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South African Learners' Conceptual Understanding about Image Formation by Lenses

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ABSTRACT
The purpose of this research was to explore South African Grade 11 learners' conceptual understanding of 'image formation by lenses'. The participants for this study were 70 Grade 11 learners from a selected senior secondary school in Mthatha, Eastern Cape Province, South Africa. The qualitative approach employed in the study made use of a two-tier open-ended questionnaire as the data collection instrument. The study explored several alternative conceptions the learners had held in terms of the roles that the lens and the screen play in the image formation and the characteristics of the image formed when a lens with a larger diameter is used and when a portion of the lens is covered. Most of the participants could not respond correctly in the situations presented in the questionnaire. However, almost all of them were found to have adequate conceptual understanding about the role of a lens in the image formation.
Keywords: conceptual understanding, lenses, alternative conceptions, image formation

INTRODUCTION

For the past three decades, a vast body of research has documented learners' prior knowledge in many areas of science. These prior ideas, normally called misconceptions or alternative frameworks or alternative conceptions, can affect the acquisition of scientific knowledge (Chang et al. 2007). According to Posner et al. (1982), learning is a kind of inquiry, and inquiry and learning occur against a background of learners' current concepts. Moreover, constructivism views learning as a learner's active continuous process of constructing and reconstructing his/her conceptions of phenomena. Constructivism, thus, considers identification of learners' prior knowledge regarding the concepts to be taught as a prerequisite for meaningful construction of knowledge (Tynjälä 1999). Thus, in order for the effective learning and inquiry to take place, the aspects referred to as prior knowledge must be analysed to construct the proper background in the teaching-learning process.

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State of the literature

- The literature reported that learners hold several alternative conceptions about 'image formation by lenses'.
- The quantitative aspect of the above studies could not dig in detail into learners' understanding about the specific roles the lens and the screen play in the image formation and the characteristics of the image formed in situations where the diameter of the lens is increased and where a portion of the lens is covered.
- The researchers, therefore, believe that an exploratory approach would help to identify more about learners' alternative conceptions about image formed by a convex lens.

Contribution of this paper to the literature

- The researchers used a qualitative approach in which a two-tier open-ended questionnaire was used as the data collection instrument whereas most of the two-tier questionnaires reported in previous studies were comprised of multiple choice-type questions.
- The two-tier ('what' as the 1st tier and 'why' as the 2nd tier) qualitative approach adopted in this study helped the researchers to identify several alternative conceptions the learners had held which wouldn't have been possible with the use of two-tier quantitative questionnaires.

Educators and researchers need to know what expectations and intuitions the abundant experience of prior knowledge has generated in learners' minds because prior knowledge has a decisive effect on the outcome of the instruction.

Several studies have documented learners' prior knowledge about different concepts in optics. A significant body of such studies documented learners' alternative conceptions about plane mirror reflection (Eshach 2010; Lawson 2010). Some studies reported learners' alternative ideas on light and vision (Rice & Feher 1987; Selley 1996) while others dealt with shadows (Chen 2009). Evidence of research done on learners' ideas about refraction was also found (Kaewkhong et al. 2008, 2010; Sengoren 2010).

Research shows that most learners apply either the 'holistic model' or the 'pin-hole model' instead of physicists' use of the 'point-to-point mapping model' (Galili & Hazan 2000; Tao 2004) to explain image formation by lenses. In the point-to-point mapping model, an extended object is considered as an assembly of object points and each point on the object has a corresponding image point after the cone of diverging light rays is converged by the lens. The assembly of all the image points forms the image. In the holistic model, learners' conceptualisation is that parallel light rays move through space from the object, turn upside-down inside the lens and the screen blocks these rays to form an image on it. In the pin-hole model, rays from the entire object converge at the optical centre of the lens; the lens then diverges these light rays when they pass through it and, finally, the screen blocks them to form the entire object. Tao (2004) assumes that some learners hold alternative conceptions because of their study of the pin-hole camera and the formation of an inverted image by convex lenses in most cases.

