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The Transformative Effects of Guided Inquiry-based Learning on Scientific Knowledge of Vision

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The use of guided inquiry-based learning (GIBL) in a manner designed to challenge individual students' unscientific conceptions of science, has been researched widely. However, few (if any) studies have investigated the implementation of GIBL in a manner designed to challenge the fundamental patterns of students' context-dependent unscientific conceptions of science. This study investigates the effect of GIBL on transforming the fundamental patterns of Ethiopian eighth-grade students' context-dependent conceptions, schemes of knowledge, about vision. The study used a quasi-experimental pre–post design with a mixed method approach. We measured conceptual change using qualitative and quantitative assessments based on facet-scheme frequencies. Treatment-group students' conceptions expressed in a facet-scheme structure were compared with those of students receiving conventional instruction (CI). Before instruction, both student groups subscribed to *spontaneous* (observer not connected with the object/image) and *inclusive* (observer incorrectly connected with the object/image) vision schemes. After instruction, the frequencies of these schemes were decreased to a greater extent among GIBL students than CI students. The scientific scheme was observed with more frequency among GIBL students than CI students. We therefore conclude that GIBL transformed the students' schemes of knowledge from unscientific to scientific to a greater extent than CI. The study points out vital practical implications for educators.

Keywords: *Conceptual understanding; Inquiry; Geometric optics; Context-dependent*

Introduction

A challenge in teaching science is that students come to science class with prior conceptions that do not align with the scientific concepts being taught (Mills et al., 2016). These students' unscientific conceptions might hamper their conceptual learning. It has been argued that students with unscientific conceptions integrate the new information from class with their flawed conceptions and form new erroneous knowledge structures (Vosniadou, 2013).

Geometric optics is a subject in which unscientific conceptions are widespread (Kaltakci-Gurel et al., 2016). Optical phenomena—the interaction of light with optical devices—cannot be seen, identified or understood easily (Galili & Hazan, 2000). Optics concepts generally do not harmonise with everyday language, experience and common sense (Galili, 2014; Widiyatmoko & Shimizu, 2018).

Several unscientific conceptions of optical phenomena are prevalent within the concept of vision. Some studies found that students perceived the eye as a vehicle with which to 'look' at an illuminated object, without considering any connection between the eye and the observed object (Chu & Treagust, 2014; Galili & Hazan, 2000). Moreover, students believed that light's role in vision is only to 'light up' an object (Chu & Treagust, 2014) or the eye (Selley, 1996), although a few students denied entirely the role of light in vision (Chu & Treagust, 2014). Some students also counted the eye (Selley, 1996) and non-luminous objects (Chu & Treagust, 2014) as sources of light in vision.

Students' conceptions of vision have been found to be context-dependent (Chu & Treagust, 2014; Galili & Hazan, 2000). This implies that students give different answers to questions that require similar concept applications in different inquiry contexts. However, these context-dependent student conceptions are patterned and can be described using holistic terms that depict their common features (Galili & Hazan, 2000). Galili and Hazan (2000) organised college students' knowledge in geometric optics into a facet-scheme structure. The s*pontaneous vision scheme* emerged from this organisation (see definitions in Table 1). This scheme has been reported to be resistant

