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Representation of Image Formation—Observation in Optics in Ethiopian Textbooks: Student Learning Difficulties as an Analytical Tool

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Abstract: Studies have reported that students find geometric optics topics difficult partly because of representations in textbooks. In Ethiopia, textbooks are the main source of content in schools. Therefore, a study of how textbooks present certain topics can shed light on students' learning difficulties. This study specifically examines how image formation–observation is presented in Ethiopian textbooks and how these representations might be the possible causes of students' learning difficulties. Sixth-, eighth-, and tenth-grade physics textbook chapters containing topics related to image were analyzed. The analysis followed a directed approach to qualitative content analysis. The results show that textbooks sometimes contain explanations that explicitly clarify pictorials and are consistently integrated. However, the textbooks also contain implicit, missing, and incorrect verbal representations as well as incomplete, selective, and patterned pictorial representations that are presented inconsistently. Moreover, the textbooks rarely show alternative representations that complement the problematic representations, hence limiting their misinterpretations. Students may intuitively interpret implicit, selective, and patterned representations that may not conform to scientific concepts. Similarly, incorrect, missing, and incomplete representations could be seen as a direct source of students' misconceptions. The results suggest that authors and teachers of optics textbooks should be aware of students' learning difficulties because of representations and should emphasize alternative representations.

Keywords: image and light; misconception; optics; textbook analysis

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1. Introduction

Representation denotes concepts, is defined as "something that stands for something else" [1] (p. 164), and is often categorized as either external or internal. External representations exist in the natural world and can be expressed in verbal (written or spoken) or pictorial (static or dynamic) modes, whereas internal representations denote knowledge and structure held in human memory [1,2]. Internal representation is a mental image formed based on external representations [3,4]. Therefore, the external representation (hereafter representation) is crucial for learning, such as learning physics [1,5]; thus, this is the focus of the present study.

Most physics concepts require pictures and verbal descriptions to better understand them. In addition, physics concepts are described with mathematical models that explain the relationships between variables [5]. Therefore, effective physics discourse requires students to use and switch between many forms of representation [1,6]. However, students often have difficulties in translating and using representations as intended [3,6]. This is because the association of two or more representations is not automatic [3]. Moreover, students are expected to understand the syntax and scope of representations in order to use them effectively [7].

Geometric optics is one of the topics in physics that is predominantly taught using two or more representations [7]. However, it has been reported that students find geometric optics topics difficult and have developed a wide range of misconceptions about the topic [8–10]. This has been partly ascribed to the problem of representation [8,11,12].

Representations are presented to students mainly in textbooks and through teacher instructions. Therefore, representations in the textbooks and their use by teachers can affect students' understanding [10,13,14]. Moreover, textbooks are the primary source of information for students and teachers in many countries [15], being an essential feature of formal education that influence teachers' choice of content and teaching approaches [15,16]. Science teachers use textbooks as the main reference material for designing and delivering their lessons [15,17,18]. In the Ethiopian context, textbooks are the most widely and extensively used teaching material [19,20]. Textbooks, therefore, have a significantly high impact on student learning [13,15,16] and are worth analyzing.

Research on science textbooks is a growing field [21]. Vojíř and Rusek [21] reported that fewer studies have analyzed physics textbooks compared with other science disciplines. In particular, the analyses of textbook representations as a possible cause of student learning difficulties and misconceptions have focused more on chemistry textbooks. Few studies have examined representations in physics textbooks as a possible source of student learning difficulties (e.g., [22–24]).

Regarding geometric optics in physics textbooks, Gurel and Eryilmaz [23] studied the representation of the observer in image formation–observation in Turkish textbooks. However, their results are limited to the Turkish context, and they only examined the inclusion of the observer in the image formation–observation. The representation involving the observer can also be a source of students' learning difficulties in other aspects, such as the pattern of representations [25], placement [2], and light ray usage [8,11]. A detailed analysis of the representation of image formation–observation might be important to avoid students' learning difficulties and misconceptions.

Moreover, recent and relevant studies on science textbook analysis in the Ethiopian context have been limited. Existing studies include analyses of the student-centeredness of chemistry and physics textbooks [26–28], the incorporation of higher-order domains of learning in chemistry textbooks [29], and the representation of some concepts, such as history and philosophy of science, in chemistry textbooks [19]. However, to the best of our knowledge, no relevant study has examined the representation of a scientific phenomenon in Ethiopian science or physics textbooks as a possible source of students' learning difficulties. The present study examines the representation of image formation–observation in geometric optics in Ethiopian physics textbooks. It has the following primary research questions: (1) How is image formation–observation in geometric optics presented in Ethiopian science textbooks? (2) How might image formation–observation representation cause students to have misconceptions and learning difficulties related to the topic?

The answers to the research questions will provide insights for future textbook authors, especially in the Ethiopian context. In Ethiopia, textbooks are commonly prepared by college or university lecturers in science disciplines who have no prior experience with textbook writing [19]. Because the authors are not science educators, the textbooks may not be informed by the science education literature. Studies aimed at examining the properties of representations, such as the present one, can be essential in identifying the missing links between textbooks and the research literature. It will also educate future textbook authors and teachers about the properties of representations, their values, and the disadvantages for student learning. In addition, the study may inform an international audience about the practice of a developing country, helping to provide a complete picture of the ways in which image formation–observation is presented and taught in schools around the world.

2. Literature Review

In this section, we present students' misconceptions and learning difficulties about image formation–observation and the possible causes of these difficulties according to existing studies. In the present study, the possible causes of students' learning difficulties related to representations that have been identified by studies on geometric optics and multimedia learning served as the basis for the categorization of the representations of image formation–observation in the textbooks we analyzed.

2.1. Students' Learning Difficulties

Studies have revealed that students of different ages and cultures have misconceptions about image formation–observation [8,10,30]. Kaltakci-Gurel et al. [10] found that students use key terms in geometric optics such as "image" arbitrarily or erroneously. The students referred to an image as a reflection of light rays from optical devices or anything that can be seen by the eye. The students in the studies by Galili (1996) and others considered the image to be a movable entity that moves with the help of light rays [8,11,30]. Kaltakci-Gurel et al. [10] reported that students struggled to scientifically define real and virtual images.

