education sciences

MDPI

Article

Elementary Students' Understanding about How Convex Lenses Affect Light Propagation

Aggeliki Kottara [1], Maria Dimitrakou [2] and Ioannis Starakis [3,*]

[1] Department of Early Childhood Education, University of the Aegean, 85132 Rhodes, Greece; kottaraaggeliki@gmail.com
[2] Department of Early Childhood Education, University of Western Macedonia, 53100 Florina, Greece; fepms01025@uowm.gr
[3] Department of Early Childhood Education, National and Kapodistrian University of Athens, 10680 Athens, Greece
* Correspondence: gstarakakis@ecd.uoa.gr

Abstract: In the present study, K-3 and K-4 students' understanding of the effects that convex lenses have on light propagation is investigated. Specifically, the study examines the extent to which these students are able to construct a scientifically accepted explanation for the role convex lenses play in converging rays of light and creating inverted images in the case of both self-luminous and hetero-luminous objects. Eight students from two primary schools run by the Municipality of Piraeus in the region of Attica (Greece), took part in the survey. They were divided into groups of two. The research was conducted using the teaching experiment method, which combines elements of the clinical interview and formal teaching. According to the results, students of this age recognise the convergence of light as a process that takes place through a convex lens. However, they have difficulty attributing the aforementioned convergence to the light refraction that takes place during the interaction of the light beams with the converging lens. At the same time, while they can easily ascertain that light beams continue along the same straight line after the convergence point, they find it difficult to relate this conclusion to the creation of an inverted image of a hetero-luminous object.

Keywords: convex lenses; learning processes; teaching experiment; primary education

check for updates

Citation: Kottara, A.; Dimitrakou, M.; Starakis, I. Elementary Students' Understanding about How Convex Lenses Affect Light Propagation. *Educ. Sci.* **2024**, *14*, 432. https://doi.org/10.3390/educsci14040432

Academic Editor: Daniel Muijs

Received: 13 February 2024
Revised: 13 April 2024
Accepted: 18 April 2024
Published: 20 April 2024

1. Introduction

Optics is a topic which features frequently in research into the teaching of science. The understanding of light-related phenomena has attracted the interest of several researchers from different countries. There are two main reasons why such importance has been attributed to light-related phenomena. First, they occur widely in everyday life. At the same time, the teaching of these phenomena seems to present students with various conceptual difficulties since they are both complex and abstract [1,2].

The way a convex lens affects light propagation (convergence of light beams, inverted image formation) is directly connected to light refraction. As will be discussed in the next unit, the literature review revealed a lack of research on this phenomenon at the primary school level; however, it is part of several primary science curricula.

So, this pilot study set out to determine K-3 and K-4 students' understanding of how convex lenses affect light propagation under the prism of geometrical optics. To this end, we designed and implemented tasks based on experiments with convex lenses.

2. Literature Review

Past research has shown that people present the same difficulties understanding geometric optics from primary school through to adulthood [3]. The literature contains studies covering several topics related to geometric optics, both in terms of students' perceptions and the related teaching approaches [4].

The most common topics in the relevant literature are light propagation [5–8], the process of vision [9,10], image formation [11,12], shadow formation [13,14], light reflection [15], and light refraction [16–18].

On the refraction of light, in cases relating to prisms and plane surfaces, the relevant research mostly concerns secondary and higher education students and reveals that students find it difficult to explain their observations based on the law of refraction of light, even when they have already been taught it. In their related explanations, they either attribute the phenomena to the reflection of light or to the material of the propagation medium (e.g., water), without further explanation [19–21].

The relevant research on convex lenses has primarily focused on the formation of inverted images and has largely been implemented in secondary and higher educational contexts [22,23]. The main perceptions brought to light by the aforementioned research on the creation of inverted images are as follows: (i) "Crossing rays", according to which the rays from the object's edges cross behind the lens, causing the image to appear inverted; (ii) "image change", according to which the rays that originate from the object's extremities do not converge at all, but the image appears inverted; (iii) "Rays through lens-point", according to which the rays from any part of the object pass through a specific point in the lens and end up at the corresponding point of the inverted image; (iv) "construction rules", according to which the two rays from the object's top edge diverge and converge at the bottom edge of the inverted image; (v) "the pin-hole", according to which the rays converge over the centre of the lens; and (vi) "the diverging and converging model", according to which two rays diverge from a point on the object and converge at a point on the image [24]. With regard to the removal of the convex lens and the views students in secondary and tertiary education hold about it, two main categories emerge from the literature review. In the first category, the students argue, correctly, that if the convex lens is removed, the image will continue to exist but will no longer appear inverted because without the lens, there will be no refraction. The second category of students are of the opinion that without a lens, there will be no image at all, on the grounds once again that without a lens, no refraction will take place [25,26].

The literature review also highlighted that there is a lack of research relating to the convergence of rays from self-luminous objects and a general shortage of studies relating to refraction and convex lenses in primary education; however, they are part of several relevant curricula, including, for example, the primary science curricula of Greece [27], England [28], and Ireland [29]. Specifically, in the Greek primary science curricula, light refraction is examined in a lesson that deals exclusively with convex and concave lenses (the title of the concerned lesson is Refraction). Specifically, as far as convex lenses are concerned, the lesson is based on an experiment in which light from a torch is directed into a cylindrical glass filled with water. According to the directions given in the relevant teacher's guidebook, students are expected to conclude that: "As light beams pass through a convex lens, such as a cylindrical glass filled with water, they come closer to each other and converge to a single point". The procedure followed in the course is similar for concave lenses [30]. It is obvious that the objective of the course focuses only on recording the observational data of the experiment and not on its interpretation (namely, that the convergence of light beams occurs due to the change in the direction of the light beams, depending on the angle of their incidence on the convex lens). It would therefore make sense to investigate how primary school students interpret the convergence of light beams so that the conceptions that emerge will form the basis for the planning of teaching activities that will connect convergence with refraction. At the same time, in the aforementioned activity (convex lens experiment), there is no mention of the path of light beams after the convergence point; however, in a subsequent lesson related to human vision, an experiment creating an inverted image of an object through a converging lens is proposed. In this context, it would make sense to investigate the extent to which students can observe the path of light beams after the convergence point and relate this path to the formation of an inverted image.