Table 1. Definitions of concepts

Guided inquiry-based learning (GIBL)	A pedagogical approach that promotes students' learning of science through investigation. It helps students internalise scientific concepts by encouraging them to take responsibility for their learning (Bybee, 2014; Heng & Karpudewan, 2017).
Conventional instruction (CI)	An approach involving 'transferring' knowledge through verbal and visual explanations with little student involvement in meaning-making and higher-order thinking (McLaren & Kenny, 2015).
Facets of knowledge	Students' ways of understanding contexts. These are students' context-specific strategies for solving particular problems (Galili & Hazan, 2000; Minstrell, 1992). Facets are extracted directly from students' responses to problems.
Facet abundance	The percentage of students who exhibited a particular facet in their response to a context. One facet might be observed in responses to two or more questions. In that case, the average facet abundance from each question was taken as the abundance of a given facet (Galili & Hazan, 2000).
Parameter t	$t = -1$ for an unscientific idea, and $t = 1$ for a scientific idea (Galili & Hazan, 2000).
Facet abundance before instruction (FAB)	The facet abundance calculated from the comparison/treatment group's pre-test.
Facet abundance after instruction (FAA)	The facet abundance calculated from the comparison/treatment group's post-test.
Facet gain (FG)	Calculated by subtracting facet abundance before instruction from facet abundance after instruction and multiplying by t (Galili & Hazan, 2000). FG = (FAA-FAB)t; t is introduced to avoid the possible occurrence of negative and positive FG from unscientific and scientific facets respectively that indicate the same thing, positive effect of instruction.
Scheme of knowledge	Facets of knowledge can be grouped into clusters, each of which corresponds to the same idea or physical mechanism, underpinning all facets affiliated with that cluster. This constitutes a scheme of knowledge that is less context-dependent and thus possesses a more inclusive meaning than a facet (Galili & Hazan, 2000). The researcher constructs schemes by identifying the fundamental patterns of the facets.
Scheme abundance	An average of the abundance of facets that exhibit a similar pattern.
Scheme gain	Calculated by subtracting scheme abundance before instruction from scheme abundance after instruction.
Spontaneous vision scheme	The absence of physical connection between the observer and the observed object or image (Galili & Hazan, 2000).
Inclusive vision scheme	Demonstration of a connection between the observer and the observed object or image using a light originating either in the eye or a non-luminous object. We called this scheme an inclusive vision scheme to indicate that the observer is included in the optical system, although incorrectly.

to change both through conventional instruction (CI) (Galili & Hazan, 2000) and systematically tailored instruction (e.g. Maurício et al., 2017).

Studies have reported the effectiveness of guided inquiry-based learning (GIBL) to facilitate students' conceptual change in science (e.g. Heng & Karpudewan, 2017; Maley et al., 2013). Most of these studies consider students' unscientific conceptions as central concepts, which are coherent, systematic or even theory-like (Posner et al., 1982; Vosniadou, 2013), and they aimed to challenge individual unscientific conceptions (e.g. Heng & Karpudewan, 2017). In contrast, some authors argue that students' unscientific conceptions are fragmented, context-dependent and incoherent (e.g. diSessa, 2013). According to this view, instruction should be used to activate, collect and systematise these conceptions (diSessa, 2013).

Galili and Hazan (2000) argue that students' context-dependent conceptions can be organised into schemes of knowledge. The authors add that instead of challenging context-dependent conceptions individually, challenging and transforming their fundamental patterns, i.e. schemes of knowledge, might be more effective to effect conceptual change. In addition, changes in schemes and their frequencies can reliably indicate conceptual change and thus the impact of a particular instructional mode (Galili & Hazan, 2000). However, to our knowledge, few (if any) studies have investigated the application of GIBL to transform students' schemes of knowledge in science, particularly in optics.

In Ethiopia, the use of CI predominates in science classes (Tesfamariam et al., 2017). Furthermore, we are unaware of any study that examines students' unscientific conceptions of optics in Ethiopia. This study, therefore, brings new knowledge about optics learning through GIBL in an understudied African school context. It aims to transform Ethiopian eighth-graders' scheme of knowledge in vision through GIBL designed using the 5E learning cycle, where the five *E*s are *engage*, *explore*, *explain*, *elaborate* and *evaluate* (Bybee, 2014). This study aims to answer the following research questions:

1. What facets and schemes of vision knowledge can be identified before instruction among eighth-grade students at a particular school in Ethiopia?
2. How are students' facets and schemes of vision knowledge altered after instruction, and to what extent?
3. What are the differences, if any, in the change in the conceptual understanding of vision between students taught using GIBL and CI?

Conceptual Framework

Conceptions are mental models or internal representations of the external world (Furlough & Gillan, 2018). There is some debate as to whether a student's conceptions are context-dependent, fragmented pieces of knowledge (diSessa, 2013) or embodied in 'theory-like,' complex knowledge structures, such as ontological knowledge structures (Chi, 2013), personal theories (Vosniadou, 2013) or schemes of knowledge (Galili, 1995; Galili & Hazan, 2000). We consider that, although student conceptions seem to be fragmented and context-dependent, they exhibit common patterns. Following the work of Galili and Hazan (2000), we thus identify context-dependent pieces of student knowledge as facets of knowledge, and we organise and subsume similarly patterned facets of knowledge into schemes of knowledge.

