the overall image gradually coincides with the shape of the aperture. On the contrary, as the distance between the aperture and the ground increases, the degree of spreading of the hole images becomes greater than the degree of increase in their size (that is, also greater than the degree of overlap), so that the overall image gradually coincides with the shape of the source.

By applying his model of analysis to similar problems (that is, mechanism of vision, lens images), Kepler formulated a consistent conceptual interpretative framework and set the basis of modern geometrical optics. The holistic mode of radiation emission was definitively abandoned, while the luminous mathematical point-element radiating rectilinearly in all directions was established as the new emission ‘unit’. The light propagation model depicted by a pyramid whose base is the total surface of the light source lost its methodological usefulness and was replaced by an inverted pyramid whose apex was every point of emission and whose base was the object underlying the light (Lindberg 1992). Finally, in approaching and studying optical phenomena, the equal contribution of the entire ‘quantity’ of light replaced views about privileged power and propagation in preferential directions.

## Research Methods

### Subjects

Forty eight students (24 boys and 24 girls) took part in this study, coming from 10 different schools and evenly distributed into three age groups. Sixteen pupils were in the Sixth Grade of primary school (approximately 12 years old), 16 were in their second year of junior high school (approximately 14 years old) and 16 were in their first year of secondary high school (approximately 16 years old). The age criteria were determined based on the distribution of geometrical optics chapters in the Greek curriculum. It should be noted that pupils in Greece are taught topics related to image formation during the last 2 years of primary education as well as in the second year of junior high school. Pupils from the first two age groups participated in the study directly after having been taught the relevant topics at school. This was done in an attempt to investigate the effectiveness of the teaching intervention by tracing representations which were either already present or were formed through the teaching intervention. The participation of subjects from the third age group was determined after an exploratory part of the research showed that, even at this level, the vast majority of pupils maintained their alternative representations 2 years after the last systematic teaching intervention. In any case, it was the degree of restructuring of these representations through the suggested teaching approach which constituted the main object of this research. The schools were chosen so as to ensure that pupils with different socio-economic backgrounds would be included in the sample. The selection of the pupils was made in cooperation with their teachers, so that pupils from the top, middle and bottom levels of the achievement range would be represented in the sample.

### Data Collection

The only children that took part in the study were the ones who expressed alternative representations after the pre-test. Moreover, students from the sixth grade of primary school and the second year of junior high school participated in the study directly after having

been taught the relevant topics on optics at school. Data were collected through individual semi-structured interviews which lasted approximately 45 to 50 min and comprised open-end questions adjusted to the empirical content of specific experimental situations. Interviews took place in a specially designed room in the children's school, since the specific experimental situations necessitated conditions of darkness in order for the results to be clearly visible. Predictions, descriptions and interpretations were formulated verbally and recorded by a tape recorder (with the children's consent), as well as marked on schematic reproductions of the experimental settings (see Fig. 4). The researchers also used special protocols which permitted any relevant non-verbal responses to be encoded. The interviews were analyzed by studying both the transcribed text and the schematic reproductions and protocol in writing.

## The Process

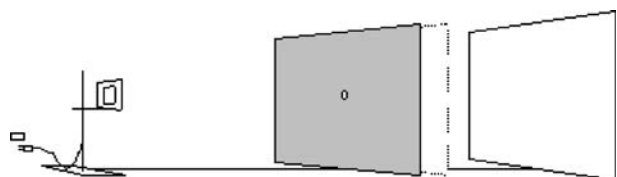
### *First Stage: Pupil Involvement in Conflict Procedures*

During this stage pupils had to deal with three tasks, purposefully chosen in an attempt to create cognitive disequilibrium in the children's existing representations. The task sequence was such that the results of each following task would provide the subjects with the opportunity to realize the inadequacy of their previous interpretative scheme. During the process, subjects were asked – in this order – to make predictions, justify them, verify or disprove them by activating the source and, finally, provide new justifications and make comparisons with the original predictions.