Keeping all of the above in mind, we designed activities regarding how convex lenses affect light propagation, for 3rd and 4th grade students from Greece (K-3 and K-4 students) in order to investigate the following research questions:

"To what cause do 3rd and 4th grade students attribute the convergence of light beams emitted by self-luminous objects that fall onto a convex lens?"

"Can 3rd and 4th grade students grasp that after the convergence point, beams of light emitted by self-luminous objects which fall onto a convex lens continue along the same straight line they were following before the convergence point?"

"Can 3rd and 4th grade students attribute the inversion of the image of a hetero-luminous object behind a convex lens to the fact that the light beams emitted by hetero-luminous objects which fall onto a convex lens continue along the same straight line they were following before the convergence point?"

3. Materials and Methods

For this study, the sample consisted of eight students from the Attica region (Greece) divided into four groups of two. Two groups consisted of K-3 students and the other two of K-4 students. The interventions were carried out outside school premises due to the restrictions in place to combat the COVID-19 pandemic.

The teaching experiment method was used to design and implement the intervention. This method allows students' perceptions to be explored along with the way in which they can construct the scientifically accepted explanation. In essence, it combines teaching with interviewing. It differs from the "classic interview" in two ways: First, it can last for several sessions depending on the research objective, and second, the interviews are deliberately organised as learning situations. Teaching experiments are carried out in groups of 2–4 children and are structured around certain learning tasks (experiments, simulations, hands-on activities, etc.) whose results are discussed with the students. Before the students engage with the learning projects, they are asked to express and discuss their initial ideas. After they have expressed their ideas about each of the objectives, the corresponding activity takes place so that they can observe what is happening and try to explain it. This method encourages discussion and the exchange of views between students. Finally, its ultimate goal is to record/study students' learning processes for the conceptual domain in question, namely: the difficulties they encountered on their way to reaching their conclusion and possible ways in which these difficulties could be overcome. The analysis of the teaching experiments, therefore, can later be a basis for the adaptation of the preliminary intervention to real classroom conditions [31,32].

For the purposes of this research, three teaching experiments lasting 60 min each were conducted. Each of them corresponded to one of the research questions listed above.

The teaching experiments were recorded audio-visually and subsequently transcribed verbatim. At the same time, the students also had the opportunity to express their thoughts with drawings.

Qualitative content analysis methods were used to analyse the data. Erickson [33] proposes that the results of a qualitative research activity can be recorded in three different ways. These are: specific description, general description, and orienting commentary. However, he claims that combining specific and general descriptions is the clearest way for the reader, as it shows not only the most frequent views, but also their full range and the relative frequency of occurrence. In accordance with this view, we adopted a narrative account of the views expressed, quoting extracts from the views the students expressed most frequently, while incorporating the frequencies of all the expressed views.

3.1. Data Collection

Data were collected through an analysis of the recordings of the teaching experiments, which were divided into steps as described below in the teaching intervention.

For each step, we attempted to record:

(a) the views and perceptions expressed by the students (either before or after each intervention),
(b) the evidence that facilitated their progress towards reaching a conclusion in each,
(c) the elements that impeded them from reaching these conclusions.

3.2. Content of the Teaching Experiments

As mentioned above, through teaching experiments, the intervention's primary objective was to record the progress of the students' thinking about the path light takes from both luminous and illuminated objects when it meets convex lenses.

The main steps in the teaching experiments were as follows:

1st teaching experiment: The convergence of light beams emitted by self-luminous objects when they encounter a convex lens.

Step 1: Formulate hypotheses about the path taken by light beams emitted by self-luminous objects when they encounter a convex lens.

In this step, the students were invited to:

- formulate hypotheses about the path taken by light beams emitted by self-luminous objects when they encounter a convex lens,
- justify their hypotheses.

To start with, there were two laser pointers on a table placed parallel to one another and facing a transparent cylindrical container filled with water (a convex lens made with everyday materials) (see Figure 1).

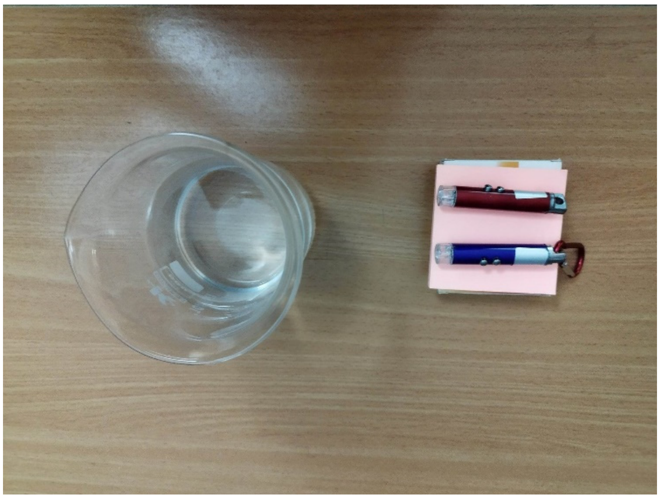

Figure 1. Activity in which pupils formulate hypotheses about the path taken by light emitted by laser pointers when it meets a convex lens.

