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Exploring Grade 11 Learners' Conceptual Understanding of Refraction: A South African Case Study

M. John, J.M. Molepo and M. Chirwa

Walter Sisulu University, Umtata, Eastern Cape Province, South Africa, 5117

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ABSTRACT This paper formed part of a larger study, which aimed to evaluate the effectiveness of an optics teaching module in enhancing Grade 11 learners' conceptual understanding about optical phenomena. The paper reports on the learners' conceptual understanding on the optical phenomenon, refraction. The sample for this study constituted 70 Grade 11 learners from a selected senior secondary school in the Mthatha District of the Eastern Cape Province of South Africa. The school was chosen using the convenient sampling technique. The data was collected using three open-ended questions and analyzed qualitatively by developing common categories from the participants' responses. The findings revealed that the Grade 11 learners experienced serious difficulties in conceptualizing the optical phenomenon of refraction. Based on the findings, some recommendations regarding substantial revision of the current teaching strategies were also made.

INTRODUCTION

The past few decades have witnessed a growing body of research on the learners' conceptions on many concepts in science. Since prior knowledge is known to have a decisive effect on the outcome of any classroom instruction, educators need to know what explanations and intuitions the learners' daily life experiences have generated in their minds (Langley et al. 1997). When the learners' responses vary from the currently accepted scientific point of view, these responses are frequently termed "misconceptions", but the constructivist view recognizes that from the learner's point of view, the conceptions s/he holds makes more sense than the scientifically acceptable one, thus making the term "alternative conceptions" a suitable one to convey the message that 'it is necessary to take learners' conceptions seriously' (Hewson and Hewson 1988).

Several studies have been conducted in different parts of the world to identify the learners' conceptions and alternative conceptions about light and its properties such as reflection, refraction, image formation, vision and so on (Hardman and Riordan 2014; Treagust and Chu 2014; Taslidere and Eryilmaz 2015). These studies revealed that learners did not understand the concepts and principles of many optical phenomena correctly. Most of these studies shared some common aspects in the findings of the conceptual understanding of light and related phenomena, reflecting a cultural and linguistic independency (Osborne et al. 1990).

A significant body of research documented the learners' conceptual difficulties about 'image formation in a plane mirror'. Taslidere and Eryilmaz (2015) assessed pre-service teachers' misconceptions in Geometrical Optics using a three-tier diagnostic instrument. The results revealed that most of the pre-service teachers have limited conceptual understanding about light and related phenomena and they hold misconceptions about light, shadow and plane mirror reflection. A case study carried out by Watts (1985) revealed some difficulties in the conceptual understanding of image formation in a plane mirror. The image was often described as formed on the mirror surface rather than behind it. The viewing of the image in a mirror was considered to be related more to the quality of the person's eyesight than any light entering the system. Similar conceptual difficulties were reported by other researchers. Eshach (2010) reported that many learners believed that the image could not be behind the mirror since the light rays (and consequently the image) could not "get there". Yap and Wong (2007) concluded that Singaporean learners had problems related to conceptual learning when they were asked to solve a quantitative problem regarding the height of the mirror required to see the full length of oneself, and the majority of the learners argued that in order to see a full length image of oneself, the top edge of the mirror and the top of one's head should be at the same level.

Even though many studies have been done on the learners' conceptions on reflection, only a few studies were located by the researchers, which reported on the learners' conceptual understanding about the optical phenomenon, 'refraction'. The study conducted in Turkey by Gunay and Ogan-Bekiroglu (2014) revealed certain areas where learners experienced conceptual difficulties.Firstly, the transition of light from a lower-index medium to a higher-index medium and the results of the transition, and secondly, the transition of light from a higher-index medium to a lower-index medium and the results of the transition. Sengören (2010) identified the fact that most learners understood that the phenomenon of refraction (and also interference) could be explained by the wave theory of light, but did not correctly construct a diagram that demonstrated the reason for refraction by changing the wavelength. While the learners could identify the changes in wave velocity and wavelength as explanations for light refraction, most of them could not change wavelengths in their diagrams. Moreover, according to the results of an investigation on Thai high school students' conceptual understanding of refraction, Keawkhong et al. (2008) indicated that most students could not apply the refraction principles to explain the real world situation. The students, even after having studied simple geometric optics, still had misunderstandings in drawing rays according to refraction principles.