*Task 1a (T1a)* The following items were placed in the following order along a school desk: a quadrangular fluorescent light source with dimensions  $10 \times 10$  cm, shaped by a glass tube with a cross-section of 1 cm; an opaque diaphragm bearing a circular aperture of 1 cm diameter (that is, small compared to the dimensions of the source) located at the same height as the centre of the quadrangular source; and, finally, a projection screen (Fig. 5).

The source–diaphragm distance was 80 cm while the diaphragm–screen distance was 5 cm. While the light source was kept deactivated, the subject was first asked to predict the results on the screen as well as on the diaphragm surface and to justify these predictions by tracing the light path on the schematic form of the optical system. Subjects adopting the holistic mode of emission predicted that a lit rectangle with the same dimensions as the source would appear in the centre of the diaphragm, while the rest of the diaphragm's surface as well as the screen would remain unlit. Subjects adopting the second representation category (that is, the radial mode of light emission) correctly predicted that a lit spot would appear on the centre of the screen, while the diaphragm would be uniformly lit. Finally, subjects actuated by the combinative mode of emission predicted that a lit spot would appear at the centre of the screen and the quadrangular image of the source would appear on the diaphragm, while the rest of its surface would only be faintly lit. Following

**Fig. 5** Schematic representation of the optical system in Tasks 1a and b

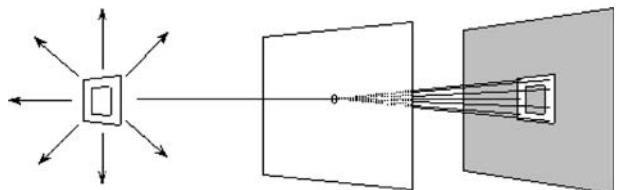


this, the light source was activated, causing a lit spot having the same dimensions as the aperture to appear on the screen, while uniformly illuminating the diaphragm. The child was then reminded of his/her own original prediction and asked for an explanation and, if the prediction was disproved, for a new justification. The contradiction between predictions and results occurring for part of the sample caused the representations of holistic and combinative emission to be rejected and led the subjects to unanimously (100%) adopt the radial interpretative scheme, which in this particular task exhibits absolute explanatory adequacy.

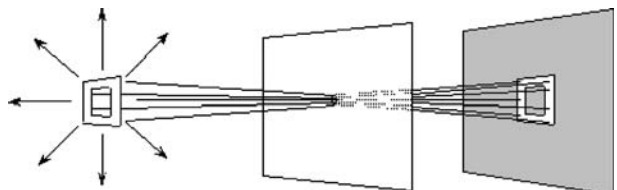
*Task 1b (T1b)* The light source was deactivated and the screen drawn away from the diaphragm to a distance of 30 cm. This time, the subjects' answers were all compatible with the radial mode of emission, as all the children predicted even illumination of the diaphragm and formation of a lit spot at the centre of the screen. Then the light source was activated and the quadrangular image of the source appeared on the screen. The explanatory adequacy of the radial emission mode was severely injured, however it still detained the subjects from recognizing the correct scientific model; only a very small percentage of the children did so (Sub. 21 and Sub. 33: percentage 4.2%). The vast majority of the children (66.6%) was led to a dead end in interpretation, while a significant percentage of them (29.2%) maintained the characteristics of the radial scheme while at the same time appealing to the contribution of certain active properties belonging either to the light (see Fig. 6) or to the elements of the setting (see Fig. 7). For example: "This ray passes and then widens like this [the child draws an horizontal ray that expands directly after passing through the aperture] and makes the shape of the lamp ... the ray has the shape of the source inside it and reshapes it at a greater distance" (Sub. 42) or "The hole attracts the light ... because the hole is small, the rays gather close together and then open up again and the shape of the source comes out again" (Sub. 13).

*Task 1c (T1c)* The light source was then deactivated once again and, without modifying the relative distances, a small opaque object was placed in front of the lower side of the quadrangular source, so as to modify its shape into the form of an upright II. No change was observed in the prediction stage, since all the children (except for those who had recognized the correct scientific model in the previous task) predicted the formation of a bright II on the screen, without being able to provide adequate justification. Following that,

**Fig. 6** Representations of active light



**Fig. 7** Representations of active hole





the source was reactivated once more and the image of an inverted  $\Pi$  appeared on the screen. Thus, conflict conditions escalated, since by now the interpretation of the result did not agree with any of the interpretative schemas that had been suggested this far, except that of punctiform emission. Two more subjects (Sub. 19 and Sub. 26: percentage 4.2%) recognized the characteristics of the correct scientific model, while all the other children declared they were unable to interpret the result and were thus led to a situation of cognitive destabilization.