The students were asked to express their ideas by answering the following questions:

"If we turn on both lasers, will we see their light? Can you show us the path the rays will take on their way to the glass? Will the light continue to travel inside the glass? Will the light continue to travel when it has passed through the glass? How will that happen?"

The students were then asked to answer the same questions, but to imagine that there was a torch emitting white light instead of the two lasers (see Figure 2).

Figure 2. Activity in which pupils formulate hypotheses about the path taken by light from a white-light-emitting lens when it encounters a convex lens.

In this step, taking into account their previous everyday experience that had shown them how light travels through transparent bodies, students are expected to argue that light will pass through the convex lens without changing its linear path.

Step 2: Carry out the experiment with light converging from a conventional torch and laser pointers encountering a convex lens. How do the students interpret the convergence of the light?

In the second step, the students were asked to:

- determine experimentally that the light beams emitted by luminous objects converge when they encounter a convex lens,
- express their ideas about the cause of the convergence.

The materials used were those listed in the previous step.

First, the students were asked to turn on the two red laser pointers, which were placed at specific points on the table, and to shine them on the convex lens (glass container) to see if the laser beams pass through it (see Figure 3).

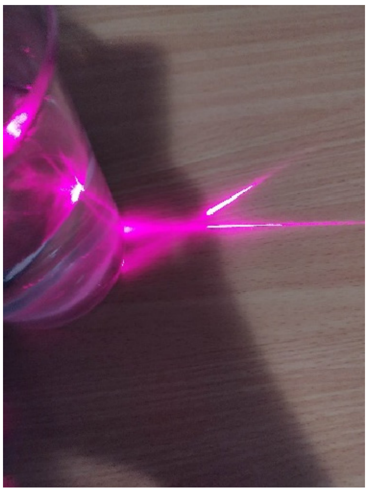

Figure 3. Observing the convergence of the two red laser beams.

The students were asked to answer the following question:

"What do you observe to be happening to the laser beams? Why do you think that is happening?"

Next, the students were asked to turn on the torch in front of the convex lens (glass container filled with water) on the table (see Figure 4). This allowed the children to observe the convergence of the rays with the torch.

Figure 4. Observing the convergence of the rays with the torch.

In the context of these observations, the students were invited to answer the following question:

"What do you observe to be happening to the light from the torch? Why does that happen?"

At the end of this activity, students are expected to determine that the rays of light emitted by a self-luminous object converge and to express their ideas about the cause of this convergence.

2nd teaching experiment: The path followed by light beams emitted by self-luminous objects that encounter a convex lens after the convergence point.

Step 1: Formulate hypotheses about the path taken by light beams emitted by self-luminous objects that encounter a convex lens after the convergence point.

In this step, the students were asked to:

- formulate hypotheses about the path of light beams emitted by two laser pointers with different colored beams (green and red) that meet a convex lens after the convergence point,
- back up their hypotheses.

On the table, one of the two red laser pointers from Figure 1 has now been replaced with a green laser pointer.

The students were then asked to express their ideas by answering the following questions:

"If we turn on the two lasers, what do you think the paths of the green and red beams will be?"

The children could draw the paths followed by the two laser beams on paper (as seen from above) using a red marker for one and a green marker for the other.

Some children are expected to posit, in line with the scientifically accepted explanation, that the beams will continue along the same straight line after the convergence point, too (the green beam from the left will go to the right, and the red beam coming from the right will go to the left) (see Figure 5).

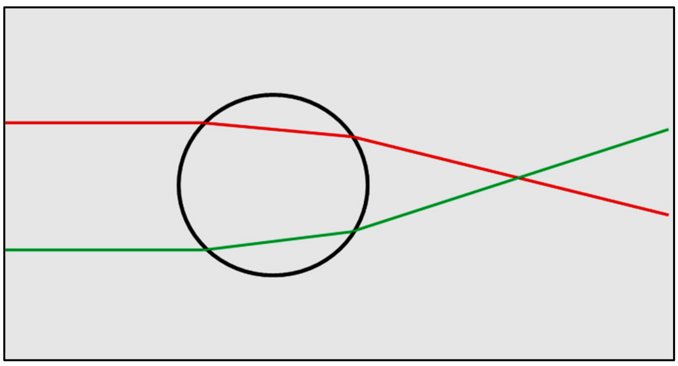

Figure 5. The image above depicts a student's possible sketch concerning the path that the light beam follows after the convergence point (in accordance with the scientifically accepted model).

Other students are expected to posit that the beams will "reflect", bouncing off each other, at the convergence point. So, the green one will continue to the left after the reflection, while the red one will continue to the right (see Figure 6).

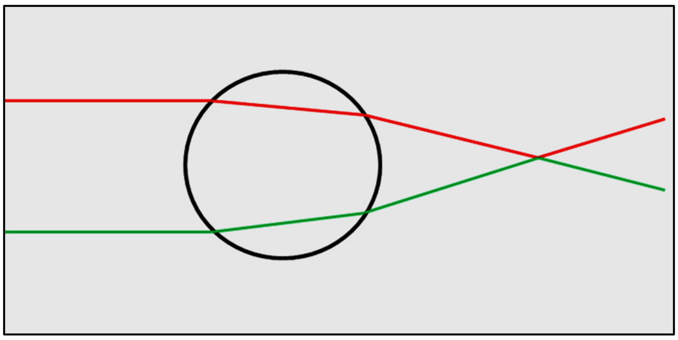

Figure 6. The image above depicts a student's possible sketch concerning the path that the light beam follows after the convergence point (alternative idea).