Alternative conceptions might have originated in a variety of ways. In a study regarding learners' conceptual understanding about the optical phenomena, Langley et al. (1997) found that the origin of learners' difficulties was the fragmented, pre-scientific knowledge constructed on the basis of experience. Since the key factors leading to fragmentation were not addressed and remedied, these difficulties persisted. Corni (2006) argues that examples used by educators in their instructional processes can be a reason for the creation of incorrect conceptions about optical phenomena. When educators, for instance, include the example of an object, which is dipped partially in a glass of water to teach refraction of light, even when those with scientific knowledge see such an object looking as if it were broken or bent at the water surface, but Corni says that the object will appear perfectly intact and straight. Yap and Wong (2007) argued that learners fail to understand clearly the image formation in a plane mirror because typical textbooks do not pay attention to such examples or exercises where sight is also included. Yalcin et al. (2009) also consider textbooks as potential sources of misunderstandings. Some common expressions used in teaching and discussion may also be misinterpreted by learners (Viennot and Kaminski 2006), and common expressions like, "image is received on a screen" may give learners the erroneous idea that an image is a kind of copy that travels in space like an ordinary object and reaches the screen after undergoing some limited transformations.

According to the Department of Education of South Africa (2008), South African Grade 11 learners are supposed to learn the optical phenomena reflection, refraction and total internal reflection under the core knowledge area of 'Waves, Sound and Light'. The name of this particular core knoweldge area remains the same in the revised curriculum too, which follows Curriculum and Assessment Policy Statement (CAPS) (Department of Education 2011). Little research has been conducted to document the South African learners' conceptions about any topic on light. Since optics have been identified as an area in which learners have many conceptual difficulties, the researchers believe that the research on investigating learners' conceptual difficulties in different areas in optics should be extended to developing countries like South Africa. The purpose of this paper is, therefore, to report on an investigation into Grade 11 learners' conceptual understanding of refraction in a selected senior secondary school in Mthatha, Eastern Cape Province, South Africa. The paper thus sought to answer the following research question:

What are Grade 11 learners' conceptions about the optical phenomenon of 'refraction'?

METHODOLOGY

Even though a mixed method, quasi-experimental research design was employed in the larger version of the study, this paper reports only on the qualitative data collected in the initial stage of the larger study. The data was collected using three open-ended questions. The content validity of the questionnaire used in the paper was assured by two experts in the field, one who holds a PhD in Education and the other one, a PhD in Physics. However, the questionnaire assumed its final form after piloting the original version of the questionnaire and then making the necessary changes thereafter. The piloting was done on a group of Grade 11 learners who were not part of the main research study.

The sample for this study comprised of 70 Grade 11 learners from a selected senior secondary school in the Mthatha District of the Province of Eastern Cape in South Africa. The school was conveniently chosen since one of the researchers was a Physical Sciences educator there at the time when the research was conducted. The data reported in this paper was collected in the academic year 2012. Since the primary objective of the whole research study was to test how effective the designed optics teaching module was in enhancing the Grade 11 learners' conceptual understanding of the optical phenomena, the researchers decided not to use too many learners and too many schools as the sample for the main study.

The data were analyzed qualitatively, that is, the participants' responses to the open-ended questions were analyzed by reading and re-reading each response and then grouping the responses into categories. Each category was represented using a certain code, which was a combination of letters or/and numbers, or/and symbols. Johnson and Christensen (2006) define coding as a process of marking segments of data with symbols, descriptive words or category names. After identifying the categories, the researchers compiled the responses which belonged to each category and thus all the responses were grouped in terms of the identified categories. The codes developed from the responses of the learners in this study were inductive codes, that is, the codes were generated by the researchers by directly examining the data (Johnson and Christensen 2008: 538) instead of developing the codes before examining the current data (which are known as a priori codes). There were some responses which did not belong to any of the identified categories and such responses were eliminated from the discussion.