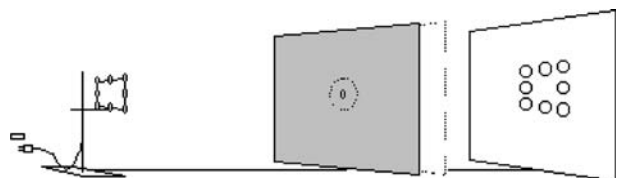
### *Second Stage: Teaching Intervention*

At this stage, in order to achieve reorganization of the pupils' representations, Kepler's historic experiment was utilized in an educational manner so as to gradually guide the children to perform the experiment cooperatively within an interactive environment. To this end, a special optical device was constructed, which provided the possibility of 'decomposing' the extended light source into a certain number of 'point' sources. This device consisted of an array of eight tiny halogen light bulbs with dimensions  $1 \times 1$  cm (12 V, 20 W), evenly placed along the sides of an imaginary quadrangle with dimensions  $10 \times 10$  cm; that is, equal in size with the quadrangular fluorescent light source used in the previous experiment. Each light bulb could be independently activated through an improvised control console, causing an image on the screen which bore the shape of the diaphragm aperture at that time. Each time the overall shape of the image resulted as a synthesis of the illumination patterns of each 'point' source. Only subjects who had failed to approach the correct scientific model during the previous stage participated in this teaching intervention. These children had to deal with two new tasks.

*Task 2a (T2a)* The setting was modified by replacing the fluorescent source with the improvised one and by placing a diaphragm at a distance of 50 cm from that. This diaphragm had an aperture whose diameter could vary from 1 to 5 cm. The screen remained behind the diaphragm, at a distance of 80 cm from the source (see Fig. 8).

In cooperation with the subject, one of the tiny light bulbs was chosen at random and, while using the smallest aperture diameter possible, a prediction was requested. Then the light bulb was activated and the spot of light was marked on the screen. The circular shape of the spot and corresponding shape of the aperture were pointed out. Then the rectilinear propagation of light was verified using an 80 cm long, thin, straight metal rod to connect the source and the spot through the aperture. Following that, the light bulb was deactivated and the aperture diameter was increased. The rod, which bore a pen on one end, was used to draw the circular base of the cone that was formed when the rod travelled the circumference of the aperture while keeping its other end constantly on the source. By reactivating the source, the coincidence of the image and the drawn circle was verified. This procedure

**Fig. 8** Schematic representation of the optical system in Tasks 2a and b



continued and, each time the aperture diameter was adjusted, a prediction was required and was then followed by direct verification. Following that, the subject was asked to visualize the result produced in the imaginary case of a source with infinite dimensions, so as to conceptually consolidate the rectilinear and equal emission of light in all directions. The aperture was then reduced to its original size (that is, to a 'point' source) and the subject was asked to predict the results (that is, the position, size and shape of the image) produced each time by the successive and independent activation of the remaining light bulbs, which was immediately followed each time by the verification or disproval of the prediction. All the light bulbs were then activated successively and remained lit, so that the rectilinear shape of the image was gradually formed as a composition of the eight circular spots of light. Finally, the lower-middle and then the lateral-middle light bulbs were deactivated successively and independently, so that the extended source assumed the shape of an upright and then a sidelong  $\Pi$ , respectively. This modification allowed the children to interpret the inversion of the shape onto a vertical as well as a horizontal plane, which is observable only in the case of a non-symmetrical light source.