Step 2: Carry out the beam convergence experiment with two different colored lasers (red, green).

In the second step, the students were asked to:

- determine experimentally that after the convergence point, beams of light emitted by self-luminous objects which meet the convex lens continue in the same straight line as before the convergence point.

The materials used were (1) a transparent cylindrical container, (2) water, (3) a red laser pointer, (4) a green laser pointer.

The students were given one red and one green laser and asked first to position them in accordance with existing markings (see Figure 7).

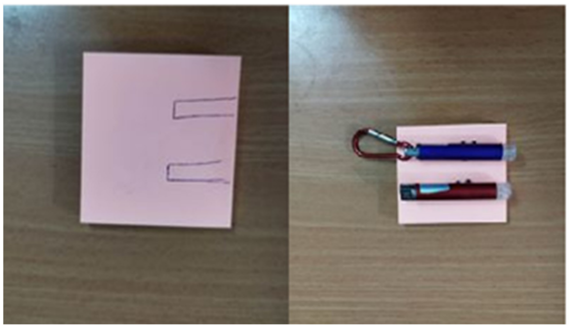

Figure 7. The positions at which the 2 lasers were positioned.

They were then asked to turn them on in order to observe the path taken by the beams of light after the convergence point (see Figure 8).

In the context of these observations, the pupils were asked to answer the following question:

"In the end, which path can you see the red and green rays following?"

At the end of this activity, children are expected to conclude that the rays continue after convergence in the same straight line they were describing prior to convergence.

3rd teaching experiment: Creating an inverted mirror image of a hetero-luminous object due to a convex lens.

Step 1: Formulate hypotheses about the cause of a hetero-luminous object's image inversion behind a convex lens.

In the first step, the students were asked to:

- formulate hypotheses on the features of the image of a hetero-luminous object behind a convex lens,
- justify their hypotheses.

First, we placed a paper with two differently colored oval sketches, one yellow and one orange (see Figure 9), in front of an empty glass (see Figure 10).

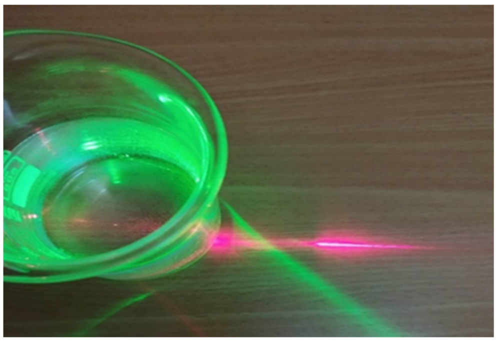

Figure 8. Observing the convergence of the beams emitted by one red and one green laser.

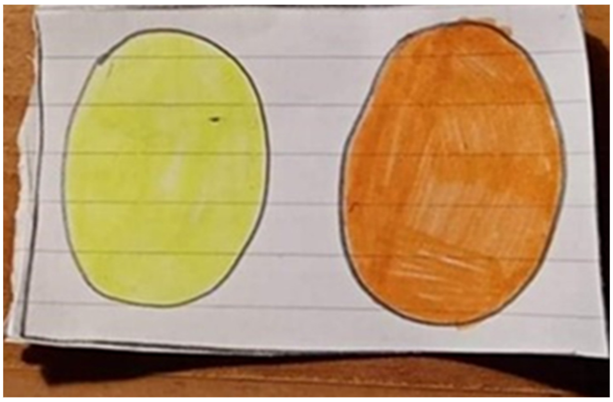

Figure 9. A paper with two differently colored oval sketches.

Figure 10. What the paper looks like before we pour water in the glass.

Students were then asked to answer the following questions orally and/or with drawings:

"Imagine that we fill the glass with water. Do you think it will change anything about the way we see the two sketches on the paper, if we stand about a meter away from the glass? Can you draw the path followed by one ray starting from the yellow sketch and another ray starting from the orange sketch on its way to reaching our eye? Why do you think the rays will follow this path?"

Based on the conclusions they hypothetically reached at the end of the second teaching experiment, the students are expected to assume that the image will be reversed (the yellow will appear on the right and the orange on the left).

Step 2: Carry out an experiment to create an inverted mirror image of an illuminated object behind a convex lens.

In the second step, the students were asked to:

- observe that the image of an object formed behind the convergence point of a convex lens is reversed,
- attribute this observation to the fact that beams of light emitted by hetero-luminous objects which encounter a convex lens continue in the same straight line as before the convergence point.

The materials used were: (1) a cylindrical transparent glass, (2) water, (3) a paper with two differently colored oval sketches.

At this point, the students were asked to fill the empty glass with water and then observe the image formed, having placed themselves at a distance of about one meter from the glass (see: Figure 11).

Figure 11. Inverted mirror image.

In the context of these observations, students were asked to answer the following question:

"Why have the yellow and orange sketches swapped places?"

At the end of this step, the students are expected to determine that a hetero-luminous object will appear inverted (horizontal inversion) when observed through the convex lens due to the fact that the light beams emitted by the object that encounter the lens initially converge, then continue in the same straight line relative to their path before the convergence point.

4. Results

1st teaching experiment: The convergence of light beams emitted by self-luminous objects when they encounter a convex lens.

Step 1: Formulate hypotheses about the path taken by light beams emitted by self-luminous objects that encounter a convex lens.