In the current study, we focus on transforming student schemes of knowledge from unscientific to scientific. A student's scheme of knowledge may be restructured after replacing an unscientific with a scientific scheme (Vosniadou, 2013), replacing facets of knowledge with scientific concepts, or completing incomplete schemes (Tyson et al., 1997). This restructuring can be driven by the cognitive conflict created by discrepant activities (Posner et al., 1982; Tyson et al., 1997). When students are confronted with a conception different from their own, cognitive conflict may occur, and this may lead to dissatisfaction. If they find an 'intelligible and plausible alternative that appears fruitful for further inquiry', dissatisfaction may lead to change (Posner et al., 1982: 214). Instructional strategies which have been shown to be potentially effective in facilitating such change include use of context-rich activities (Chu & Treagust, 2014; Maurício et al., 2017) and representational tools (Tytler & Prain, 2013), and promotion of social learning (Miyake, 2013).

Methods

This study uses a quasi-experimental pre-post design involving treatment and comparison groups. The study follows a mixed-method approach, in which qualitative data were collected and analyzed, and quantified using facet-scheme frequencies. We adopted the data analysis method from Galili and Hazan's (2000) study, which has already been validated.

One of the three schools in a central region of Ethiopia consented to participate in the study, so this school was selected out of convenience. The school taught four classes, of which two were randomly selected for the treatment and the comparison groups. Seventy-nine students participated in the study: 39 in the comparison group and 40 in the treatment group. The students were 14–19 years old (mean age = 16).

The students' desks were arranged traditionally, in columns and rows facing the blackboard. This arrangement was changed to a group set up in the treatment group to favor group learning. Hands-on activities were integrated in the classroom as part of the intervention.

Instructional Strategies

The first author ran the teaching-learning process for 5 hours in each of the groups. The comparison group was taught using CI. For this, the teacher used the lecture format commonly used in Ethiopia, to which she was accustomed through her experiences, spanning several years, as both student and instructor. This included the teacher: drawing the students' attention to information in the textbook, including examples of ray diagrams; occasionally posing questions which a few students attempted to answer, after which the teacher explained the answers more fully; assigning exercises from the textbook as homework, followed by the teacher demonstrating their solutions while the students corrected their answers.

The treatment group was taught using GIBL, which was designed using the 5E model (Bybee, 2014). The teacher first raised relevant questions to *engage* the students and elicit their facets of knowledge or incomplete schemes of knowledge. Next, the students were provided with activities to *explore* the concepts in a manner designed to produce cognitive conflict and dissatisfaction (Posner et al., 1982), help them to alter any unscientific facets or schemes of knowledge they held, and to rebuild or reorganise scientific schemes of knowledge (Posner et al., 1982; Tyson et al., 1997). The teacher encouraged the students to *explain* what they learned from their investigations. The students were encouraged to support their explanations with drawings as needed (Tytler & Prain, 2013), and they were given additional opportunities to apply their conceptions during the *elaborate* stage of the 5E learning cycle. Finally, the students' new conceptions were *evaluated* through questions and drawings. Examples of activities given are presented in Table 2.

Data-gathering Instrument

The pre- and post-tests featured open-ended questions and drawing requests. The drawings were included because they are argued to be more motivating for students' reasoning expression than writing (Heng & Karpudewan, 2017; Quillin & Thomas, 2015). The test questions involved varied contexts to reveal students' understanding and to disclose facets appearing when the same conceptual issue is addressed in a variety of contexts (Galili & Hazan, 2000). The questions used are presented in Table 3.

Instruments were adapted from the literature (i.e. Andersson & Bach, 2005; Goldberg & McDermott, 1986; Viennot, 2004). Some cultural variations, such as the names of persons, were changed to contextualise the questions. The questions were presented in both the students' mother tongue (Amharic) and English to avoid linguistic barriers. The first author translated the Amharic versions of students' responses into English.