To comply with the ethical requirements of the study, permission was requested of the Provincial Department of Education and the principal of the selected school. The participants were given informed consent forms to fill in, sign and give back to the researchers. Since the participants were under 18 years of age, permission from their parents/guardians was sought via the same informed consent forms. The researchers assured the participants about their rights regarding non-participation, to remain anonymous and also their right to confidentiality.

RESULTS

Analysis of Question 1

In the first question, some media were listed in a table with the corresponding speed of light in each medium. The learners were asked to give the medium in which the light ray bends the most when it travels from the air to each medium given in the table (see Appendix). The categories developed from the participants' responses to this question are discussed below.

Category 1: A Light Ray Bends More in that Medium in which the Speed of Light is High

Many learners associated a higher speed of light with more bending of light. Some such verbatim responses are given below:

If a light ray travels very fast, light is fastly bent or I may say it quickly bends.

Light travels at a faster speed so it is easily bent.

Category 2: The Amount Light Bends in a Medium Depends on how Transparent the Material is

Some participants' responses, which belonged to the above category, are given below:

Water and perspex are transparent substances and they really bend light in a strong way such that they bend more than others.

Light rays bend the most in materials that are not transparent.

The above responses showed that some learners thought that bending of light was most likely to be in materials which were more transparent while others thought that light bent more in materials which were not transparent.

Category 3: Light Ray Bends More in Shiny Materials

Some learners believed that the extent of bending of a light ray in a medium depended on how shiny the material was. According to such learners, bending of light would be higher in materials which were shinier. The following responses from the learners illustrate this category:

Because diamond is shinier than all the above mentioned materials, light bends more in a diamond.

Diamond shines so bright when you expose it to light, so light bends more in diamond.

Category 4: As the Speed of Light in a Material Decreases, Bending of Light Rays in the Material Increases

Very few learners believed that bending of light was higher in materials in which the speed of light was less. One such response is given below:

Speed of light is the least in diamonds, meaning that light is bent more in diamonds.

The above category of responses is scientifically accurate and the learners who used the above argument succeeded in identifying the correct material (diamond) in which bending of light is greater compared to the other materials listed.

Category 5: Light Rays Bend More in Less Dense Materials

Given below are examples of some responses from which the above category was developed:

Because water is less dense than all the other media, a light ray bends more in water.

Water is less dense than other materials, so bending of light is more in water.

Category 6: Light Rays Bend More in Denser Materials

Some learners held a scientifically acceptable conception that light rays bend more in materials which were denser, but they failed to identify the densest material from the given list. Some of such responses are given below:

Glass is the densest material, so light bends more in glass.

Water has high density than air, so bending is more in water.

Even though the above argument is scientifically acceptable, most of the learners who presented arguments corresponding to the above category could not correctly relate the speed of light with the (optical) density of the medium, so despite having a scientifically accepted conception, these learners did not succeed in identifying the correct answer.

Category 7: The Bending of Light is Higher in Materials which have Many Crystals or Edges

Some learners thought that the way in which an object or medium was structured was the factor which decided how much a light ray bent in that object or medium. Some such responses are given below:

Light bends more in diamond because it has a smooth, dark surface and so many edges.

It is diamond because diamond has many crystals.

Analysis of Question 2

In question 2, four ray diagrams were given and the learners were asked to select the situations represented by the diagrams in which the light ray travels at a constant speed (see Appendix). The responses from the participants were grouped under the categories which are discussed below:

Category 1: Light Has the Same Speed in Two Different Media

There were some learners who thought that the speed of light did not vary when it travelled from air to water. The following are some such responses from the learners:

In air and water, light is travelling in the same speed.

Water and air have the same speed of light.

These learners seemed to have a lack of understanding of the optical phenomenon, 'refraction', and thus failed to identify the change of speed of light when it travels from one medium to another.