At this step, there were two tendencies. Five out of eight students claimed that light will keep on propagating when it meets a convex lens. Four of them argued that the rays would pass through the convex lens:

Researcher: We assume that this lens will open here. What will the light do?

Student 1: It will pass through. It will travel through the container.

The fifth student argued that the light will spread around the perimeter of the convex lens:

Student 5: The light won't pass through. It will stop here (pointing to the part of the lens which the light strikes first).

Researcher: Why do you think that will happen?

Student 5: Because the container is glass and not a simple slide for it to pass through. It's thicker so the light goes round.

The explanation of student 5 underlies notions according to which the propagation of light is not linear under certain conditions.

The other three students did not believe that the light would pass through the container in either case (the white light and the laser), as they seemingly attributed the transparency of the objects not to their color but to their thickness and shape:

Student 3: The glass will not pass through the other way. Only if the glass was thin, it could (pass).

Step 2: Carrying out the experiment in which light from a conventional torch and a laser pointer converges when it encounters a convex lens.

The experiment helped all the students to determine that the light does not stop in the glass, but passes through it:

Student 3: It passes through eventually.... It passes through, because there's nothing like cardboard to keep the light in there. So it passes through.

However, none of the pupils attributed the rays' convergence to the shape of the lens, meaning the angle of incidence of the light beams on several points of the glass filled with water. Seven out of eight students attributed it to the water in the container alone:

Student 1: So the two lasers beams enter the water and split at a certain point (pointing to the two ends) and then they go all the way to the end and combine.

Researcher: Why do they combine?

Student 1: The water first unites, then separates them.

Student 2: The water turns the rays and then they come together to form an x.

One student answered the relevant question tautologically:

Student 4: They (the rays) pass through the glass and then join together...

2nd teaching experiment: The path of beams of light emitted by self-luminous objects that meet a convex lens after the convergence point.

Step 1: Formulating hypotheses about the path beams of light emitted by self-luminous objects (green and red lasers) that meet a convex lens follow after the convergence point.

Half the students (four out of eight) argued that the rays would converge and then continue as a single ray:

Student 6: The rays join together like this (see Figure 12)... They join at the end somewhere here (pointing to the point of convergence) and continue on together somehow.

This view is probably due to observational data acquired by the students in their everyday lives, as in many cases where convergence occurs randomly, the path of the light after the convergence point is not evident.

Two students argued that the rays converge and then split (see Figure 13).

Student 1: So the two lasers beams enter the water and split at a certain point (pointing to the two ends) and then they go all the way to the end and combine.

Researcher: Why do you think this happens?

Student 1: It's just the water joining them and then separating them.

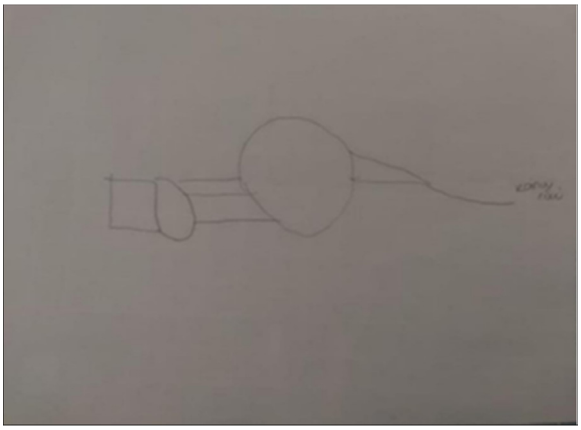

Figure 12. Student 6's drawing: the rays converge and continue as one.

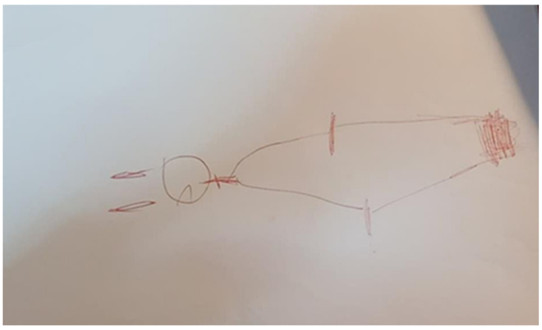

Figure 13. Student 1's drawing: the rays converge and then split.

This view most likely reflects an attempt by the students to interpret the properties in question by connecting them to macro-phenomena (e.g., elastic collisions). In the present case, this tendency seems to act as a cognitive obstacle, as the light beams do not act like two macroscopic objects which collide elastically when they meet. This logic seems to agree with the contemporary literature, which finds that students tend to adopt a macroscopic logic to interpret microscopic phenomena [34,35].

Finally, two students argued in line with the officially accepted model: namely, that the beams converge and then continue along the same straight path they were following before.

Student 7: They start to join and after joining, they continue and go back, like in the drawing (see Figure 14).

Figure 14. Student 7's drawing: the rays converge and then continue on their path.

Step 2: Carrying out the beam convergence experiment with two lasers of different colors (red, green).

This activity helped all students to see that the rays after convergence continue in the same straight line as before convergence:

Student 7: Oooooooh it's forming!!!! The path of the green one is forming!!

Student 8: And it joined the path of the red one.

Researcher: And what happens after they join?

Student 8: They continue straight on (Student 8 forms the letter x with both hands).

3rd teaching experiment: Creation of an inverted mirror image of a hetero-luminous object with the help of a convex lens

Step 1: Formulate hypotheses about the characteristics of the image of an object behind a convex lens.

Concerning the prediction of the path followed by the light from the two precious hetero-luminous objects in the treasure chest, only one student (1/8) argued that the rays would continue in the same line after convergence, essentially adopting the conclusion drawn from the second teaching experiment, but this time for hetero-luminous objects (see Figure 15):

Figure 15. Student 2's drawing: the rays will continue in the same straight line after convergence.