Regarding real images, in some studies, the students did not identify the process involved and the function of each component in the optical system; they believed that the function of a lens or mirror in image formation was to invert the image [31]. When asked what would happen if the convex lens or concave mirror were removed from the optical system, they replied that they saw an erect image. The students also thought that a screen is needed to form and see real images and that the position of the screen determines the size and orientation of the real image [10,31]. In the absence of a screen, an aerial image (real-image points in space) can be formed. The aerial image is visible when the observer is positioned in a place where the light rays diverging from the aerial image point can enter the eye. However, the students failed to explain the position of the eye to see the aerial image [12,31].

In geometric optics, two special rays are commonly used: the ray parallel to the principal axis and the ray passing through the focal point. This is because special rays are convenient because of their simple rules for tracing the path of light rays. Two of these rays are sufficient—but not necessary—to locate the position of the image. However, studies have found that some students assumed that special rays are necessary to form or see an image [10,31]. If part of the spherical mirror or lens was covered with an opaque object, the students predicted that either half of the image [8,11,31] or no image would be formed [10]. Their argument for this was that the opaque object may block some of the special rays that carry part of the image [10,31].

In the case of a virtual image, the students believed that image formation by a plane mirror is independent of the observer's presence and that image formation and image observation are separate events. In this view, the image of an object formed by a plane mirror remains in the mirror, whether it is observed or not [8,10,11]. The scientific explanation, however, is that a virtual image is formed and seen simultaneously in the observer's eye/mind; hence, the observer is an integral part of the optical system. In addition, the students thought that they could see the image of the object placed in front of the mirror, even though they were out of the range of the reflected light [31]. They subverted the role of the eye and reflected light from a plane mirror in image formation.

2.2. Potential Causes of Students' Learning Difficulties

Studies on the teaching and learning of geometric optics and multimedia learning have argued that representations might be possible sources of students' learning difficulties. The lack of explicit definitions of key multimedia terms and symbols used in textbooks could be a source of difficulties [2,7,32]. Mayer [2,32] argued that, to facilitate students' learning using multimedia, such as pictorial representations, the key parts of the media need to be explicitly communicated. The author added that textbooks or other forms of media presentation should describe the key features of multimedia before presenting it. Otherwise, it will be difficult for the students to learn from the multimedia content. For instance, if students do not see the benefits and limitations of using light rays, they may not benefit from learning with ray diagrams [7]. In addition, when key terms, such as images, are not explicitly and scientifically defined, students are forced to intuit its meaning, which may not be consistent with the scientific concept [8,9].

Sometimes, textbook authors aim to present entities as real objects and sometimes as symbols of real objects [25]. This may confuse students when discerning between real objects and the symbols of real objects. This seems to be the case with light ray representation in geometric optics, where students accept the light ray as a material object rather than a light model [8,9], probably because of the lack of explicit information about whether the light ray is a model or object [25]. It has been argued that this misunderstanding of light rays precludes students' image formation learning [8,9,11].

However, in a multimedia presentation, ambiguity in interpreting a representation can be reduced by presenting another familiar representation [3,25]. For instance, the ambiguity of accepting a light ray as a model can be solved by presenting an explicit verbal or visual explanation of it. In some cases, the static representation of pictures may not facilitate student learning [2,32]. Therefore, a dynamic representation of light as an alternative representation that might limit misinterpretation of it can facilitate student learning [3,31]. In addition, the procedure of presenting abstract and familiar representations may affect students' understanding of a particular representation [33,34]. Rather than presenting the abstract representation at first glance, it has been reported that it is better to present a concrete representation and allow for students to model their observations and experiences of the concrete representation. For instance, instead of showing the refraction of light using ray diagrams, it has been argued that it is better to allow for students to experience the phenomenon of refraction in a hands-on manner. This can prevent students from misinterpreting the pictorials used to represent light refraction [33,34].

Textbook authors sometimes omit some parts of an image, finding it impossible or unnecessary to depict certain aspects of an image [25]. This omission, in turn, can lead to learning difficulties and misunderstandings among students. For instance, omitting the observer in the image formation–observation representation may lead to students misunderstanding image formation by optical devices, such as a plane mirror [10,11,25]. The students in Galili's [11] study thought that image formation by a plane mirror was independent of the observer. Even in the case of a real image, in the absence of a screen, it is convenient to display an observer and field of view. Otherwise, it has been pointed out that it may be difficult for students to understand where the real image is visible from [12]. In addition, at least two diverging light rays entering the eye must be shown in image formation–observation representations [25].

Furthermore, a lack of information about the omitted part of the pictorial representation, either in words or in other forms of representation, can exacerbate the students' difficulties in learning. When a single representation does not carry all the necessary information, it is recommended that another mode of representation that complements the intended concept be included [3,25].

Emphasizing the specific aspects of a representation at the expense of others may also lead students to misunderstand the intended concept [25]. In geometric optics, an object is viewed as the collection of object points from each point an infinite number of rays are emitted or reflected in all directions. The use of special rays by neglecting these other rays in textbooks has been mentioned in some studies as one of the sources of student misunderstanding regarding image formation [10,31]. The students who took part in these studies viewed these special rays as necessary to form an image. If one is blocked, either no image [10] or half an image would be formed [8,11,31]. In addition, the depiction of light rays emanating from only one point of the object at the expense of many other object points can make it difficult for students to understand the image formation–observation [12,35].

Students may also have difficulty reading representations because of their placement on the page. This can happen when an element of an image is presented in a specific but unintended pattern that can mislead students into giving it incorrect attributes [25]. For instance, the left-to-right depiction of light transportation may reinforce the idea of an image as a movable entity that can stop wherever a screen is placed. Similarly, placing text and corresponding pictorial representations in a separate location may split students' attention, causing difficulty in making connections between them [32,36]. Therefore, the integration of the corresponding text and diagram representations might help in avoiding the noted difficulty.

3. Context of the Study

In Ethiopia, science teaching and learning begin at the primary level. Environmental science, which comprises geography, history, art, and science, is given to students from grades one to four. Science, here as the integration of life and physical sciences, is taught to pupils in the fifth and sixth grades. Physics, as a separate and compulsory subject, is taught to all students starting in grade seven. This continues until the end of tenth grade. Starting from grade 11, physics, here as a separate subject, is given for the natural science stream after students who have completed grade 10 choose between two options: natural science and social studies. Geometric optics is taught in grade six in the integrated science course and continues to be taught as one chapter in grades eight and ten physics textbooks.