*Task 2b (T2b)* The size of the aperture was kept to the minimum diameter possible while the screen was drawn nearer to the diaphragm to a distance of 5 cm. Following the same methodological approach (prediction–immediate validation–discussion–guidance–interpretation), the remaining light bulbs were then activated successively. The virtually total overlapping of the circular spots caused, as an overall result, a circular image with the same dimensions as the aperture. The screen was then slowly drawn away from the diaphragm and placed in its initial position. The increase in the dispersion of the lit spots as well as their size was established through collaborative discussion while, by changing the diameter of the aperture, the one-to-one relation between each element of the source and its corresponding image was demonstrated.

## Results

In order to check the effectiveness of the intervention, certain tasks were used which had the same cognitive presuppositions and yet different empirical content with respect to the tasks of the previous stages. Thus, the rectilinear fluorescent source was replaced by a cross-shaped one, while the diaphragm was sometimes replaced by other diaphragms with different aperture shapes (that is, triangular and rectilinear). Changing the source shape was the safest way of verifying whether the children had assimilated the characteristics of the correct scientific model, since during the post-test they were asked to apply the constructed representations to situations different to those under which they were constructed. The investigation into the representations that were finally constructed took place 15 days later, again through personal interviews, whose structure remained the same as that of the initial stages: the subjects were asked to provide predictions, descriptions, interpretations and justifications, both verbally and diagrammatically – this time, naturally, without the chance to verify or disprove them. Discussion during justification was particularly careful and thorough, given the risk that correct answers might spring from mechanistically reproducing and transferring the results observed during the previous stages to the new empirical data. In order to minimize this risk, the tasks chosen and developed were those whose results had not been sensory-detected during the teaching intervention.

Table 1 presents the children's representations on the mode of light emission by extended light sources prior to and following the entire process, classified by age group.

**Table 1** Frequencies of pupils' representations of light emission by extended light sources

Mode of light emission	Sixth grade of primary school (N=16)				Second year of junior high school (N=16)				First year of secondary high school (N=16)			
	Pre-test		Post-test		Pre-test		Post-test		Pre-test		Post-test	
	Subjects	Number	Subjects	Number	Subjects	Number	Subjects	Number	Subjects	Number	Subjects	Number
Punctiform	0	0	1, 3, 6, 7, 8, 9, 10, 12, 14, 16	10	0	17, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31	13	0	33, 34, 35, 37, 40, 41, 42, 43, 44, 45, 46, 47, 48	13	0	33, 34, 35, 37, 40, 41, 42, 43, 44, 45, 46, 47, 48
Holistic	2, 3, 6, 7, 8, 10	6		0	19, 27, 28, 29	4	0	33, 36, 38, 46	4	0	33, 36, 38, 46	
Radial	1, 5, 12, 14, 16	5	2, 13, 15	3	20, 21, 23, 32	4	2	35, 39, 40, 41, 42, 43, 45, 48	8	2	35, 39, 40, 41, 42, 43, 45, 48	
Combinative	4, 9, 13, 15	4	4	1	17, 18, 22, 25, 26, 30, 31	7	0	34, 37, 44, 47	4	0	34, 37, 44, 47	
Other	11	1	5, 11	2	24	1	18	0	39	1	0	39

## Analysis of Findings

### Pre-test Representations

After analyzing children's alternative representations, as these have been recorded in the literature and confirmed during the pre-test of the present study, the following findings have been drawn:

The holistic scheme of light emission (that is, 29.2% acceptance in total, see Table 1) is directly linked to reasoning derived from the dominance of the intuitive way of thinking. Since the propagation of light in space is not usually perceptible, representations are often constructed from fragmented empirical data which, due to the lack of mental logico-mathematical acquisitions, assume general validity in the children's thought (Tiberghien et al. 1980). Even in cases where, under special conditions, sensory detection is indeed possible, it is a known fact that this does not suffice for the creation of correct representations. Perceptual control merely places what is observed into the existing mental scheme (Piaget 1978). Thus, observations from the immediate environment coming from specially formulated light beams (that is, torches, laser games, special lighting effects) create the impression of a holistic transfer of the source shape towards the direction targeted – as also results from the subjects' justifications. In this case, by simply accumulating perceptual data derived from sensory experience and without the possibility of any systematic abstractive process, children's thought is led to generalization. The holistic scheme's acceptance percentages per age group (33.3, 25, 25%, see Table 1) constitute a measure of the power of intuitive reasoning.