Amongst several aspects of image formation by convex lenses, learners' conceptions about the characteristics of the images, when part of the lens is covered, have been investigated by many researchers. The findings indicated that even after instruction, most learners still had the alternative conception that part of the image would disappear when the corresponding part of the lens was covered (Goldberg & McDermott 1987; Saxena 1991; Galili & Hazan 2000; Chang et al. 2007). According to Chang et al. (2007), such a belief exists because those students tend to think that the nature of light is like a kind of material. Galili and Hazan (2000) argue that because of the learners' tendency to use the point-to-point mapping conception to describe the refraction of the lens, they resort to the alternative conception, that is, when the upper half of the lens is covered, the half-image is obtained. However, the findings do not present proofs of seeking further explanations from the participants on why the participants responded in the way they had responded.

Chang et al. (2007) reported that most learners are usually confused about the images formed by lenses and mirrors as it is not easy for them to understand how the shape, size and position are determined. Goldberg and McDermott (1987) indicate that a number of students confuse the image formed by a lens with the shadow. Tao (2004) states that the ray-tracing technique, which is normally used to locate the image formed by a converging lens, does not lead students to a basic understanding of the role of the lens in forming the image, however, the ray-tracing technique is useful in predicting the position and size of the image formed by the lens. As reported by Viennot and Kaminsky (2006), knowing what a lens does to a few rays (at least two), enables one to predict what it does to any other ray emitted by the same point source and reaching the lens.

Since learners interpret new information on the basis of their existing knowledge, the constructivist teaching method is based on learners' previous conceptions and beliefs (Tynjälä 1999). The researchers are of the view that a holistic understanding about learners' idea of image formation by convex lenses might be helpful for Physics education researchers and teachers to design constructivist-informed teaching modules in which the ray-tracing technique can suitably be coupled with simple practical activities using apparatus such as optic bench. However, special attention should then be given in these teaching modules to address in detail the common identified alternative conceptions.

Some common statements made in Physical Sciences textbooks were identified as a reason for learners' conceptual difficulties about image formation by a converging lens. Corni (2010) argues that some statements often reported in textbooks are, for example, 'You can see the real image of an object in front of a convergent lens by placing a screen in the position where it is formed'. These might lead students to also consider true the statement which says 'You cannot see a real image in the position where it is formed if you do not place a screen there.' Corni (2010) goes on to say that textbooks rarely specify that the function of the screen is only to make the image visible from any point of view by diffusing light coming from the lens to all directions.

In light of the above findings, it should be assumed that learners experience serious conceptual difficulties with 'image formation by lenses', irrespective of their age and geographical locations. However, the quantitative aspect of the above studies could not dig in detail into learners' understanding about the specific roles the lens and the screen play in the image formation and the characteristics of the image formed in situations where the diameter of the lens is increased and where a portion of the lens is covered. The researchers, therefore, believe that an exploratory approach would help to identify more about learners' alternative conceptions about image formed by a convex lens. The study therefore sought to answer the following research question following a qualitative research approach:

What are South African Grade 11 learners' conceptions/alternative conceptions about image formation by lenses?

METHOD

The participants in this study were 70 Grade 11 learners in a selected senior secondary school in the Mthatha District of the Province of Eastern Cape in South Africa. The school was conveniently chosen as the research site because of its easy accessibility for one of the researchers, who was a full-time Physical Sciences educator in the same school (during the period when the research was conducted). It is an urban public senior secondary school which caters for learners in Grades 10 to 12. All learners in the school are South African Blacks and the mother tongue for all of them is IsiXhosa. The school has excellent infra-structural facilities compared to a large majority of other schools in the district. Physical Sciences and Mathematics are two compulsory subjects for all learners in the school.

The research adopted a qualitative mode of data collection where the participants were asked to give explanations to four two-tier open-ended questions in which the first part of each question asked the participants to write what happens to the image formed in each of the following situations:

- lens is removed;
- screen is removed;
- the upper half of the lens is covered; and
- the lens with a larger diameter is used.