The preparation of textbooks in Ethiopia is guided by the national curriculum framework. From this framework, a syllabus, content flow charts, and minimum learning competencies are prepared and used to guide the textbook preparation. The prepared textbooks consist of two sets: student textbooks and the teacher's guide. The teacher guide is mainly a set of instructions that the teacher follows when presenting the content from the student textbooks. In the present case, as noted above, student textbooks are the most important sources of content in schools [19,20]. There are other books on the market that could serve as additional references for teachers and students, but in practice, only interested teachers and students can use them. Therefore, the present analysis focuses on student textbooks.

Textbooks in use during the period of the present study from the three grade levels that include geometrical optics were selected. All three textbooks were published in 2012. The grades six (TB6), eight (TB8) and ten (TB10) textbooks consisted of 206, 171, and 240 pages, respectively. The chapters about geometric optics comprised 23, 36, and 45 pages in TB6, TB8, and TB10, respectively. TB6 was written in Amharic, while TB8 and TB10 were published in English. The textbooks mainly used verbal and pictorial (ray diagrams and photographs) representations to present geometric optics content.

4. Methods of the Study

In the current study, we have applied qualitative content analysis to make sense of the data. We examined meanings, categories, and patterns that may be manifest or latent from a particular content [37,38]. In this context, "content" is understood as words, meanings, pictures, symbols, and ideas communicated in textbooks. More specifically, a directed content analysis approach guided the study [38,39]. Based on a review of the existing research on the topic presented above, we identified key categories for our analysis; in the next step, we operationalized, refined, and amended them, and developed subcategories.

Below, we (1) describe the units of analysis, (2) outline the stages in the construction of the analysis framework presented in Table 1, where we then (3) elaborate on the coding process.

Table 1. Framework for textbook analysis emerged from the potential causes of student learning difficulties related to representations in optics.

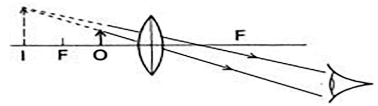
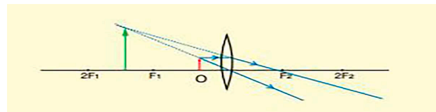
Categories and Their Description	Subcategories and Their Description	Examples and Their Explanation
Explicitness: Examines whether concepts, models, real objects, and symbols are explicitly defined and described [2] or whether they are used without explicit representation of them. It also examines whether the given representations are missing or incorrectly represented. It focuses on the verbal representations that clarify pictorials and concepts related to the image. Key concepts considered: Light, special ray, light ray, image, virtual and real image, screen, a field of view, reflection and refraction of light, light propagation direction, the extent of complete beam of light, terms related to lens and mirrors (focal length, principal axis, etc.) Objects: Optical instruments (mirrors and lenses), and other objects Models and Symbols: Light ray, upward arrow, and broken lines.	Explicit concepts: Whether definitions, descriptions, and depictions of key terms, real objects, models, and symbols in the image formation–observation representation are explicit.	"*Plane mirror a mirror whose surface lies in a plane*" (TB10, p. 201). A plane mirror is explicitly defined in the textbook.
	Explicit, but incorrect concepts: Explicit but wrong definitions and descriptions of key terms, real objects, models, and symbols in image formation–observation representation are present.	"*The position of the image formed by a plane mirror is behind the mirror*" (TB6, p. 149).
	Implicit concepts: Key terms or concepts, models, and symbols are used in the textbooks without explicit definitions. The concepts used in the pictorials without explicit verbal explanation are considered implicit.	"*When you can focus the light from an image on a screen, the image is called a real image*" (TB10, p. 205). The concept screen is used but not defined in the textbook.
	Absence of concepts: Key concepts that are important to understand image formation–observation, are absent from the textbooks. They are missing in all mode of representations in the textbooks.	Field of view is not mentioned and explained in TB6.
Completeness: A pictorial representation of image formation–observation should include an object, optical instrument, light rays emitted or reflected from the object, screen or observer, at least two reflected or refracted rays entering an observer's eye, and an image. The category examines whether all of the above-mentioned components are present in the pictorial representations of image formation–observation (complete representation) or whether at least one component is missing from the representations (incomplete representation).	Complete representation: Pictorial representations of image formation–observation that contain all the components.	The representation of a convex lens image below is complete because it contains an object (O) symbolized by an upward arrow, an optical instrument (lens), light rays emitted from the object, an image (I), an observer's eye and two rays entering the eye (TB10, p. 225). 
	Incomplete representation: Pictorial representations of image formation–observation where at least one component is missing.	 This pictorial representation lacks an observer (TB10, p. 223).
Selectiveness: Examines whether a specific representation emphasis at the expense of others in the image formation–observation pictorials or not [25].	Selective representation: A representation obtains emphasis at the expense of others in the image formation–observation pictorials.	The textbooks use one object point as a light source at the expense of other many object points.
	Nonselective representation: No representation obtains emphasis at the expense of others in image formation–observation pictorials.	There is no nonselective representation found in the textbooks.