Category 2: Speed of Light is the Same Whenever it Travels Without Bending

A large majority of the learners associated the speed of a light ray with the direction of the propagation of the light. They believed that whenever the light ray travelled in the same direction, its speed would also be the same. They did not consider the change in the medium (and the resulting change in the refractive indices) as the deciding factor of the speed of light. The following responses from the learners illustrate this category:

Since the ray does not bend, the speed will stay the same.

Rays will go at the same direction with the same speed.

The above learners expressed a conception, which was not scientifically accurate and they failed to choose the correct answer.

Analysis of Question 3

The learners were given the same situations as those in the previous question. The learners were then asked to identify the situations in which the light ray undergoes refraction. The categories which were developed from the learners' responses to this particular question are discussed below.

Category 1: Refraction Happens only when Light Rays, Travelling from One Medium to Another, Hit a Surface at an Angle to the Normal (Perpendicular Line to the Surface Drawn at the Point of Incidence)

There were some learners who had an alternative conception that refraction happens only when the light rays hit an angle to the normal. Some such responses are given below:

A light ray, which is travelling from air to water at an angle to the normal, creates an effective and efficient refraction.

Light ray travelling from air to water at an angle to the normal is said to be undergoing refraction because the light rays are bent.

The above learners associated refraction of light with the change in direction or bending of the light ray and not with the change in speed of the light ray when it travels from one medium to another. This led them to choose the incorrect answers.

Category 2: When Light Rays Travel from One Medium to Another, Refraction Takes Place

Some learners specified that when light rays travelled from one medium to another, refraction took place. Some such responses are given below:

It is because the light is travelling in two different media and one medium is denser than the other.

When light travels from air to water, light ray undergoes refraction.

Even though the conception represented by the above category was scientifically accurate, most of these learners failed to apply this conception in choosing all the correct answers.

Category 3: Refraction Happens When a Light Ray Hits a Medium Through which it Cannot Pass

A few learners thought that refraction happened in a medium through which light cannot pass. Some such responses are listed below:

Because light does not pass through the mirror…

When light is travelling from air to mirror, the light will not penetrate through the mirror.

The above arguments led those learners to think that since a mirror was opaque to light rays, the rays get refracted when light rays hit a mirror.

DISCUSSION

The study revealed that most learners could not correctly relate the bending of light in a medium with the speed of light in the medium. They did not understand that speed of light was less in a medium with a higher refractive index (or a higher optical density), which in turn results in more bending for the light ray in such a medium. It was also revealed that most learners were confused with deciding about conditions under which the speed of a light ray remains constant. Similar conceptual difficulties were identified in the study conducted by Gunay and Ogan-Bekiroglu (2014) in that the participants could not understand clearly the transition of light from a lower-index medium to a higher-index medium, and vice versa.

The learners seemed to have associated the speed of light with the direction in which the light ray travels, with or without bending. Some learners thought that the light ray travelled with the same speed when it hit a surface at an angle to the normal. Others thought that the speed of the light ray remained the same if the light ray hit the surface normally (perpendicularly). The learners had obviously not understood the effect of the nature of the medium in which the light ray travels on the speed of light rays.

Many of the respondents were found to have experienced difficulties in identifying the conditions under which the optical phenomenon 'refraction' occurs. From the ray diagrams given along with question 3, none of the learners could identify all the situations in which refraction is possible. Most of the learners associated refraction with the bending of light rays when light rays travel from one medium to another. Such learners thought that the light ray did not undergo refraction at normal incidence.

The above findings are supported by the following findings of the study by Sengçren (2010) regarding 'refraction' of light rays:

- The incident beam normal to the boundary surface is not affected by the medium.
- The incident beam normal to the boundary surface cannot be carried away.
- At normal incidence, the velocity of the incident beam decreases, but refraction does not occur.
- At normal incidence, the direction of the beam does not change because its velocity does not change.

Furthermore, the above study reported that the case where the light velocity changes and bending does not occur confused the learners who described refraction as change in light direction, and these learners had an alternative conception, that is, refraction happens only when there is a change in the direction of the light ray when it passes from one medium to another.