The second part asked the participants to write a reason for their answers to the first part. The content validity of the questionnaire was assured by piloting the designed questionnaire and making the necessary changes thereafter. Before the questionnaire assumed its final form, it was also validated by two experts in the field, one holding a PhD in Education and the other one holding a PhD in Physics.

The data for this paper were collected from four relevant questions of the questionnaire designed for the larger version of the study which was meant to explore learners' ideas about different areas in Grade 11 optics. The qualitative analysis of the participants' responses to the open-ended questions was carried out by

- arranging the responses from all the learners for a particular question together;
- developing categories from the responses for each question;
- coding the categories and marking each recurring category with specific codes; and
- seeking evidence of each of the developed categories by reading the responses again.

Since the participants' responses to the first tier of each of the four questions were short responses, various identified categories were enumerated to get a vivid and brief picture of the participants' basic understanding of what happens to the image formed by a convex lens under the given conditions. The second tier of the questions tried to dig more into the participants' responses to the first tier by asking why they responded in the way they had responded to the first tier. Even though the participants responded to the second tiers using a wide variety of explanations and some of them just repeated their answers to the first tiers or even the statements in the questions themselves, some common categories could be developed. Moreover, since most of the responses to the second tiers did not lead to meaningful categories, the researchers did not enumerate the categories developed in this regard.

RESULTS

Role of the screen in the image formation

In question 1, the learners' knowledge about the role of the screen in the image formation by a lens was investigated. The question asked the learners to predict what would happen to the image when the screen was removed. Only 2 out of 70 learners predicted that an upside down image would be formed even when the screen was removed. According to 6 (5/1) out of 70 participants, brightness of the image changes (decreases/increases) when the screen is removed. 4 out of 70 learners responded in a vague way to the first tier of this particular question. A vast majority of the learners (56 out of 70) responded that no image would be formed when the screen was removed. The reasons given by the learners for such an answer as their responses to the second tier of this particular question are categorized as below:

Category 1: When there is no screen, the image is not formed because there is no space for it to be formed

Many learners believed that since there was no place for the image to be viewed when the screen was removed, the image was not formed in this situation. The following are examples of such responses from the learners.

Learner E24: "When screen is not there, there will be nothing to see the image."

Learner C37: "There won't be any place to the image to be formed."

The above learners thought that an image could not be formed without a screen. They were not aware that even in the absence of a screen, the light rays from any point of the object can still be bent by the convex lens, be converged to a single point and form the image at that particular point.

Category 2: The screen is what reflects the image, so when there is no screen, there is no image

A few learners believed that the screen plays an important role in the formation of the image because the screen reflects the image and therefore the image is formed and can be viewed. The following responses illustrate this:

Learner E7: "Because there is no screen to reflect image."

Learner C27: "In order for an object to be reflected there must be a screen to reflect the image."

Learner C42: "There will be no screen to project the image onto, therefore there will be no image."

According to the above learners, without the image being reflected/projected by the screen, image formation is not possible. Only those learners, who had responded that no image would be formed in this context, gave clear explanations in the second tier as to why they responded in the way they had responded to the first tier of the question. Therefore, no more valid categories could be developed from remaining responses.

Role of the lens in the image formation

Question 2 was meant to assess the learners' knowledge about the role of a lens in the formation of the image of an object. The question asked the learners to predict what would happen to the image on the screen when the lens was removed. 49 out of 70 learners responded correctly to the first tier of this question by saying that no image would be formed when the lens is removed. Such learners' explanations to the second tier of this question as the reasons for their correct response to the first tier were found to fall under the following categories:

Category 1: The role of a lens is to make the image visible to the observers

The learners, whose responses belonged to this category, seemed to have accepted that a lens plays a role in the image formation, and that without a lens, there is no image, however, the above learners did not seem to understand what role a lens plays in the image formation. They thought that the role of a lens was to make the image visible to the observers. The following responses illustrate the above category:

Learner E1: "In order for us to see the image clear there must be a lens."

Learner C16: "The lens helps the observer to see the image."