Table 2. Description of instructional strategies

Guided inquiry based learning (GIBL)	Conventional instruction (CI)
Teaching how to observe objects: *Engage*: The students tried to observe objects in a dark room. They reasoned why they could not see in the dark room. *Explore*: The students were asked to draw and explain, in groups, how light helps them to observe things. Their ray diagrams were checked. *Explain*: One student from each group explained the group's ideas and drawings to the rest of the class. Students exchanged feedback and explanations between the groups and with the teacher. *Elaborate*: Flashlights and plane mirrors were given to the students to help them realise that light is entering their eye when observing an object. The teacher provoked class discussion with questions such as: 'Why could you not directly observe the mirror while light falls on it?'; 'Do you think objects other than mirrors reflect light to our eyes?' *Evaluate*: Students were asked to draw how they observe luminous and non-luminous objects and then to share with their group and the rest of the class what they had drawn and understood.	A textbook-based 'talk and chalk' approach was implemented. The teacher mainly used lectures featuring illustrative ray diagrams. The teacher occasionally asked questions to motivate the students and to revise the lesson. Examples of questions raised were: 'How do we observe objects?'; 'How does light help us to observe things?'. Students were instructed to copy notes from the blackboard.

Data Analysis

Based on a study by Galili and Hazan (2000), for each question we grouped answers that expressed the same ideas together. Each of these answer types was then assigned to the facet of knowledge it represented, and the abundance for each of these facets was calculated. See Table 1 for definitions of these terms. We collected similarly patterned facets, merged them into schemes of knowledge, and calculated scheme abundance from the average of each facet abundance in the cluster. This was done for each of the pre- and post- tests of each of the two groups. Facet gain shows how much a given facet has been altered: negative facet gain suggests a reinforcement of unscientific facets through instruction, and positive facet gain indicates a decline in presence of unscientific facets, suggesting improvement in students' scientific understanding. A higher negative scheme gain also suggests improvement in students' scientific understanding.

Results

Student Knowledge Structures before Instruction

Before instruction, students in both groups demonstrated a spontaneous vision scheme (Galili & Hazan, 2000). Table 4 lists the three facets comprising this scheme. Facet A has the highest abundance among other facets: Most of the students in both groups thought that the observer placed behind the plane mirror or in line with the object (Q4, parts A and B) could see the image. Below are the responses to this question by a student from the GIBL treatment group (ST_1) and from the CI comparison group (SC_1).

> *ST_1: Yes, he could see the image of the object, because it is formed once in the mirror.*
> *SC_1: The image is in the mirror, so anybody could see it.*

Table 3. Pre- and post-tests

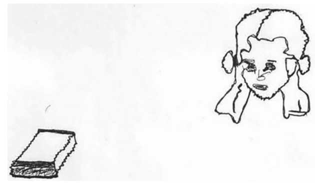
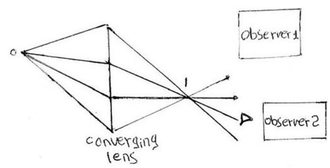
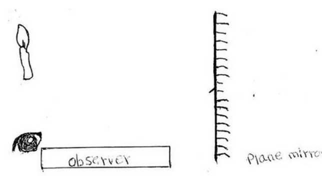
Question (Q)	Pictorial representation
1. In the diagram, Abebe sees the tree. Draw arrows to show how the light from the sun helps him see the tree.	
2. Almaz and her physics teacher are discussing seeing. Teacher: ‘Explain how you can see the book’. Almaz: ‘Signals go along nerves between the eyes and the brain’. Teacher: ‘Yes, this happens between the eyes and the brain. But, there’s some distance between the book and the eyes. Does anything happen between them? What would you answer? Draw and explain’.	
3. In the figure, there are a converging lens, observers, object point O, and image point I. Which observer can see the image point? Why?	
4. In the figure, there are an observer, a candle, and a plane mirror. How can the observer see the image of a candle that can be formed with a plane mirror? Explain in a drawing. A. If the observer changed his position to the right of the mirror, could he observe the image of the candle? Explain your answer. B. If the observer changed his position to the left of the candle, just in the same line with the candle, could he observe the image of the candle?	