It was also noted that while using scientifically acceptable arguments, learners arrived at incorrect answers in most of the situations (see category 6 in question 1 and category 2 in question 3). This suggests that these learners might not be properly trained to apply their knowledge regarding refraction in different situations. This supports the finding by Keawkhong et al. (2008) wherein most of the students did not have a deep understanding of refraction and they could not apply appropriate principles to present their idea and solve the problem.

There were many alternative conceptions revealed in this study, but were not revealed in any of the previous studies. For example, some of the participants in this study associated bending of light rays with shiny materials, while others related bending of light rays with transparent materials or opaque materials, and some others did it with materials with many crystals or edges. As a result, this study adds a lot to the existing literature, which focused on the learners' knowledge about refraction. However, the researchers could not locate considerable amount of literature in this area.

CONCLUSION

The study investigated South African Grade 11 learners' conceptual understanding of the optical phenomenon of 'refraction'. The qualitative approach used in the study helped the researchers go deep into the ideas the learners held about different aspects of refraction. The finding that emerged from this study suggests that the learners experienced serious conceptual difficulties about the optical phenomenon of 'refraction'. Most learners associated refraction with the bending of light rays and not with either the change in the medium in which light rays travel or with change in the refractive index of the medium in which light rays travel. Moreover, most learners could not correctly relate the refractive index of a medium with the speed of light in that medium. To conclude, the conceptual understanding of Grade 11 learners in the selected senior secondary school about the optical phenomenon of 'refraction' was found to be very weak and they could not apply the principles of refraction correctly in different situations.

RECOMMENDATIONS

Optics teaching in senior secondary schools should enable the learners to apply the optics principles they have been taught correctly in different situations. To achieve this, educators should provide their learners with various situations so as to be able to apply whatever optical phenomena they had been taught in the classroom. While presenting the concept of refraction, educators and textbook writers should also include the case of normal incidence in addition to the case of inclined incidence. In addition, refraction should be defined as the change in the speed of light (not the bending of light) when light travels from one medium to another. Furthermore, before presenting any scientific concept to learners, educators need to take the necessary steps in assessing the prior knowledge held by their learners and ought to plan their lessons accordingly; otherwise, the teaching and learning process may be both faulty and futile.

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APPENDIX

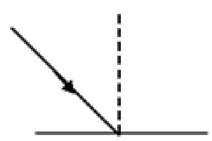
QUESTION 1

If a light ray travels from air to each of these materials (see the table below), which of these materials bends light more? Explain your answer.

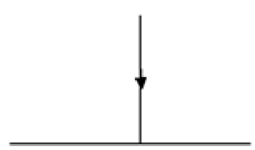
Material	Speed of light (in km/s)
A. Water	225 000
B. Perspex	201 000
C. Glass	197 000
D. Diamond	124 000
E. All media bend light equally	
F. Light will not bend in any media	
G. …………………………………………………..	

For questions 3 and 4, consider the following situations:

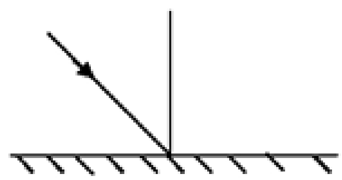
Situation 1: A light ray travelling from air to water hitting the surface at an angle to the normal



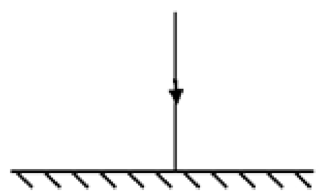
Situation 2: A light ray travelling from air to water hitting perpendicularly to the surface.



Situation 3: A light ray travelling from air to a mirror at an angle to the normal.



Situation 4: A light ray travelling from air to a mirror hitting the surface perpendicularly to the mirror surface.



QUESTION 3

In which of the above situations does the light ray travel with the same speed? Explain your answer.

QUESTION 4

(This follows the above question): In which of the above does the light ray undergo refraction? Explain your answer.