It was noted that the learners whose responses belonged to the above category considered the lens as something which helps an observer to view the image which has already been formed and not as something which forms the image. This shows that these learners did not have a sound understanding of the role of a lens in the formation of the image of an object.

Category 2: Without the lens, light cannot be refracted and thus cannot form the image

Only a few learners believed that in the absence of a lens, the light rays cannot be refracted and thus the image cannot be formed. Some learners specified the term 'refraction' in their explanation, while others stated that light rays cannot be bent in the absence of a convex lens and thus the image cannot be formed. The following responses illustrate this category:

Learner E17: "No lens to refract the light rays."

Learner E9: "There is nothing to bend the light rays."

The above learners seemed to have a fairly sound understanding of the role of a lens in the formation of the image of an object.

*Category 3: Without the lens the light cannot be reflected so as to form the imag*e

There were a few learners who used the term 'reflection' to explain the image formation, instead of 'refraction'. Such learners, even though they recognized that the lens plays an important role in the formation of the image of an object, did not have a correct understanding of the optical phenomenon responsible for the formation of the image. Given below are some examples of such responses:

Learner E7: "Because there is no lens to reflect the light."

Learner C37: "There won't be anything that will reflect both light and image on screen."

Even though the above arguments meant these learners accepted the fact that the lens is responsible for the image formation, they could not correctly identify the optical phenomenon responsible for the image formation by a convex lens.

Category 4: Without the lens, light cannot be reflected/refracted and thus form the image

A few learners showed confusion in their explanation regarding the optical phenomenon responsible for the image formation by a convex lens. They could not make a clear distinction between 'reflection' and 'refraction'; rather they used both terms in their explanations. The following are some examples of such responses:

Learner C20: "There won't be optical centre, the rays will not hit anything, the rays will not reflect/refract and there will be no focal point."

Learner C44: "There will be nothing to reflect/refract the light rays to form an object image."

The above learners had not clearly understood the difference between the optical phenomena 'reflection' and 'refraction' even though they had an idea that one of these two phenomena is responsible for the image formation by lenses.

*Category 5: The lens inverts the image, so without a lens there is no image forme*d

Very few learners from both groups believed that the role of a lens is to invert the image and thus the image is formed. Such learners seemed to have an alternative conception in that only inverted (upside-down) images can be formed by convex lenses. Such responses are given below:

Learner E21: "There will be nothing to invert and object the image."

Learner C13: "There is nothing to invert image in the screen."

The above learners did not have a sound understanding about the two types of images that a convex lens can form: real image and virtual image. When they were doing the practical experiment about the image formation by a convex lens as part of their formal teaching-learning process, they were able to see only the real image which is inverted. Since the virtual image, which is upright, cannot be displayed on a screen, some learners might have thought that the image formed by a convex lens is always inverted.

Category 6: The lens is the one which produces the image, so without a lens there is no image

There were quite a number of learners who believed that the lens is the one which produces the image of an object so without the lens, the image cannot be formed. Such responses are given below:

Learner C11: "The lens creates the image so if it is not true the image won't be formed."

Learner C39: "A lens is a transparent thing that produces images; if the lens is removed the image will not be known to be virtual or real."

Even though such learners knew that it was because of the lens that the image is formed, they did not know how the lens forms the image.

Among the 21 learners who responded incorrectly to the first tier of this question, 10 of them either did not respond to this question or gave vague answers. The remaining 6 (2/4) out of 11 learners believed that an image (upside/upright) would be formed even in the absence of the lens. The remaining 5 (1/4) learners predicted a decrease in size/brightness of the image on the screen. The above learners' responses to the second tier of the question in this context could not be considered to develop a meaningful category because they either repeated part of the first tier question or repeated the answer to the first tier itself as their responses to the reason tier of the question.

Image formed by a lens with a larger diameter

In this question, the learners were presented with a situation in which a lens with a larger diameter was used. Learners were asked to explain what happens to the image in such a situation. As their response to the first tier of the question, 18 out of 70 learners responded correctly by stating that the brightness of the image increases whereas 1 learner predicted a decrease in brightness of the image. A vast majority of the participants (25 out of 70) stated that the size of the image would increase in this context and there were 6 learners who believed that the image size would decrease. 12 learners thought that increasing the diameter of the lens would not make any change to the image. Very few learners (2 out of 70) predicted that an upright image would be formed in this context. 1 learner believed that no image would be formed in this situation. The remaining 5 learners' responses were not clear to come up with a meaningful response in this regard.