Table 4. Spontaneous vision scheme before and after instruction

	Comparison (CI) group			Treatment (GIBL) group		
Facets	FAB[a] (%)	FAA[b] (%)	FG[c] (%)	FAB[a] (%)	FAA[b] (%)	FG[c] (%)
A. Nothing blocks vision.	65	48	17	68	20	48
B. The light illuminates the object/image so that the eye can look at the object/image.	33	18	15	43	16	27
C. The light illuminates the eye so that the eye can look at the object/image.	38	17	21	40	13	27
Scheme before CI = 45%				Scheme before GIBL = 50%		
Scheme after CI = 28%				Scheme after GIBL = 16%		
Scheme gain = –17%				Scheme gain = –34%		

[a]FAB, Facet abundance before instruction; [b]FAA, facet abundance after instruction; [c]FG, facet gain (FAA – FAB) × t, where t = –1 for unscientific ideas such as these.

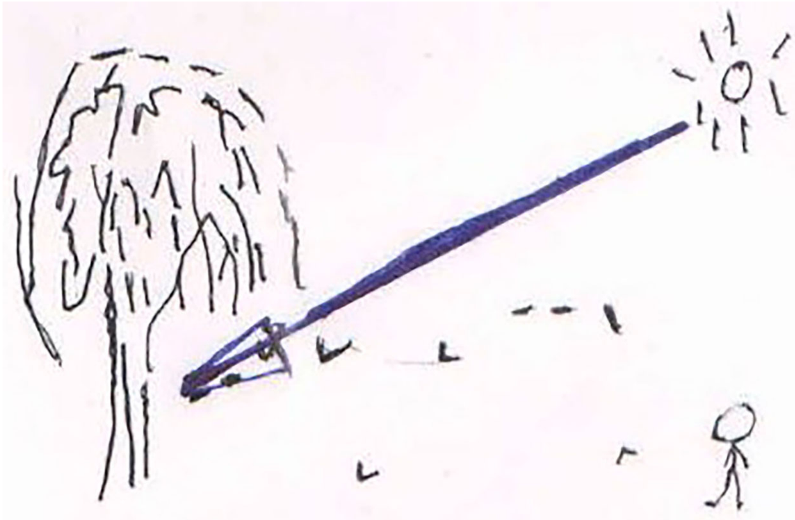


Figure 1. A student's model of observing an object.

Facet B was observed in students' responses to three questions: Q1, Q3, and Q4. Facet abundance was calculated for each of these questions, and then the average facet abundance of the three questions was calculated. Students from each group provided the following explanations for Q3:

ST_2: Observer 1 could see the image point, since it has a light already.
SC_9: Observer 2 could see the image because the image is more lighted on Observer 2's side.

These statements imply that an open eye (as suggested in the question) and light on the image are the only requirements to observe the real image.

In Q1, some of the students in both groups drew a light ray from the sun to the tree suggesting that the observer could see the tree illuminated by the sun (Figure 1).

In Q4, some students explained that they could see images of an object that was placed on the plane mirror, just by opening their eyes, suggesting that an open eye and light on the image are the most important prerequisites for observing a virtual image. Two student replies to Q4 are given below:

SC_{29}: The observer can open their eye and see the image's light on the mirror.
ST_{21}: The image on the mirror has light from the candle, so the observer can see it.

Students' explanations to Q4 indicate the presence of Facet C. Some students thought that the role of light is illumination of the eye to enable it to function as a tool for seeing an image. As the responses below indicate, students explained that the observer is expected to receive light from the candle to see the image of the candle. However, no connection was made between the observer and the observed image. This implies that the purpose of the light is to light up the eye.

ST_3: The light from the candle should reach the observer to see the image in the mirror.
SC_4: The candle can give light to the observer's eye so that the observer can see both the candle and its image.

Table 5. Inclusive vision scheme before and after instruction

Facets	Comparison (CI) group			Treatment (GIBL) group		
	FAB[a] (%)	FAA[b] (%)	FG[c] (%)	FAB[a] (%)	FAA[b] (%)	FGI[c] (%)
D. The eye sends rays to see objects/images.	45	37	8	39	12	27
E. The light should light up the object/image so that the eye can send rays to see it.	25	28	–3	21	18	3
F. The light should illuminate both the eye and the object/image so that the eye can send rays to see it.	23	35	–12	27	13	14
G. The object/image sends rays to the eye so that it can be seen.	23	33	–10	19	9	10
Scheme before CI = 29% Scheme after CI = 33% Scheme gain = 4%				Scheme before intervention = 27% Scheme after intervention = 13% Scheme gain = –14%		

[a]FAB, Facet abundance before instruction; [b] FAA, Facet abundance after instruction; [c] FG, Facet gain (FAA – FAB) × *t*, where *t* = –1 for unscientific ideas such as these.