Table 1. *Cont.*

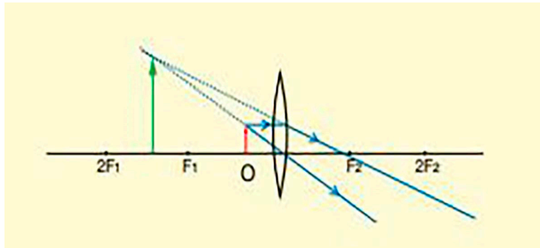
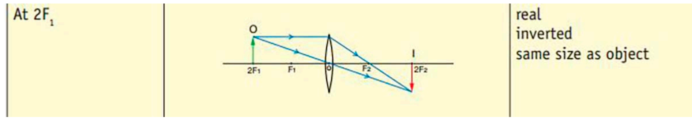
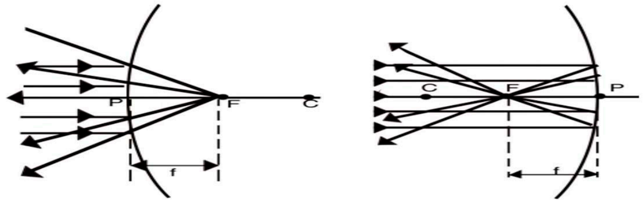
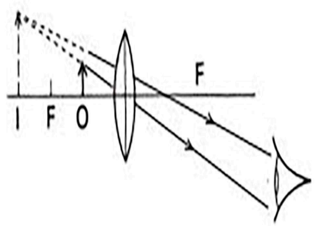
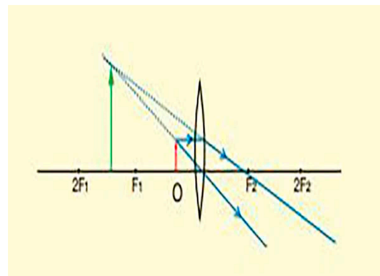
Categories and Their Description	Subcategories and Their Description	Examples and Their Explanation
Alternative representations: Examines whether there are alternative representations that complement incomplete and selective representations and constrain misinterpretation of abstract and implicit representation in image formation–observation. It also examines the procedure of presenting alternative representations.	Complementary representation: One mode of representation might not carry all the information [3]. In addition, the pictorials might give more emphasis to some representations at the expense of others [25]. In this case, another mode of representation might be used to complement the missing and less emphasized part of image representations [3]. Therefore, the subcategory examines the presence or absence of representations that complement the incomplete and less emphasized representations.	"*A cone of light will reach the lens, and the focusing action of the lens will bring this cone of light together again to a point. Our problem is to say where this point will be. Luckily within that cone, there are two particular directions of travel for which we can predict the path of the light as it leaves the lens*" (TB10, p. 222). The textbook explains the presence of many rays other than special rays supported with the diagrams (presence of complementary representation that complements special rays are not the only rays emitted from a source). At the same time, this can be counted as the *presence* of constraining representation that may constrain the misinterpretation of special rays as the only rays. The observer is missing in the image formation–observation representation as shown below (TB10, p. 223)  There is no other mode of representation that could complement the missing part (absence of complementary representation).
	Constraining representation: The presence or absence of representations that constrain the wrong interpretation of abstract and implicit representations.	"*The characteristics of image formed by concave mirror is dependent on the position of an object*" (TB6, p. 152). However, there is no explicit explanation about image, and it was important for the students to constrain intuitive interpretation of image (absence of constraining representation).

Table 1. *Cont.*

<table>
<tr><th>Categories and Their Description</th><th>Subcategories and Their Description</th><th>Examples and Their Explanation</th></tr>
<tr><td rowspan="2">Placement: Examines the place where multiple modes of representation are placed and how they are portrayed in the textbooks. It also examines if the textbooks follow a specific pattern of presenting image formation–observation pictorial representation.</td><td>Spatial contiguity: Placing verbal and corresponding pictorial representations near each other may overcome the split attention effect caused by separated representations [32,36]. The subcategory examines whether or not image formation–observation corresponding verbal and pictorial representations are integrated and placed next to each other.</td><td>

The above figure depicts an integrated textual and pictorial representation of image formation–observation (TB10 (p. 222)).


These diagrams contain English letters to refer to center of curvature (C), focal length (f), and pole (P) (TB6, p. 150). However, the verbal description of these terms is written in Amharic and does not contain these letters, which makes the integration difficult.</td></tr>
<tr><td>Pattern of representations: Whether there are a specific pattern of representation that may instigate to infer wrong attributes to it [25] or not.</td><td>The top of an upward arrow (symbol of an object) is often used to show light emanating from an object.</td></tr>
<tr><td rowspan="2">Consistency: Examines whether or not the representations of image formation–observation are consistent within or across textbooks.</td><td>Consistent representation: The presence of representations that are consistent within or across textbooks.</td><td>The object is represented by an up arrow throughout the TB10.</td></tr>
<tr><td>Inconsistent representation: The presence of representations that are not consistent within or across textbooks.</td><td>



The above two pictorials show inconsistencies in involving the observer and use of solid or broken lines to represent the virtual image. Both are taken from the same textbook (TB10, pp. 223 and 225).</td></tr>
</table>

4.1. Units of Analysis

We have limited the scope of our analysis to image formation–observation and related content from the three textbook chapters on geometric optics used in Ethiopian schools [38,40]. In our directed qualitative content analysis, we started with predefined analytical categories based on previous research on the potential causes of student learning difficulties in optics as the units for the analysis, rather than counting linguistic units such as word, sentence, or paragraph, which are commonly used in quantitative content analysis [38,41]. To ensure transparency—and thereby increase the reliability of the study [37,42]—we describe the process of constructing an analytical framework in detail below.

4.2. Construction of the Analytical Framework

First, a set of initial categories and subcategories were selected and constructed by the first author. The analytical framework consisted of (1) the categories Completeness and Selectiveness based on previous studies on learning difficulties of geometric optics; (2) the category Explicitness was constructed by adopting the concept of pretraining from the multimedia learning principle [2,32] to textbook analysis on geometric optics; (3) the category Placement was constructed by integrating the multimedia learning principle spatial contiguity [2,32] and studies on geometric optics, the pattern of representations (e.g., [25]); and (4) the category Alternative representations was constructed by adapting Ainsworth's multimedia learning framework [3] to textbook analysis on geometric optics.

Second, the first author piloted the initial analysis framework [38,39,43] to a sample content of TB6, resulting in a revised version of the framework where a new category, Consistency, was formed from the data content. Moreover, the description of the category Explicitness was amended such that the subcategories' absence of concepts and explicit but incorrect concepts were added to the literature-based subcategories explicit and implicit concepts to include those concepts found missing and wrong in the textbooks. This amendment was made after a thorough discussion between all coauthors.

As a third step, the revised analysis framework—that is, the categories and subcategories together with their characterization—was reviewed in its entirety by the research team until full agreement was achieved. It is worth mentioning that the categories are not mutually exclusive in the sense that a case is mentioned in more than one category. The complete and final versions of the analytical framework are presented in Table 1.

4.3. Data Coding

Once the analytical framework was finalized, to further enhance the internal validity [37], two of the members of the research team (the first and the last authors) independently coded the chapter dealing with geometric optics in TB8, which comprised 36 out of the selected total of 104 pages in the books (i.e., 35 percent of the content). The agreement constituted an 85 percent inter-rater reliability, demonstrating the validity of the framework as an analytical tool [37]. The few discrepancies were because of the differences in the way of abstracting and interpretating the data, which are important to consider when assessing the trustworthiness [37,41]. For instance, the two authors differed in their interpretations of which of the data should be included in the coding process. Additionally, they coded the same data into different subcategories or categories. In terms of abstraction, the first author considered a diagram to be explicit enough, for instance, while the last author saw it as abstract because a few symbols in the diagram were not explained, which also led to different coding. These discrepancies were solved by discussing them back and forth until full agreement had been reached. After this step, the first author reread TB6 and TB8 for consistency. The coding of TB10 was completed by the first author, because we, at that point, had achieved a robust and valid framework for analysis.