The categories developed from the learners' responses to the 2nd tier of this particular question are discussed below:

Category 1: When a larger lens is used, more light rays will be refracted

Very few learners believed that when a larger lens is used, more light rays will be refracted. The conception corresponding to this category can be said to be scientifically acceptable. The learners' responses corresponding to the above category are given below:

Learner E3: "Because the large lens refract the light rays too much so the image will be formed closed to the lens."

Learner C38: "Larger lens is used meaning that more light rays will be collected then image increases."

Even though the above category is scientifically acceptable, it was noted that the above learners failed to understand that it is the brightness of the image which is affected when more light rays are refracted and not its size or distance.

Category 2: Changing the size of the lens does not make any changes to the image

A few learners thought that the image does not undergo any change even if a lens of larger diameter is used. Some such responses are given below:

Learner E8: "The change in the lens won't have much effect on the image."

Learner C23: "Lens size doesn't make any difference."

The participants who held the above conception seemed not to have understood that a larger lens collects more light rays coming from the object, which in turn then makes the image brighter.

Category 3: When a larger lens is used, there will be a change in the focal point of the lens

A few learners thought that when a larger lens is used there will be a shift in the focal point of the lens. Some such responses are given below:

Learner E9: "The focal point will be closer so the image will be smaller."

Learner C42: "Larger lens has a short focus than smaller lens. Therefore the image will be formed slightly in front of screen, with less brightness and will remain inverted as it is formed by convex lens."

The above learners might have thought that a lens with a larger diameter meant that a wider lens; the learners had already learnt that for a wider lens, the focal point would be closer.

Image formed when part of the lens is covered

In question 4, a situation was presented in which the upper half of the lens was covered with a card. The learners were asked to predict what would happen to the image seen on the screen.

As their responses to the first tier of this particular question, more than half of the participants (46 out of 70 learners) were of the view that the upper half of the image would disappear when upper half of the lens is covered. There were 10 learners, however, who believed that the lower half of the image would disappear in this context. Out of the remaining 14 learners, 6 learners thought that no image would be formed, 1 learner believed that the brightness of the image would increase and 6 learners' responses could not be considered to come up with a meaningful category of responses. There was, however, just 1 learner who could respond correctly to the first tier of this question - the brightness of the image decreases when the upper half of the lens is covered.

Not many categories emanated from the learners' responses to second tier of this particular question. The categories drawn up are discussed below:

Category 1: When a portion of the lens is covered, the number of light rays passing through the lens decreases

Some learners commented that when a portion of the lens was covered, some of the light rays would be blocked by the card. The following are the responses from the learners which were placed in this category:

Learner C38: "In the upper part of the lens there are no light rays travelling through because of card."

Learner C40: "Lens will be covered from the light so the other image will not be formed."

Even though the arguments represented by this category were correct, it is surprising to see that most of the learners could not identify that when light rays are blocked by the upper part of the lens, it is the brightness of the image which is affected.

Category 2: Since the image formed is upside down, the lower part will not be displayed

Some of the learners thought that when the image is upside down, the upper part of the image is formed by the lower part of the lens and the upper part of the lens is responsible for the formation of the lower part of the image. The following responses from the learners illustrate this:

Learner E3: "Because when the image is formed, it is formed upside down so the lower part will not be displayed."

Learner C43: "Lower half will disappear because of that we use half card so it will be inverted."

The above alternative conception could not lead the learners to the correct answer in this situation.