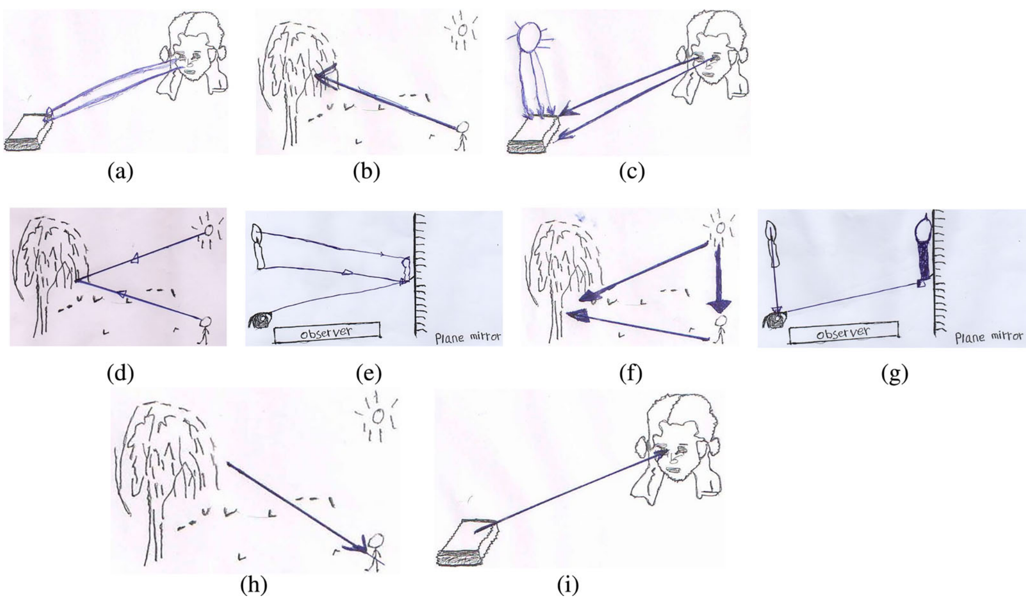


Figure 2. Student models of an inclusive vision scheme.

Some students also demonstrated an inclusive vision scheme, which emerged from four facets (D–G; Table 5).

Facet D was identified from students' answers to four questions (Q1, Q2, Q3, and Q4). In Q3, students connected the observer to the observed image with light from the eye:

> ST_5: *Observer 1 can see the image because nothing blocks the light from their eye.*
> SC_6: *Maybe both can see the image if the light from Observer 2 can reach the image*.

The students' sketches shown in Figure 2a–b also depict the connection between the observer and the observed object using only rays emanating from the eye (replies to Q1 and Q2). In Q4, some students explained that the eye could send a light ray to see the image positioned on the mirror:

> ST_7: *The observer should send light to see the candle in the mirror.*
> SC_9: *The observer should open their eye to use the light and see the image*.

Some students from the treatment group responded according to Facet D in Q4 (B) also: it appears that they thought that the observer could see the image because their eyes sent a ray of light to the image. Facet E was observed in students' answers to three different questions (Q1, Q2 and Q4), as shown in Figure 2c–e. These sketches suggest that light is perceived as necessary to light up the object/image, which the observer can see using light from their eye.

Facet F was found in the students' drawings and explanations for Q1 and Q4: an observer's illuminated eye will send a ray of light to the lighted object (Figure 2f). The students responded to Q4 that the image had a light that moved with it from the candle; consequently, the light from the candle prompted their eye to emit a ray of light and see the image. Their explanations were supported with a ray diagram, as shown in Figure 2 g.