Student 2: The two rays hit here (showing two points on the walls of the glass), they join together, make an x and continue diagonally.

Researcher: But why does that happen?

Student 2: Because it's the same as in before, with the glass (meaning the activity from the 2nd teaching experiment).

Six out of eight students claimed that the rays will converge and then continue as one ray:

Researcher: Where does the yellow one go, and where does the orange one go?

Student 4: Straight on. This is the chest here, and I think they'll continue like that, so they pass through the glass and then meet at a point and they'll continue together (see Figure 16).

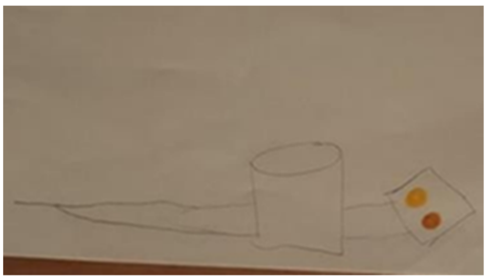

Figure 16. Student 4's drawing: the rays will converge and then continue as one ray.

Finally, one out of eight students assumed that the rays would continue vertically in the glass.

Student 5: One might go up to here say (the middle of the glass), and the other will go up to here say (above the middle) (see Figure 17).

Figure 17. Student 5's drawing: the rays will continue vertically in the glass.

When it came to predicting how the two sketches would appear through the full glass of water, one of the eight students claimed that they would appear upside down when viewed through the convex lens:

Researcher: Do you think the way we see the object will change?

Student 1: Yes. It might even be upside down.

Researcher: Why?

Student 1: Because water is like a mirror and can turn objects upside down.

This student attributed the possible inversion of the image to a supposed mirror-like property of water.

The remaining students (seven out of eight) argued that the object would simply be of a different size if it was placed in front of a convex lens:

Student 5: . . . it will look a little wider and that the colors will be a little skinnier.

Researcher: Why?

Student 5: If you look at it like this (looking down, as though looking at it from above the glass) it's like a mirror, but if you look at it like this (looking straight ahead) you see yourself broader or skinnier.

Step 2: Carry out an experiment to create an inverted mirror image of a hetero-luminous object behind a convex lens.

All the students determined that the image will be reversed if observed through a convex lens. One of them attributed the reversal of the image to the shape of the glass combined with the presence of water in it. However, the student could not relate the shape of the lens to the angle of incidence of the light beams at the various points of the glass:

Researcher: What changed in the treasure chest?

Student 3: The order. It's orange here and yellow here.

Researcher: And why do we think that's happening?

Student 3: Because the water is in a glass that's circular.

The other seven of the eight students simply argued that the inversion of the image is due to the lens acting as a mirror.

Student 6: The orange went there and the yellow went there (showing the other position).

Researcher: And why is that?

Student 6: Because it's a mirror.

None of the students used elements of geometric optics, either orally or in the form of a drawing, to explain the path taken by the light beams before or after the convergence point.

5. Discussion

This research sought to record K-3 and K-4 students' understanding regarding:

(A) the convergence of light beams emitted by self-luminous material bodies when they pass through a convex lens,
(B) the fact that these beams of light continue to move in the same straight line after convergence as before convergence,
(C) that the reversal of the image of a hetero-luminous object is due to the convergence of the beams emitted by it as they fall on a convex lens.

Regarding the interpretation of the convergence of light beams emitted by a self-luminous object, the children mainly attributed it to the material (i.e., the water in the container or the glass) and not to the angle of incidence of light at the various points of the cylindrical glass filled with water. This alternative approach, namely, to make references to specific parts of the arrangement such as the water or the container, instead of referring to the refraction of light when changing the medium of propagation, seems to be quite common among secondary school and university students, too [36,37].

In this context, it would make sense to enrich the intervention with other types of lenses (concave, flat or plano-convex lenses, lenses with different degrees of convexity or made of other transparent materials like plastic) and to focus, each time, on tracing the path taken by different light beams, before and after the convex lenses. This type of activities may help the students to determine that the convergence is due to the angle of incidence of light at the various points of the convex lens.

With respect to the path of the light beams after the convergence point, the use of laser sources of different colors (green and red) seemed to help the students to observe and then to determine that, after convergence, the rays continue on the same straight propagation as they did before the point of convergence.

Finally, regarding the reversal of the image of a hetero-luminous object, students seemed to have difficulty relating the creation of an inverted image to the convergence of the rays emitted by the hetero-luminous object. Most students simply attributed mirroring properties to the water in the glass (the water acts as a mirror). That tendency is in agreement with findings in which students who are asked to explain how images are formed tend to conceptualise the process "holistically", when they are not capable of explaining the phenomenon in terms of geometrical optics [38]. In our case, this may be due to: (i) the students' alternative ideas about how we see hetero-luminous objects [39]; (ii) the fact that it is not easy for them to apply the conclusion they had reached about the convergence of light beams with respect to self-luminous objects (mobile phone torch, laser pointer) to hetero-luminous objects; (iii) the fact that the second teaching experiment used laser lenses alone, since the students were not given the opportunity to generalise this conclusion when the convergence takes place with a light source that is not a laser (e.g., mobile phone torch); (iv) the fact that the second teaching experiment only concerned the path of two light beams, while creating an inverted image of a hetero-luminous object involves the convergence of many more light beams. In this context, we believe it would have made sense for the third teaching experiment to have been preceded by another one on how we see hetero-luminous objects. It is also proposed to enrich the second teaching experiment with an experimental procedure in which the path of light beams is examined before and after convergence when the light source is not a laser. For example, the torch on a mobile phone could be used, with half of the convex lens having been painted a different color from the other half (using a vertical axis of symmetry). In this example, it would make sense for the students to observe how the inversion of the two colors is captured, not only in the horizontal but also in the vertical plane, so that it can then be connected to the creation of an inverted image of an object in the third teaching experiment. At the same time, it should be emphasised that, regarding the conditions for the children to see the inverted image of a hetero-luminous object through the glass (filling the glass with water and placing the children behind the point of convergence of the rays), the addition of relevant questions and activities in the third teaching experiment (e.g., bringing the children closer to the glass so that they no longer see the mirror upside down) may help them further on their way to the desired conclusion.