From a conceptual point of view, the radial scheme could be considered as the one nearest to the correct scientific model, as it contains the seed of the punctiform emission view. According to this scheme, each point of the source emits autonomously in space, while the radiation propagates – though not isotropically – in all directions without there being any privileged dependencies which might indicate concentrations of an intuitive nature. Thus, construction of this scheme entails deconcentration from the subjective viewpoint of privileged propagation and – to some degree – marks the activation of logical mental operations. In this case, thought is driven towards the formulation of simple yet functional explanatory schemes. Thus, due to its structural simplicity and, mainly, due to its interpretative adequacy for most of the optical phenomena encountered by children, this scheme is prevalent in the responses of children belonging to the eldest age group (50% percentage). However, the persistence in preserving the one-to-one mapping of each source point to its illumination pattern through a single ray (and not a light beam) clearly implies the schematic and mechanistical transfer from the radial emission model of a point source to the case of an extended one, without accounting for the particular characteristics entering the transition. That is why this scheme, despite its obvious interpretative superiority to the holistic one, still remains virtually inadequate, since it ignores a large part of the 'quantity' emitted from the light source.

Finally, with respect to the combinative scheme, this was obviously formed by incorporating the primary sensory representations of the holistic scheme into the model provided by regular school instruction, namely that of radial emission of the point source. The subjects do not use the two schemes in a mutually exclusive way; rather, they attribute to the source the possibility of dual simultaneous emission at all times. Each student perceives things in a way that is generally different to that of the teacher, so that children often attribute a totally different sense to what their teacher presents to them than what he/she intended. It is in this way that particular meanings are shaped regarding phenomena and

concepts, which then lead to the construction of personal interpretative schemes. In the case at hand, the children maintain the ‘elaborated’ model of radial emission, which possesses both validity due to its scientific origin and safety due to its sensory validation, without however forsaking the naïve conceptualizations formed before they were initiated into the organized teaching process. In a psychological approach, Gowin (1983) asserts that ideas thus shaped tend to strongly resist teaching activities, since students maintain an alibi for the scientific origin of their representations. They feel at ease with them so they can afford to act without the possible mistake costing them too much. As can be seen in Table 1, the combinative scheme is prevalent among the answers given by students in the second year of junior high school (43.7%) – which is an indication of the sturdy resistance of their initial conceptions – while it falls seriously short of the radial scheme (25 as compared to 50%) among students in the first year of secondary high school.

### Teaching Conflict Procedures

It can be concluded from the subjects’ answers in task 1a that the contrast between the observed data and the initial interpretative schemes fulfilled the requirements for cognitive progress. On the one hand, it helped reject the holistic and combinative modes of emission while on the other it led the children’s thought towards the radial interpretative scheme. The absolute explanatory adequacy of the latter scheme in this task, in conjunction with its interpretative scope over a wide range of phenomena in everyday experience, seems to have acted decisively towards its unanimous acceptance (100%) by all subjects from all three age groups. The percentage of students who maintained the characteristics of the radial model during the development of task 1b is also worth mentioning (29.2%). It is obvious that ‘cooperative’ interpretative schemes (i.e. active light, active hole) do not subtract from the power of the radial model. These schemes do not relate to the way in which radiation is emitted from the source but rather to the attribution of special properties to the light or to the setting’s elements. However, its interpretative value is indeed impaired during the development of task 1c. There, the interpretative weakness stated by the subjects under strong conflict conditions is by no means accompanied by its representational replacement. As a result, the vast majority of the pupils (91.6%) are led to a situation of cognitive destabilization.

### Teaching Intervention and Transformation of Representations

In order to reorganize the subjects’ representations following the conflict procedure stage, the geometrical optics model was experimentally developed within a learning environment appropriately configured through mediation of the researcher. So the issue of cognitive progress was raised here not only in terms of the subjects’ activity but also in terms of social interaction. From the results of the post-test, as recorded in Table 1, it can be seen that restructuring of representations was achieved to a percentage of 62.5, 81.2 and 81.2% for the first, second and third age group, respectively. Furthermore, a significant percentage of subjects in every age group (18.8, 12.5 and 12.5%, respectively) maintained the radial interpretative scheme in the end, a representation whose formation marks the rejection of conceptions derived from the intuitive way of thinking. By adding up these two percentages by age group, the total progress is found to be 81.25, 93.75 and 93.75%, respectively.