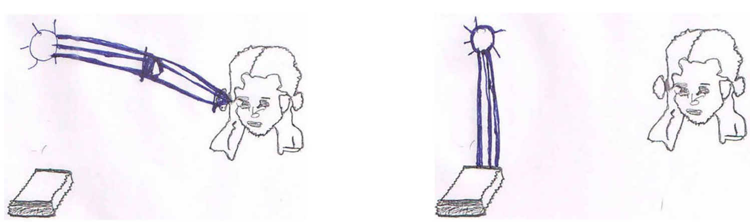
Facet G was observed in two settings (Q1 and Q2), as shown in the drawings in Figure 2h–i. Some students in both groups thought that the object would send a light ray to the eye to be seen. Some of the CI comparison-group students also demonstrated this facet of knowledge in Q4: they thought the image formed by a plane mirror could send a ray of light to the observer's eye so that it could be seen:

> SC_{20}: *Light from the image of a candle travels to the eye, so someone could see the image.*
> SC_{31}: *The eye should get light from the image of the candle to see it.*

Student Knowledge Structure after Instruction

We will now present the changes observed in the facets and schemes of knowledge after instruction. After the CI, most of the students displayed unscientific facets of knowledge for different questions in the post- than they had in the pre-tests. For instance, the facets B and C (listed in Table 4 and illustrated in Figure 3) were not observed for Q2 of the pre-test, but they were observed from some CI students for Q2 of the post-test.

For the comparison group, spontaneous scheme abundance dropped from 45% to 28% after CI (Table 4). Each facet of knowledge showed a positive gain, however, a considerable proportion of students still exhibited Facet A (48%) after instruction. The treatment group's abundance of spontaneous



(a) (b)

Figure 3. Students' models of how light is needed to light up either the eye or the object.

Table 6. A scientific explanation of vision

The eye sees reflected light.	Abundance in comparison group (%)	Abundance in treatment group (%)
Light reflected from the object reaches the eye enabling observation of the object.	23	51
Light from the real image diverges and reaches the eye enabling observation of the image.	10	54
The virtual image is formed and seen simultaneously.	0	44
Average abundance (%)	17	50

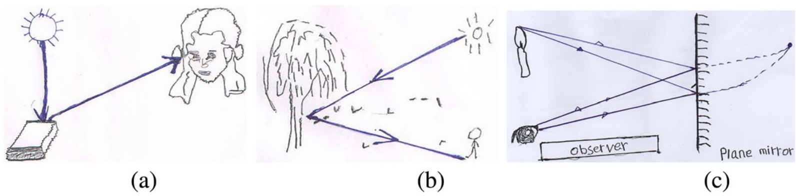


Figure 4. Students' scientific explanations of vision.

vision dropped to a greater extent than for the comparison group, i.e., from 50% to 16%, after GIBL (Table 4). Similarly, each facet of knowledge showed a greater positive gain for the GIBL than the CI groups and the difference in scheme gain was higher among GIBL students (–34% scheme gain) than among CI students (–17% scheme gain).

After CI, the abundance of the inclusive vision scheme increased from 29% to 33% (Table 5), while Facet D decreased slightly (45–37% facet abundance). Some of the students thus seem to have moved away from thinking that the eye could send a ray of light to see an object or image. However, other facets (E–G) saw negative facet gains, which indicates a reinforcement of facet abundances. This implies that CI was not effective to overcome the scheme. In contrast, GIBL students demonstrated positive facet gain for all facets under the inclusive vision scheme, which dropped from 27 to 13% abundance.

After CI, a few students developed the scientific scheme that the eye sees reflected light. Some students in the comparison group applied this scheme to seeing objects related to Q1 and Q2 (Figure 4a–b), but only a few of the students attempted to apply the scheme to observing real images (Q3). None of them could explain how a virtual image formed by a plane mirror could be seen (Q4). As a result, the abundance of scientific explanations was only 17% among CI students (Table 6). The abundance of this scientific scheme in the GIBL treatment group (50%) was much higher than its abundance in the comparison group (17%; Table 6) after instruction. The sketches presented in Figure 4 are sample answers showing GIBL students' demonstrations of scientific conceptions.

Discussion

Students held spontaneous and inclusive vision schemes before instruction. The spontaneous vision scheme has been reported in studies from other countries (Galili & Hazan, 2000; Maurício et al., 2017). Although we have developed and named the inclusive vision scheme, the facets of knowledge that comprise it (Table 5) have been observed in other studies (Chu & Treagust, 2014; Selley, 1996). Our students' conceptions of vision were therefore similar to those of students in other countries. This could be because globally students' conceptions arise from their commonsense interpretations of their experience and language misuse (Galili, 2014; Galili & Hazan, 2000). However, we observed a difference in the abundance of student schemes of knowledge compared with equivalent studies from other counties (such as Galili & Hazan, 2000; Maurício et al., 2017). We found facets of knowledge that reflect a scheme other than the spontaneous vision scheme. These facets include the observer in the optical system, though incorrectly, so we called this scheme that we formulated the inclusive vision scheme.