This was a pilot study with a small and non-representative sample. It would make sense to apply it to a larger sample with the same methodological tool (teaching experiments) in order to enrich and generalise the relevant conclusions. In addition, the teaching experiments should be adapted on the basis of the aforementioned conclusions. Finally, at a later stage, it would make sense to apply this application, with appropriate adaptations, to real classroom conditions.

Author Contributions: A.K., M.D. and I.S. contributed to the study conception and design. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: According to Greek legislation (Law 4957/2022, Chapter L, Paragraph 279, https://www.kodiko.gr/nomothesia/document/807164/nomos-4957-2022 accessed on 20 November 2023), ethics approval for a study by the relevant ethics committee is mandatory only for funded research. In this context, our research did not require the approval of an ethics committee because it is not funded, while at the same time did not pose any threats or risks to the participants, and it was not associated with high physical or emotional stress. However, we strictly followed all ethical guidelines of the research ethics and ethics committee of the National and Kapodistrian University's Department of Early Childhood Education (https://www.ecd.uoa.gr/deontologia-erevnas/—in Greek) as well as the Declaration of Helsinki.

Informed Consent Statement: Informed consent was obtained from the parents of all participants.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Castro, D. Light mental representations of 11–12-year-old students. *J. Soc. Sci. Res.* **2013**, *2*, 35–39. [CrossRef]
2. Osborne, J.F.; Black, P.; Meadows, J.; Smith, M. Young children's (7–11) ideas about light and their development. *Int. J. Sci. Educ.* **1993**, *15*, 83–93. [CrossRef]
3. Tural, G. Cross-Grade Comparison of Students' Conceptual Understanding with Lenses in Geometric Optics. *Sci. Educ. Int.* **2015**, *26*, 325–343.
4. Kaltakci-Gurel, D.; Eryilmaz, A.; McDermott, L.C. Development and application of a four-tier test to assess pre-service physics teachers' misconceptions about geometric optics. *Res. Sci. Technol. Educ.* **2017**, *35*, 238–260. [CrossRef]
5. Fleer, M. Early learning about light: Mapping preschool children's thinking about light before, during and after involvement in a two-week teaching program. *Int. J. Sci. Educ.* **1996**, *18*, 819–836. [CrossRef]
6. Langley, D.; Ronen, M.; Eylon, B.-S. Light propagation and visual patterns: Preinstruction learners' conceptions. *J. Res. Sci. Teach.* **1997**, *34*, 399–424. [CrossRef]
7. Hubber, P. Explorations of Year 10 students' conceptual change during instruction. *Asia-Pac. Forum Sci. Learn. Teach.* **2005**, *6*, 1–27.
8. Ravanis, K. Mental representations of light propagation time for 10-and 14-year-old students: Didactical perspectives. *J. Balt. Sci. Educ.* **2019**, *18*, 276–285. [CrossRef]
9. Rice, K.; Feher, E. Pinholes and images: Children's conceptions of light and vision. *Sci. Educ.* **1987**, *71*, 629–639. [CrossRef]
10. Selley, N.J. Children's ideas on light and vision. *Int. J. Sci. Educ.* **1996**, *18*, 713–723. [CrossRef]
11. Gallegos-Cázares, L.; Flores-Camacho, F.; Calderón-Canales, E. Preschool science learning: The construction of representations and explanations about color, shadows, light and images. *Rev. Sci. Math. ICT Educ.* **2009**, *3*, 49–73. [CrossRef]
12. Hardman, M.; Riordan, J.P. How might educational research into children's ideas about light be of use to teachers? *Phys. Educ.* **2014**, *49*, 644–653. [CrossRef]
13. Ravanis, K.; Christidou, V.; Hatzinikita, V. Enhancing conceptual change in preschool children's representations of light: A sociocognitive approach. *Res. Sci. Educ.* **2013**, *43*, 2257–2276. [CrossRef]
14. Herakleioti, E.; Pantidos, P. The contribution of the human body in young children's explanations about shadow formation. *Res. Sci. Educ.* **2016**, *46*, 21–42. [CrossRef]
15. Tekos, G.; Solomonidou, C.; Stavridou, H. Teaching Light Reflection and Diffusion Using Constructivist Digital Tools and Methods in Greek Primary School. In *Proceedings of the EdMedia + Innovate Learning 2008, Vienna, Austria, 30 June 2008*; Luka, J., Weippl, E., Eds.; ED-MEDIA AACE: Waynesville, NC, USA; pp. 138–139.
16. Srisawasdi, N.; Kroothkeaw, S. Supporting students' conceptual development of light refraction by simulation-based open inquiry with dual-situated learning model. *J. Comput. Educ.* **2014**, *1*, 49–79. [CrossRef]
17. Merlin, J.; Jacob, M.; Max, C. Secondary school learners' contextualized knowledge about reflection and refraction: A case study from South Africa. *Res. Sci. Technol. Educ.* **2017**, *36*, 131–146. [CrossRef]

