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The Impact of an Interactive Ray Diagram Teaching Module in Enhancing Grade 11 Learners' Conceptual Understanding of Image Formation in a Plane Mirror

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This paper reports on one part of a larger study which aimed at testing the effectiveness of an interactive optics teaching module in enhancing Grade 11 learners' conceptual understanding of reflection. The focus of this paper is to evaluate the effectiveness of a part of the interactive optics teaching module in enhancing learners' conceptual understanding about the characteristics of the image formed in a plane mirror. The sample consisted of 70 learners, selected from one school in the Eastern Cape Province in South Africa. Within the quasi-experimental design, the data were collected from four relevant questions of the questionnaire (designed for the larger study). Findings indicated that the designed teaching module was effective in enhancing learners' understanding of image formation by a plane mirror.

Keywords: alternative conceptions, four-tier questionnaire, plane mirror reflection, ray diagram

INTRODUCTION

Over many years, learners' ideas concerning scientific phenomena have been a subject of study by many researchers all over the world. Pinarbas and Canpolat (2003) stated that if learners' ideas conflict with the generally-scientifically-accepted ideas, these are labelled as learners' conceptions, misconceptions, preconceptions, children's science, alternative conceptions, or alternative frameworks, depending upon the researcher's view of the nature of knowledge. Moreover, Vosniadou (2007) views the conceptions developed by children on the basis of everyday experience as naïve, intuitive, domain-specific theories. The constructivist view, however, recognizes that from the learner's point of view, the conception he or she holds makes more sense than the scientifically-acceptable one,

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thus making the term "alternative conceptions" able to convey a message that 'it is necessary to take students' conceptions seriously' (Hewson & Hewson 1988). An overwhelming body of educational research has repeatedly documented learners' alternative conceptions because schooling has been unable to deal with the problem of conceptual change (Saxena, 1991; Osborne, Black, Meadows & Smith 1993).

Children come to school holding prior knowledge regarding many scientific phenomena. Everyday-life experiences expose them to rich and direct experiences of optical phenomena, from which they construct concepts regarding optics (Eshach 2010). Such ideas often persist even when these are not consistent with the experimental results or explanation of an educator (Driver & Oldham 1985). These ideas play a significant role in the learning experiences in the classroom; therefore, it is important that the prior knowledge of learners regarding scientific concepts must be taken into consideration while planning teaching of science topics in order to make the learning-teaching process more effective and fruitful. Many studies have explained children's alternative conceptions about light, vision and optical phenomena. These suggest that the alternative knowledge held by learners with regard to the optics phenomena may be different from formal scientific knowledge (Saxena 1991; Osborne et al. 1993; Kaewkhong, Mazzolini, Emarat & Arayathanitkul 2010).

Looking in a mirror is one of the most common and simple optical experiences students have in their every-day lives (Chen, Lin & Lin 2002). Even though several attempts have been located which explored learners' conceptions about image formation in a plane mirror (Goldberg & McDermott 1986; Langley, Ronen & Eylon 1997; Chen et al. 2002; Heywood 2005; Aydin 2012), the researchers could not locate a single piece of work which focused on designing and implementing a teaching module based on the ray diagram of an extended object to promote learners' conceptual understanding of the characteristics of the image formed in a plane mirror.

Several studies have shown that it can be difficult to convince a learner to give up a long-held conception unless the new concepts are more valid, more powerful and more useful (Driver & Oldham 1985; White & Gunstone 1989). However, learners who followed conceptual change procedures were found to correct their concepts and give up their alternative conceptions. Examples of such conceptual change strategies used in the field of optics teaching in the past studies are convergence lens simulation designed by Bryan and Slough (2009) and collaborative learning mediated by multimedia, computer-assisted learning programs (Tao 2004) for developing an understanding of image formation by lenses. This means that if conceptual change strategies were to be designed and implemented properly, the correction of alternative conceptions would be possible and thus learners would be

State of the literature

- The literature revealed that learners from various parts of the world experience conceptual difficulties in understanding properties of the image formed in a plane mirror.
- Few studies have been carried out on developing teaching module to improve learners' conceptual understanding about 'image formation in a plane mirror'.
- The researchers are of the view that the use of 'ray diagram for the image formation of a point object by a plane mirror' is not always useful in teaching learners effectively the various properties of image formed by a plane mirror.

Contribution of this paper to the literature

- The focus of this study was on the design, implementation and validation of an interactive ray diagram teaching module; the teaching module aimed at enhancing learners' conceptual understanding of image formation in a plane mirror.
- The researchers included several ray diagram tasks (for the image formation of an extended object) in the teaching module, from which the learners were supposed to derive conclusions about the properties of the image formed by a plane mirror.
- In the design of teaching module, the researchers made sure to include situations which created cognitive conflict with the alternative conceptions they had acquired from their daily-life experiences.

able to replace their inaccurate ideas with scientifically-accepted concepts. Most of the science education researchers agree that the learning of science involves conceptual change (Novak 1977; Posner, Strike, Hewson & Gertzog 1982). Posner et al. (1982) postulate certain conditions that should be met before the conceptual change might happen: learners must first feel dissatisfaction with the existing conceptions and then the learners must find the new conception as intelligible, plausible and fruitful. If educators can identify the alternative conceptions from a lower or basic level, the learning-teaching processes can be designed in such a way so that the learners would be able to replace their alternative conceptions with scientifically-accepted conceptions from an earlier stage.