After instruction, GIBL students had abandoned unscientific schemes of knowledge in favor of a scientific scheme to a greater extent than CI students. The spontaneous and inclusive vision schemes of the GIBL students decreased in abundance from 50 to 16% (–34% scheme gain) and from 27 to 13% (–14% scheme gain), respectively (Tables 4 and 5). In comparison, the spontaneous vision scheme decreased in abundance after CI from 45% to 28% (–17% scheme gain; Table 4), and the abundance of inclusive vision schemes increased from 29% to 33% (4% scheme gain) (Table 5). The abundance of the scientific scheme of knowledge was 50% after GIBL, but it only 17% after CI (Table 6). This result suggests that GIBL caused a greater conceptual change in our student groups than did CI.

After CI, there were positive gains in erroneous schemes, possibly because students were not actively involved in their learning, and their prior knowledge was not explicitly challenged and scrutinised (McLaren & Kenny, 2015; Tyson et al., 1997; Vosniadou, 2013). When instruction did not consider the students' prior knowledge, the students may have combined the new knowledge from instruction with their existing knowledge structure, resulting in a mixed model (Vosniadou, 2013). An inclusive vision scheme may be seen as a mixed knowledge structure which may be aggravated by CI, as demonstrated by the rise in this scheme for the CI group, contrasted with its decline for the GIBL group.

Maurício et al. (2017) argue that students' learning difficulties in optics, such as the intangible and instantaneous interaction of light with optical phenomena, need to be explicitly addressed. Consistent with this, in the GIBL treatment group, we used a plane mirror and flashlight to help students recognise that light hits their eyes during the process of vision. We also asked students to illustrate their understanding using ray diagrams. We suggest that the extensive use of a variety of representations, such as inclusion of different language forms and use of drawings, within the GIBL strategy, may have stimulated the students' imagination and promoted their 'individual expression of understanding' (Tytler and Prain, 2013: 176).

Limitations of the Study

On one hand, the use of the first author as the teacher for both groups may have introduced unconscious bias in the GIBL group's favour, reducing the validity of the claims made here. On the other hand, use of a single teacher decreased differences in important variables between the groups, enhancing validity. Furthermore, the teacher-researcher is well accustomed to CI in Ethiopia, is an experience teacher, and made every effort to teach each class to the best of her ability. Analysis of pre–post test data alone might give limited insight into students' thinking, understanding and the effect of the instruction. This limitation was mitigated to some extent by including data from open-ended questions and students' drawings. Further investigation may also include data from interviews and group interaction.

Conclusions

Students' conceptions of vision have been investigated extensively internationally. However, the African context has largely been excluded from such investigations. We have contributed to addressing this research gap by reporting Ethiopian students' conceptions of vision. We have done this in terms of facets and schemes of knowledge, and have reported on the presence of spontaneous vision schemes, in correspondence with other studies, as well as introducing a new scheme, the inclusive vision scheme.

Similarly, the GIBL strategy has been investigated widely. However, few (if any) studies have investigated GIBL's efficacy at transforming the fundamental patterns of students' context-dependent conceptions of science, i.e. schemes of knowledge. Our study contributes to this literature gap within the science topic of vision. This is done in the under-researched Ethiopian context. Furthermore, we adopted a unique data analysis method, facet scheme frequencies, which effectively shows students' conceptual change after GIBL and CI.

The results indicate that the students in the GIBL treatment group achieved better conceptual understanding than those in the comparison group. This result suggests that it is necessary to go beyond CI to allow students to develop a scientific understanding of optics. Although there is evidence that students' schemes of knowledge about vision are resistant to change, even with innovative instruction (Maurício et al., 2017), this study suggests that this resistance can be overcome, to some extent, through use of various representations within the GIBL approach. Therefore, this study has contributed to a growing body of literature that supports the view that identification and confrontation of fundamental patterns of students' context-dependent conceptions can effectively promote conceptual change.

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No potential conflicts of interest were reported by the authors.

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