18. Fyttas, G.; Komis, V.; Kaliampos, G.; Ravanis, K. Mental Representations and Cognitive Schemata of Ninth Grade Students for the Refraction of Light. *Educ. Sci.* **2023**, *13*, 467. [CrossRef]
19. Chen, J.-Y.; Chang, H.-P.; Guo, C.-J. The development of a diagnostic instrument to investigate students' alternative conceptions of reflection and refraction of light. *Chin. J. Sci. Educ.* **2004**, *12*, 311–340.
20. Saxena, A.B. The understanding of the properties of light by students in India. *Int. J. Sci. Educ.* **1991**, *13*, 283–289. [CrossRef]
21. Singh, A.; Butler, P. Refraction: Conceptions and knowledge structure. *Int. J. Sci. Educ.* **1990**, *12*, 429–442. [CrossRef]
22. Yu, N.; Genevet, P.; Kats, M.A.; Aieta, F.; Tetienne, J.P.; Capasso, F.; Gaburro, Z. Light propagation with phase discontinuities: Generalized laws of reflection and refraction. *Science* **2011**, *334*, 333–337. [CrossRef] [PubMed]
23. Goldberg, F.M.; McDermott, L.C. An investigation of student understanding of the real image formed by a convex lens or concave mirror. *Am. J. Phys.* **1987**, *55*, 108–119. [CrossRef]
24. Merlin, J.; Molepo, M.J.; Chirwa, M. South African learners' conceptual understanding about image formation by lenses. *EURASIA J. Math. Sci. Technol. Ed.* **2017**, *13*, 1723–1736. [CrossRef]
25. Grusche, S. Developing students' ideas about lens imaging: Teaching experiments with an image-based approach. *Phys. Educ.* **2017**, *52*, 044002. [CrossRef]
26. Galili, I.; Hazan, A. Learners' knowledge in optics: Interpretation, structure and analysis. *Int. J. Sci. Educ.* **2000**, *22*, 57–88. [CrossRef]
27. Institute of Educational Policy. *Physics Curriculum for the 5th and 6th Grades of Primary School*, 1st ed.; Institute of Educational Policy: Athens, Greece, 2021; Available online: https://dipe.ark.sch.gr/wp-content/uploads/2021/12/%CE%A6%CF%85%CF%83%CE%B9%CE%BA%CE%AC_%CE%94_%CE%A0%CE%A3-1.pdf (accessed on 18 October 2022). (In Greek)
28. The Identity Business. Science: Social, Environmental and Scientific Education, Primary School Curriculum. 1999. Available online: https://curriculumonline.ie/getmedia/346522bd-f9f6-49ce-9676-49b59fdb5505/PSEC03c_Science_Curriculum.pdf (accessed on 18 October 2022).
29. Department of Education. The National Curriculum in England Framework Document. 2014. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/381344/Master_final_national_curriculum_28_Nov.pdf (accessed on 18 October 2022).
30. Apostolakis, E.E.; Panagopoulou, S.; Savvas, N.; Tsagliotis, V.; Makri, G.; Pantazis, K.P. *Science Grade K-6, Teacher's Book [Φυσικά Στ' Δημοτικού, Βιβλίο Δασκάλου]*; Diofantos: Athens, Greece, 2017.
31. Duit, R.; Roth, W.M.; Komorek, M.; Withers, J. Conceptual change cum discourse analysis to understand cognition in a unit of chaotic systems: Towards an integrative perspective on learning in science. *Int. J. Sci. Educ.* **1998**, *20*, 1059–1073. [CrossRef]
32. Komorek, M.; Duit, R. The teaching experiment as a powerful method to develop and evaluate teaching and learning sequences in the domain of non-linear systems. *Int. J. Sci. Educ.* **2004**, *26*, 619–633. [CrossRef]
33. Erickson, F. Qualitative research methods for science education. In *Second International Handbook of Science Education*; Barry, J.F., Kenneth, T., Campbell, J.M., Eds.; Handbooks of Education; Springer International: Dordrecht, The Netherlands, 2012; pp. 1451–1469. [CrossRef]
34. Valkanou, E.; Starakis, I. Exploring k5 students' learning pathways regarding water's electrical conductivity. *Res. Sci. Technol. Educ.* **2023**, 1–24. [CrossRef]
35. Ben-Zvi, R.; Eylon, B.; Silberstein, J. Is an Atom of Copper Malleable? *J. Chem. Educ.* **1986**, *63*, 64–66. [CrossRef]
36. Andersson, B.; Kärrqvist, C. How Swedish pupils aged 12–15 years understand light and its properties. *Eur. J. Sci. Educ.* **1983**, *5*, 387–402. [CrossRef]
37. Bouwens, R.E.A. Misconceptions among pupils regarding geometrical optics. In *Misconception and Educational Strategies in Science and Mathematics, Proceedings of the Second International Seminar, Ithaca, NY, USA, 26–29 July 1987*; Novak, J., Ed.; Cornell University: Ithaca, NY, USA, 1987; Volume III, pp. 23–28.
38. Galili, I.; Bendall, S.; Goldberg, F. The effects of prior knowledge and instruction on understanding image formation. *J. Res. Sci. Teach.* **1993**, *30*, 271–301. [CrossRef]
39. Kokologiannaki, V.; Ravanis, K. Mental Reprasentations of sixth graders in Greece for the mechanism of vision in conditions of day and night. *Int. J. Res. Educ. Meth.* **2012**, *2*, 78–82.