5. Results and Discussion

In this section, we present the explicitness of verbal representations, and the completeness, selectiveness, and placement of pictorial representations. The interdependence and consistency of verbal and pictorial representations are discussed under the categories of alternative representations, consistency, and partly placement. Regarding the research literature, we also discuss how the representation of image formation–observation in the textbooks can lead to misunderstandings and learning difficulties among students.

5.1. Explicitness

We see that, in the analyzed textbooks, only limited emphasis is given to clarifying pictorial representations and making them understandable for students through verbal representations. Most of the concepts that clarify pictorials are implicit, overlooked, and even incorrect. See Table 2 for detailed information on the explicit and implicit representations in textbooks.

Some explicit concepts were found in the textbooks (Table 2). For instance, TB8 and TB10 indicate that special rays are not the only rays emitted from a light source. TB8 explicitly states that light is emitted in all directions from the source. These concepts clarify the use of only special rays in a specific direction in pictorial representations [8,11].

There are, however, few explicit but incorrectly defined concepts in textbooks. These concepts could transmit misconceptions to students [10,14]. In science, an image is defined as an optically formed reproduction of an object. However, TB8 incorrectly defines an image as "*the reflection of an object in a mirror*" (TB8 p. 146). The explanation also reflects that an image is formed in the mirror, which is not true. Similarly, the position of the plane mirror image is falsely claimed to be behind the mirror (TB6&TB8).

There are also concepts, models, and symbols used in textbooks without explicit verbal explanation (Table 2). This may lead to students intuitively assimilating their meaning, which may not be in line with scientific concepts [8,9]. For example, using the concepts "image" (TB6) and "screen" (TB6, TB8, TB10) without explicit definitions may prevent students from providing scientific definitions of the concepts [8–10]. Similarly, the use of lenses and mirrors without definition (TB6) may contribute to students' difficulty in understanding the role of these optical instruments in the image formation–observation process [8,31].

In addition, overlooking the explanation of broken and solid lines shown in pictorial representations (TB6, TB8, and TB10) may leave students unaware of when and where this syntax is important. When symbols such as focal length, image distance, object distance, and the like are depicted without prior explanations (TB6 and TB8), students may have difficulty in reading and understanding image formation–observation pictorials [2,7]. Similarly, none of the textbooks have described light rays explicitly as a model; this may confuse students when categorizing light rays as a model or object [25], leading to the students misinterpreting a light ray as an object, which eventually affects their understanding of image formation–observation [9,11].

Furthermore, some concepts and their explanations, which are important for learning image formation–observation, are missing from the textbooks. The extent of a complete beam of light emitted by a point source, for example, is not discussed in TB6 and TB8. Similarly, an aerial image is formed and shown in pictorial representations in the textbooks (Figure 1), but none of the textbooks explained an aerial image. In the case of aerial images, it is necessary to describe the field of view, the location from which the observer can see the image, but TB6 and TB8 have not explained this.

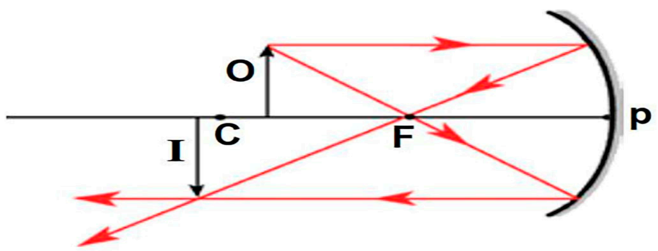


Figure 1. Real-image pictorial representation (TB8).

Table 2. Explicit and implicit concepts in the textbooks with example statements.

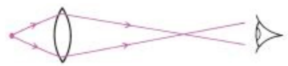
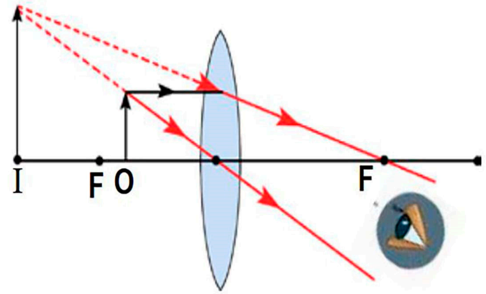
Subcatagories	Concepts	Textbooks	Example Statements (Italicized Statements Are Direct Quotes from the Textbooks)
Explicit concepts	Light	TB8	"*Light is an electromagnetic wave which is emitted from a hot body*" (TB8, p. 136)
	Light ray	TB6 andTB8	"*Rays that show the direction of light propagation are called light rays*" (TB6, p. 144).
	Special rays	TB6, TB8, and TB10	"*There are three rays that are important to study the characteristics of image formed by mirrors*" (TB6, p. 151). However, TB6 is not explicit about rays other than these three mentioned.
	Light emission direction	TB8	"*Light travel in all directions from a source*" (TB8, p. 141)
	Extent of complete beam of light	TB10	"*A beam of light will reach the lens, and the focusing action of the lens will bring this beam of light together again to a point*" (TB10, p. 222).
	Mirrors	TB8 and TB10	"*Plane mirror a mirror whose surface lies in a plane*" (TB10, p. 201).
	Terms related to mirrors	TB6, TB8, and TB10	"*Center of curvature is the center of sphere which the mirror is made from*" (TB6, p. 150).
	Lenses	TB6, TB8, and TB10	"*Lenses are objects that made up of transparent mediums in different shapes. One kind of lens which is thick in the middle, but thin at the edge is called convex lens*" (TB6, p. 154)
	Image	TB10	"*Image is an optically formed reproduction of an object*" (TB10, p. 201).
	Virtual image	TB6, TB8, and TB10	"*A virtual image is one through which rays of light do not pass but which isnevertheless visible to the eye*" (TB8, p. 147).
	Real image	TB6, TB8, and TB10	"*Real image is an image that can be captured on a screen*" (TB10, p. 205).
	Field of view	TB10	 "*To view an image and make best use of the available light, you need an arrangement such as that shown in Figure*" (TB10, p. 224).
Implicit concepts	Light	TB6 and TB10	"*Rectilinear propagation of light simply means that light waves travel in straight lines*" (TB10, p. 200).
	Light ray	TB10	"*The beam of light on its way to the mirror is called the incident ray*" (TB10, p. 200).
	Light propagation direction	TB6 and TB10	There is no verbal information about light propagation direction, only a pictorial representation.