The variations observed in the results show that the subjects from the youngest age group face the greatest transformation difficulties. The improvement of transformation percentages with age is, of course, to be expected in this type of intervention. However, the

stability observed in the percentages from the second to the third age group could be interpreted as a result of two factors: the mental development occurring with age and the time span of the teaching of the relevant topics in class. It is widely accepted that pupils in their first year of secondary school are considered as having a higher level of thinking in terms of mental processes. However, the 2-year gap that elapsed since the last time they were taught the relevant cognitive objects seems to have inhibited any further increase in the percentages of the desirable knowledge acquisition.

Therefore, from this point of view, it would be of some interest to repeat the research using students from senior high school who – during the teaching of relevant topics in previous years – would have approached the process of image formation with experimental presentation of a correct scientific model through a procedure similar to the one we have applied here. Such an attempt would provide, among other things, the possibility of comparing and validating our proposal over a more prolonged period of time.

Furthermore, the results of this research indicate that even the subjects of the youngest age group are capable of transforming – though certainly with greater difficulty – their experienced representations to satisfactory percentages when taking part in an interactive teaching procedure that is supported by the presentation of the correct scientific model.

For the statistical elaboration of the data the subjects were evaluated as to the change in their performance according to an ordinal scale which comprised four categories: progress, relative progress, stagnation and regression. With a view to checking the changes in the students' responses, their alternative representations were classified into two categories after having been evaluated and classified based on their conceptual consistency with the correct scientific model. The first category consists of representations related to the radial mode of emission, their characteristics not being completely incompatible with scientific theory, but merely resulting from poor application of the principles of geometrical optics. The remaining representations were classified into the second category. Thus, progress is defined as a subject's transition from any alternative representation to that of punctiform emission, while relative progress as the transition to representations of radial emission mode. Regression is defined as the exact opposite transition, while stagnation is marked by a subject remaining at the same level of representation. Differences between the pre-test and post-test are considered statistically significant for a 0.05 level of significance. The statistical check of the data was carried out at two levels with the following results:

In order to evaluate the improvement in class performance following the teaching intervention, a goodness-of-fit test ( $\chi^2$ ) was performed for each age group. From the results of the three tests, it follows that the number of subjects who made progress is significantly larger than the number of subjects in all the other categories. In the sixth grade of primary school, 62.5% of the subjects made progress, while 18.8, 12.5 and 6.2% of them made relative progress, stagnation or regression, respectively ( $\chi^2[3]=12.5$ ,  $p=0.006$ ). In the second year of junior high school, the percentage of subjects that progressed is as high as 81.2%, which is much higher than the percentages of relative progress, stagnation and regression for each category, respectively ( $\chi^2[3]=16.625$ ,  $p<0.001$ ). In the first year of secondary high school, the percentage of subjects who progressed is also significantly higher (81.2%) than percentages pertaining to all other categories, namely 12.5, 6.2 and 6.2% for relative progress, stagnation and regression, respectively ( $\chi^2[3]=16.625$ ,  $p<0.001$ ). The absolute frequencies and performance percentages per class are presented in detail in Table 2.

Moreover, because the percentage of students who progressed was fairly lower in the 6th Grade of Primary School than it was in the other two age groups, the non-parametric Kruskal–Wallis test was carried out. This checked for equality of mean variation in

**Table 2** Changes in performance and percentages per class

Change in performance	Sixth grade of primary school (N=16)		Second year of junior high school (N=16)		First year of secondary high school (N=16)		Total (N=48)	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Progress	10	62.5	13	81.2	13	81.2	36	75.0
Relative progress	3	18.8	1	6.2	2	12.5	6	12.5
Stagnation	2	12.5	2	12.5	0	0.0	4	8.3
Regression	1	6.2	0	0.0	1	6.2	2	4.2

Percentages not summing up to 100 due to rounding errors

performance between the three classes and its result was non significant ( $\chi^2(2)=1.915$ ,  $p=0.384$ ). Here, pupils are graded on a scale of 1 to 4 (regression=1, stagnation=2, relative progress=3, and progress=4) as to the change in their performance.