DISCUSSION

The way in which learners conceptualise image formation by a lens has been researched in various parts of the world. Most of the findings emerged from this study were found to agree with those of previous studies; for example, the studies conducted by Galili and Hazan (2000), Goldberg and McDermott (1987), Saxena (1991) and several others identified the alternative conception that 'a half-lens produces a half-image'. Moreover, the alternative conception, 'size of an image depends on the size (diameter) of the lens' identified in this study was also identified by Galili and Hazan (2000). However, because of the qualitative approach adopted in this study, we could go even deeper into the learners' conceptions as to what happens to the image when there is i) no screen, ii) no lens iii) a lens with a larger diameter and iv) a half-covered lens. In addition to elicit alternative conceptions which were already identified by previous researchers, our findings shed light on some other alternative ideas held by learners on the same topic. This is clear from the various categories derived from the participants' responses to the second tier of all the four questions used in the reporting of this paper.

It is worthwhile to note that some of the categories of alternative conceptions developed from the participants' responses in this study could have helped them to choose the correct answers if multiple-choice type questions were used as a data-collection instrument. This stresses the fact that multiple-choice questionnaires cannot be considered as a viable tool to explore learners' conceptual understanding about various scientific concepts accurately (Caleon & Subramaniam 2010a, b).

A few categories developed from the participants' responses in this study were found to be scientifically acceptable, but the participants could not correctly apply the arguments represented by those categories to arrive at a scientifically-accepted conclusion. The following examples illustrate this argument:

- According to some of the participants, when the size of the lens increases, more light rays are refracted (correct conception) and so the size of the image increases (incorrect conception); and
- According to some others, when a portion of the lens is covered, the number of light rays passing through the lens decreases (correct conception) and so a part of the image disappears (incorrect conception).

This shows that the participants had held only a partial conceptual understanding about many concepts in relation to the image formation by convex lenses. As explained by Haney and McArthur (2002), in a constructivist classroom, the role of the educator is to orchestrate the environment and provide opportunities for learners to create meaning through active and relevant experience rather than providing information on a certain topic. We feel, however, that had the learners been given appropriate learning situations to create the scientific meaning of the optics concepts they were taught, they could have been able to reach the correct conclusions in this regard. Moreover, it is vital for educators to seek their learners' points of view in order to understand learners' present conceptions for use in subsequent lessons.

CONCLUSION

This paper reports on a case study of South African Grade 11 learners' conceptual understanding of image formation by lenses. The qualitative approach, using a two-tier qualitative questionnaire as the data collection instrument, adopted in this study helped the researchers to conduct in-depth research into the learners' conceptual understanding. The findings that emerged from this study suggest that only a few learners had a proper conceptual understanding about certain concepts pertaining to the topic 'image formation by lenses'. Most of the participants could reach correct conclusions only when they were provided with a situation where they were asked to predict what would happen to the image when the lens was removed; most of them agreed that without a lens, image cannot be formed. However, even when such participants could arrive at the correct conclusion in this particular situation, they were not able to explain correctly the role of the lens in the image formation. On the other hand, almost all the participants reached incorrect conclusions in all the other situations; however, in some situations, using correct explanations, the participants reached incorrect conclusions. To conclude, the participants in this study were found to have displayed serious conceptual difficulties about image formation by lenses.

RECOMMENDATIONS

In light of the findings that emerged from this study, the researchers recommend that the learners should be given proper learning situations to create meaning of the scientific concepts they have been exposed to in the classrooms. As suggested by Chu et al. (2008), well-structured practical activities and lecture demonstrations to reinforce concepts that are discussed in lectures should be an integral part of any Physical Sciences curriculum. The findings reported in this paper also suggest that in their normal teaching-learning process, the participants seemed to have hardly been exposed to many of the situations of image formation by lenses as reported in this paper, even though all these situations were in close relation to the concepts they were supposed to be taught. The descriptions in the textbooks normally follow a routine order and probably concentrate on numerical questions or questions which are of the same patterns as those asked in the previous years' examinations. Little effort has been made to present situations that learners may encounter and which challenge their alternative conceptions. Thus, textbook writers and those who set question papers (or examiners) for the Physical Sciences should present such situations in the form of discussions or questions which are designed to test conceptual understanding of learners rather than testing the memory power or the ability to solve complex numerical questions.

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