Table 2. *Cont.*

Subcatagories	Concepts	Textbooks	Example Statements (Italicized Statements Are Direct Quotes from the Textbooks)
	Mirrors	TB6	"*An image formed by plane mirror has the same size as the object*" (TB6, p. 149).
	Image	TB6	"*An image formed by convex mirror is always upright*" (TB6, p. 153).
	Screen	TB6, TB8, and TB10	"*A real image is one through which rays of light pass if a screen is placed at the position of a real image, the image is seen on the screen*" (TB8, p. 147).
	The difference between broken and solid lines	TB6, TB8, and TB10	As shown in the figure (TB8, p. 163) below, the textbooks use broken and solid lines in their pictorial representations without verbal explanation of them. 

5.2. Completeness

The image formation–observation pictorial representations in the textbooks were mostly incomplete. This may affect students' understanding of image formation–observation [25]. Students hardly consider the missing part. For instance, Figure 1 depicts real-image formation completely; however, the real-image observation part in Figure 1 is missing; neither the screen nor an observer are included. In a real-image formation–observation pictorial representation, either the screen or observer should be indicated.

A translucent screen is convenient for the observation of real-image points in space, and it reflects and transmits light from the image in all directions. An observer in almost any position may receive some of this light and, therefore, will be able to see the point of illumination on the screen. In this case, indicating the place of the observer is not necessary. In the absence of a screen, an observer located within the beam of light diverging from the aerial image point should be indicated. When this fails, students may face difficulty in understanding from where the real image is viewable [12].

In the case of virtual images, pictorial representations lack an observer and at least two diverging rays enter the eye. The absence of an observer in the virtual image formation–observation representation may cause students to think that an observer is necessary for virtual image observation but not for image formation [8,11,44]. These explanations may cause students to think that the virtual image is formed in the mirror and is transported to the observer using light rays [11]. Therefore, it may lead to the misconception that whether the mirror image is observed or not always stays in the mirror [10,11,45].

TB8 and TB10 sometimes considered observer in virtual image formation–observation pictorial representations. However, the representations did not depict at least two diverging rays entering the eye (TB8, Figure 2). As Galili et al. [44] stated, a single ray entering the eye does not represent the simultaneous virtual image formation–observation process. Thus, the students might infer wrong concepts from such ray diagrams; they may think that a single ray entering the eye is enough to form and observe a virtual image.

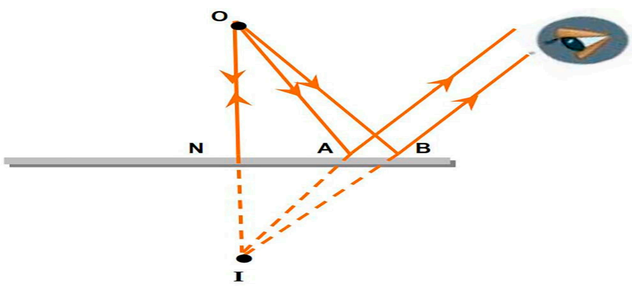


Figure 2. Construction of a virtual image using a ray diagram (TB8, p. 147).

There were, however, a few pictorial representations of image formation–observation in TB8 and TB10 containing all the necessary parts (see, for instance, Figure 3). It is complete except for a minor error, where one of the light rays did not arise from the object.

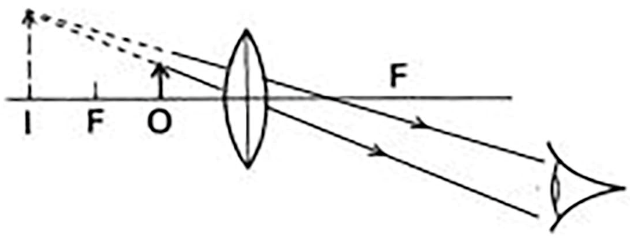


Figure 3. Representation of virtual image formation (TB10, p. 224).

5.3. Selectiveness

The textbooks did not contain nonselective pictorial representations of image formation–observation; almost all the pictorial representations were selective. Except for TB10 (Figure 4), the textbooks used special rays at the expense of other rays in their ray diagrams (Figure 5) (Figure 6). The common use of special rays in the textbooks may cause students to think that special rays are necessary rays to form an image [10,31]. Thus, this may cause them to have a misconception that masking half of the optical instrument, which may block some of the necessary special rays, results in either a half image [8,11,31] or no image [10].

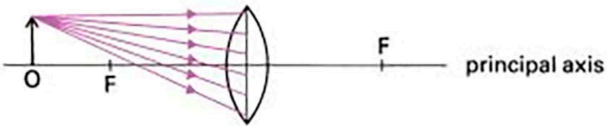


Figure 4. Rays emitted from a single object point (TB10, p. 222).

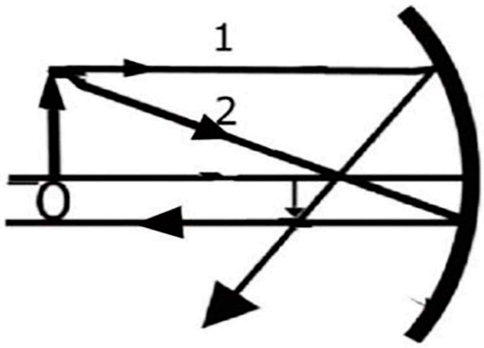


Figure 5. Rays emanating from a single object point (TB6).

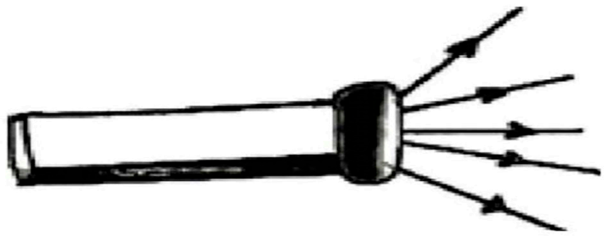


Figure 6. Flashlight rays (TB6, p. 144).