From the above results it is concluded that, following the didactical elaboration of the scientific model through tasks whose cognitive and empirical content is derived from the H. S., and within an interactive educational environment, the subjects of the research are rendered capable of dealing with image formation through holes by extended light sources using reasoning that proves the acquisition of the model of punctiform emission.

### Implications for Teaching

It is known from research in Science Education that, in certain areas of the curriculum, students' alternative representations exhibit significant resistance when 'encountering' scientific knowledge, at least the way it is conveyed in the classroom (that is, school science). In this particular experiment, perceptual data obviously do not contribute to the immediate recognition of the image formation mechanism, given that the path travelled by light in space is not sensory detectable. Thus, construction of a scientific model entails the ability for deductive mental operations as well as the possibility of processing perceptual data through a mental process of analysis and synthesis. These qualities have not yet been achieved at these stages of cognitive development. Since the pursued representation transformation requires a framework of cognitive abilities that is of a higher standard than that of spontaneous thought, the teaching intervention should then be based on activities that will lead the children to a reorganization of their intellectual tools. Therefore, it is deemed necessary to guide pupils, with a view to discerning the problem's variables and parameters as well as understanding relations between the parameters, so as to facilitate the development of their representations towards approaching the scientific model.

A second factor to which the extremely weak influence of school teaching could be attributed is the absence of any thorough mention of the mechanism of punctiform emission during class. As this model is not explicitly mentioned in the Greek curriculum, neither in primary school nor in junior high school, one may assume that this particular issue would only be mentioned in passing in the classroom. Thus, students' representations continue being based on the 'image projection' conceptualization (in terms of Galili 1996), by means of a single light ray that contributes to the construction of the corresponding image point. In this way, the major part of emitted radiation is ignored and so is the overall contribution of light to the formation of images. At the same time, the interpretative mechanism which uses the concept of the light ray

instead of that of the light beam (that is, by means of a flow of light, shading the whole area of light expansion) is fixed in the student's mind. Besides, pupils' representations are reinforced by the approach adopted in physics textbooks. In these, in computational problems regarding the tracing of images or shadows, the source-image connection is only achieved through the presence of 'special' rays. The preferential use of the necessary rays may serve purposes of design economy, but nevertheless, at the level of representation formulation, these 'special' rays prove to be not only sufficient but also necessary conditions of the formation of images.

In teaching topics of geometrical optics, it is of paramount importance to overcome this 'obstacle' and reveal the contribution of the entire light 'quantity' to the formation of images. In this matter, the use of diaphragms of varying aperture in optical settings could constitute a fruitful means for assimilating the equal and isotropic emission of light in all directions. It would also be of great importance to extend the experiment, as carried out in the present study, to other curriculum topics dealing with image formation by extended light sources. Such an attempt would provide the possibility of comparison with the results of the present study, while at the same time setting the perspective of a unified approach in confronting relevant issues.

From an educational point of view, not only is it necessary that the curriculum persist on the topic of light emission from extended sources, but it is also imperative that the teachers be sensitized to this issue. Making systematic and thorough mention of the punctiform emission model while teaching topics related to image formation by extended light sources may create the conditions necessary for transforming students' representations and approaching the desired knowledge. At the same time, applying Kepler's theoretical concept to optical settings chosen to assist theoretical teaching (that is, developing light sources in such a way as renders possible their 'decomposition' into a number of elementary sources) may prove to be extremely useful instructional material. It would help achieve learning objectives more efficiently while accentuating the significant role that History of Science can play in Science teaching. Of course, suitable guidance of the pupils constitutes a sine qua non condition for understanding any property or theoretical model related to light. When mediated by a structured intervention, interaction between object and subject may decisively contribute to deconcentrating the pupils' thought from its spontaneous or intuitive representations and focusing their reasoning on the characteristics of the correct scientific model.

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