In addition, a single object point was chosen as a light source, and hence, other object points were neglected, a tendency found in all the textbooks (Figures 4 and 5); this may not facilitate students' understanding of image formation–observation [12,35]. The pictorial representations of image formation–observation in TB6 and TB10 depicted a specific direction of light emission. TB6 showed a single ray of light emanating from a point source (Figure 6); this cannot fully support the scientific way of image construction. Therefore, it can reinforce the idea that light rays traveling in a certain direction from an object point create the corresponding image point [11].

5.4. Placement

The textbooks usually integrated pictorial and textual representations. Except for TB6, there were no major integration issues. In TB6, the explanation of terms related to spherical mirrors was given pictorially with English letters, but the verbal explanation was in Amharic and did not contain these letters. In addition, the textbook did not label the center of curvature, focal point, pole, and image in ray diagram representations (Figure 5). This may split students' attention and cause difficulty in making connections between representations [2,32,36], which may, in turn, contribute to students' learning difficulty of image formation–observation.

The analyzed textbooks, however, shared some similarities in their pictorial representation. In all image formation cases, the pictorial representation depicted light traveling from left to right (Figure 5). This may reinforce students' thoughts of an image that is transported by light rays [11,25]. In addition, image formation–observation representation that depicts light rays emanating only from the top of the object (TB6, TB8, and TB10) may cause students to provide a wrong attribute to it [25].

5.5. Alternative Representations

The textbooks placed less emphasis on alternative representations. Some concepts, such as image, light ray, and special ray, are abstract and might be wrongly perceived by the students. In particular, light rays and special rays are simplified representations of light flux; therefore, they are abstract for the students [9–11]. As noted earlier, some concepts were also conveyed implicitly in the textbooks. The abstract and implicit concepts, therefore, need additional representation that makes them explicit and less abstract, which in turn may constrain misinterpretation of them [3,46].

TB10 described the extent of a complete beam of light emitted from a point source (Figure 4), which may constrain misinterpretation of special rays as the only rays. It may help students understand that masking some part of the optical instrument will affect only the brightness of the image [9]. However, this was missing from TB6 and TB8. TB8 (p. 151) stated that "*we take rays whose directions after reflection are known . . .* ", which indicates that there are rays other than special rays, but it is not as explicit as depicting the extent of a complete beam of light.

TB10′s description of the extent of the beam of light was also problematic. It depicted light as a collection of rays. As noted, the textbooks were also not explicit about light rays, whether as a model or object, and they displayed light in terms of rays. Thus, the students may count light rays as a material object and light as a collection of rays [8,11]. This misunderstanding is the core cause of students' thoughts that reflecting a single object point traveling in a particular direction forms a corresponding image point, which is not in line with the scientific idea of image formation [9,11]. There is no representation that depicted light propagation as a flux in all textbooks which might hinder students' misinterpretation of light as the collection of light rays and light rays as an object.

In addition, the textbooks did not consider constraining intuitive interpretations of the implicit concepts mentioned so far (Table 2). For instance, the screen was mentioned in the textbooks, but neither a pictorial nor verbal explanation was given. In a nutshell, the textbooks did not place much emphasis on constraining the possible misinterpretations of abstract and implicit representations.

Furthermore, in the textbooks, there were pictorial representations with missing and overemphasized components that needed alternative representations to complement the missing and less emphasized parts [3,46]. In rare cases, the textbooks tried to complement selective representations, such as special rays (TB10 and TB8) and light emission direction (TB8). More often, the textbooks did not consider complementing selective and incomplete representations. For instance, TB6 and TB8 omitted both screen and observer in the real-image formation–observation representations, TB6 never considered the observer in the virtual image representations, TB8 and TB10 did not include the observer uniformly in diagrams, and these textbooks did not include verbal explanations either. This may cause students to have difficulty in identifying the role of the observer and screen in the image formation–observation process [12,31]. In summary, verbal explanations did not often complement pictorials, and there was no consideration of dynamic pictures in textbooks.

Furthermore, the textbooks generally did not emphasize how alternative representations can be presented. There is a way to start a topic with questions about a specific topic in textbooks. However, the questions were worked out immediately in the textbooks, and few experimental presentations were given after text and picture representations were presented. This can make the concept complex for students, leading them to misinterpret the pictorials used [33,34]. Furthermore, the students did not have an opportunity to gain a concrete understanding by observing and experiencing the phenomenon before facing abstract pictorials.

5.6. Consistency

Most image formation–observation representations were not consistent within and across textbooks, except in using symbols and models, such as light rays. In the same textbook, different representations of a specific case could be observed. For instance, TB8 included an observer in ray diagrams of plane mirror image, but not in the illustrations (Figure 7); it also included an observer in the virtual image formed by lens, but not in the virtual image formed by spherical mirrors (Figure 8).

Figure 7. Representation of image formation by a plane mirror (TB8, pp. 146 and 147).

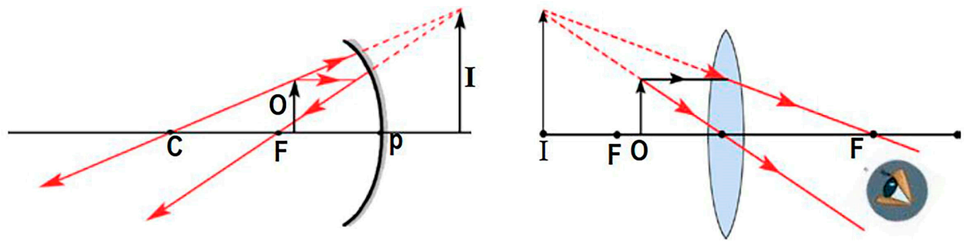


Figure 8. Representation of virtual image formation by a lens and spherical mirror (TB8, pp. 153 and 163).

Similarly, TB10 indicated a field of view for the mirror image and the extent of the complete beam of light for the lens image. Nothing was stated about whether these concepts can be transferred to other optical instruments. The textbook sometimes included an observer, sometimes not (Figure 9). The textbook also gave a virtual image with a broken line (Figure 9). TB6 also lacked consistency in describing some concepts, such as optical instruments.

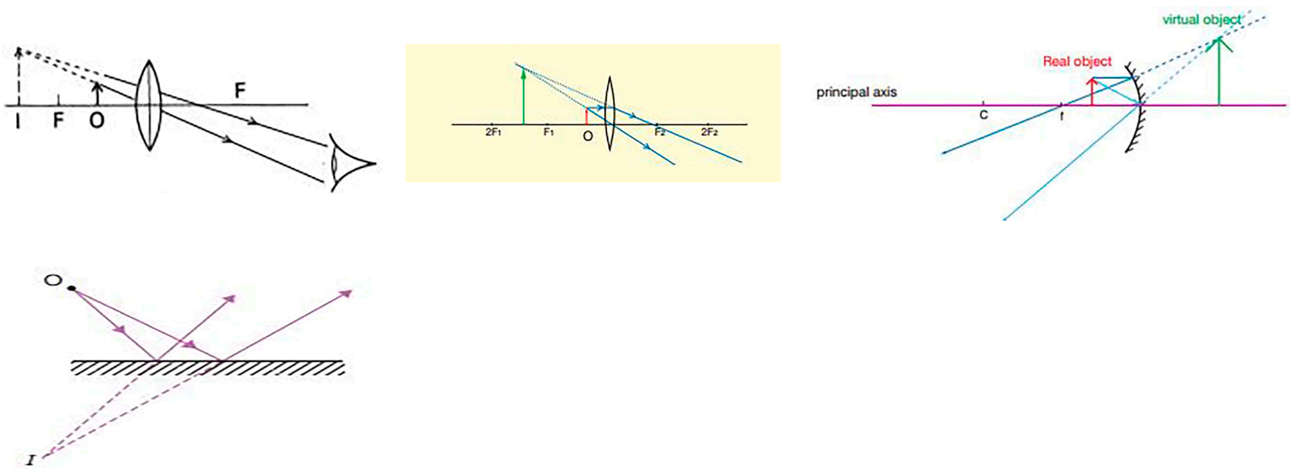


Figure 9. Virtual image formation–observation representation (TB10).

The image formation–observation representations were not consistent across the textbooks, either. For instance, TB6 never considered an observer in virtual image formation–observation, but other textbooks sometimes considered it. In verbal representations, TB6 did not explain special rays, but TB8 and TB10 somehow did. Unlike other textbooks, TB8 explicitly explained light and light rays; only TB10 depicted the field of view and the extent of the complete beam of light. The inconsistency of image formation–observation representation may confuse students when and how specific representation can be used [7]. The students may face difficulty in identifying the wrong and correct representations.

The problems observed in textbooks might be because of the authors' lack of textbook preparation experience [19]. As noted, authors in Ethiopia commonly have specializations in one of the science disciplines, and they may lack knowledge of students' science learning difficulties to inform the creation of textbooks. In addition, in Ethiopia, a graphic artist who may not know science is assigned to illustrate in the textbooks. This may bring unintentional errors, such as neglecting light rays arising from the object point (Figure 3). Errors may cause students to have difficulties in understanding pictorials and concepts [2,7]. Similarly, the selection of sources for textbook writing may also cause problems. Authenticated sources are necessary for textbook writing. However, we found incorrect pictorial representations in the textbooks (Figure 7), suggesting that they have been taken uncritically from unauthenticated internet sites.

5.7. Conclusions

It has been reported that students find geometric optics topics difficult and develop misconceptions about these topics [10]. It has been argued that the difficulties emerged, in part, from the problem of representations in textbooks and instruction [8,11]. Textbooks are used as the main sources of content for teaching in Ethiopia, as well as in many other countries [13,15,20]. This implies that textbooks have a considerable influence on students' learning of a certain topic. Therefore, an analysis of representation in textbooks is important to avoid students' learning difficulties and misconceptions arising from representations.

A few studies of physics textbook representations exist [21]. However, to the best of our knowledge, no relevant study exploring the representation of a scientific phenomenon in Ethiopian science textbooks exists. Our study has aimed to contribute to filling this gap. Our study also provides the international reader with evidence of perspectives on school practice in developing countries, helping obtain a complete picture of how image formation–observation is presented and taught in schools around the world.

The results indicate that the textbooks explicitly defined some concepts, integrated verbal and pictorial representations, and consistently used some symbols and models. However, the textbooks contained implicit, missing, and incorrect concepts. They also contained incomplete, selective, and patterned pictorial representations. The verbal representations in the textbooks rarely complemented pictorials and constrained intuitive interpretations of abstract and implicit representations. The textbooks were inconsistent in how they defined concepts and depicted diagrams within and across textbooks.

Students may intuitively interpret implicit concepts and selective and patterned diagrams that may not be consistent with scientific concepts. Likewise, the incorrect, missing verbal representations and incomplete diagrams in the textbooks could be seen as direct sources of students' misconceptions. When one component of the image formation–observation representations is missing, students might think that it is not important, and this may lead to a misconception. The inconsistent use of representations can create confusion among students regarding where a particular representation is necessary and where it is not.

5.8. Implications for Future Research

As noted, physics textbooks mostly use verbal, pictorial, even mathematical representations to present concepts. This means that the use of more than one representation in physics textbooks is common. The use of multiple representations is important, but it could hinder student learning if presented arbitrarily [5]. It should be presented in a way that facilitates student learning. In this sense, our analytical framework, which was developed in part by the authors based on recommendations from the literature, can be used to assess the extent to which textbook representations are explicit, consistent, interdependent, and integrated. The framework also can help examine the extent to which a particular representation conveys the intended message. However, our study is limited to the analysis of image formation–observation representation. We did not examine actual classroom practice or determine how students and teachers interpreted what we have called problematic representations. Future research can be conducted on the representation of scientific phenomena in the textbooks and their interpretation by students and teachers in actual classroom settings.

5.9. Implications for Best Practices

In textbooks, there are few representations that are exemplary and can be used in optics lessons. For example, Figure 4 in TB10 shows that numerous rays emanate from a point light source. This is an important point for students to understand that special rays are not the only rays emanating from a point source. This might prevent students from misunderstanding image formation by half-optic instruments. Such representations should be emphasized in textbooks and used in optics classes to circumvent the student learning difficulties mentioned so far.

In addition, alternative representations that could eliminate the misinterpretations of pictorial representations should be highlighted. Our results can alert optics textbook authors and teachers to the difficulties that representations may present to students. This might encourage authors and teachers to think of alternative representations that might help students understand the intended concepts. The present study has also highlighted the method of presenting alternative representations; less abstract and concrete representations should be preferred to more abstract representations when presenting concepts. Therefore, optics teachers should begin their lessons with less abstract and familiar representations and move toward more complex representations to help students understand the intended concepts in optics.

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