In the South African secondary school (Grades 10 to 12) Physical Sciences' curriculum, the learners are expected to learn how to draw a ray diagram both for a point object and for an extended object, but less focus is normally given to the ray diagram for an extended object (Department of Education 2008). Moreover, these learners are not trained to apply these ray diagrams in arriving at the characteristics of the image formed in a plane mirror. Instead, the textbooks and probably the Physical Sciences educators present the ray diagram for the image formation (of a point object) in a plane mirror first and then simply list the properties of the image formed in a plane mirror without attempting to apply the ray diagrams in arriving at the image properties. The researchers therefore focused on designing a teaching module primarily based on the ray diagram of an extended object and then testing how the designed ray diagram teaching module was effective in enhancing Grade 11 learners' conceptual understanding about characteristics of the image formed by a plane mirror.

THEORETICAL FRAMEWORK

Constructivism is the theory of knowing; the main view is that the acquisition of knowledge is metaphorically described as a building process in which knowledge is actively constructed by individuals or social communities (Tynjälä 1999). Different branches of constructivist thoughts can be found in the literature, such as radical or cognitive constructivism, social constructivism, the socio-cultural approach, symbolic interactionism and social constructionism (Tynjälä 1999). Following a detailed examination of the literature concerning different learning theories, the researchers found the perspectives of social constructivism proposed by Vygotsky (1978) as the most effective tools in the present study.

According to the social constructionist viewpoint, much learning occurs when children interact with more capable individuals such as adults, peers and educators. So it can be understood that educators have a central role in providing guidance and support to learners (Palmer 2005). Following are some explanations of how the perspectives of social constructivism are adopted in this study:

- Vygotsky takes into account both everyday concepts the children acquire outside the classroom and scientific concepts they are taught in the classrooms (Howe 1996). Conceptual understanding develops under the influence of instruction that encourages integration and consolidation of the two types of concepts. It is, therefore, clear that children's prior knowledge that they acquired from their everyday lives (everyday concepts) must be taken into consideration as a starting step of any classroom instruction. In the present study, the researchers collected prior knowledge held by the learners prior to the design and implementation of the teaching module, thereby enhancing the conceptual understanding of the learners in the area of optics.

- According to Vygotsky, conceptual change is an ongoing process in which a child, in collaboration with a teacher or other students, integrates everyday concepts into a system of related concepts and transforms the raw material of experience into a coherent system of concepts (Howe 1996). In the present study, as a part of teaching intervention, the learners were given classroom activities; the educator then guided, directed and encouraged the learners throughout the activities thereby allowing true collaboration between the learners and the educator (one of the researchers). The learners were allowed to participate in active debates and discussions in groups while they were engaged in the activities, thus allowing active collaboration among the learners themselves.

Aim and research questions

The aim of the study was to test how the designed ray diagram teaching module enabled enhancement of Grade 11 learners' conceptual understanding about characteristics of the image formed by a plane mirror. To accomplish this aim, the following research question was posed:

> To what extent does the ray diagram teaching module help the learners in enhancing their conceptual understanding of the image characteristics in plane mirror reflection?

METHODOLOGY

Sample selection and research design

The participants for the study were learners from two Grade 11 classes in an urban senior secondary school in the Eastern Cape Province, South Africa. The school caters for learners in Grades 10 to 12. Learners are admitted at Grade 10 and normally, there is no intake of learners in the subsequent grades. Learners from diverse backgrounds attend this school. All learners in the school are South African Blacks and the mother tongue for almost all of them is IsiXhosa. Since the school provides hostel facilities for both boys and girls, there are also learners who come from other nearby districts, other than Mthatha. The data reported in this paper were collected in 2012 and the enrolment for the year was 1854 (930 in Grade 10 + 430 in Grade 11 + 494 in Grade 12).

Physical Sciences and Mathematics are two compulsory subjects for all learners in the school. Learners are free to choose one from among the elective subjects: Agricultural Sciences, Geography, History, Tourism and Computer Applications Technology. English is studied as the second language for all learners in the school, whereas IsiXhosa is the home language. When learners are admitted in Grade 10, those who opt for a particular optional subject are randomly allocated to different classes by the school which then allocates 5 streams per grade in the school. Learners in different classes in a particular grade who belong to a particular stream are, therefore, randomly distributed and they are not allowed to swap their subjects or even classes during the subsequent grades after such a random allocation is made in Grade 10. With its large number of learners from diverse socio-economic backgrounds, the school is well known for its academic excellence.

The researchers adopted the pre-test-post-test non-equivalent group design or more simply, non-equivalent comparison-group design for the present study. One intact group of learners was chosen as the experimental group (EG) and another intact group was chosen as the comparison group (CG), both associated with Grade 11. To match the EG and the CG as far as possible, the researcher decided to draw two Grade 11 classes purposively as the sample for the study because of some defining characteristics that made them the holders of the data needed for the study (Maree 2007: 79). These are discussed below:

- The school has a total of seven Grade 11 classes and these seven classes are taught by three different Physical Sciences educators. As an initial step in matching the two groups, the researcher selected two classes which are taught by the same Physical Sciences educator. The Physical Sciences educator for these two classes was a highly-experienced and professionally-qualified educator.
- The next step in matching the two groups was to choose two Grade 11 classes which belonged to the same stream since learners were randomly allocated to the two classes when they were admitted in Grade 10. The researcher thus could include some randomness in the selection of the two groups. The sample for the study, therefore, included two Grade 11 classes which were taught by the same educator and which belonged to the same stream.

During the first stage of the study, a pre-test (PrT) was given to both groups to identify the conceptions/alternative conceptions held by the participants. The information from the analysis of the PrT was used as a guide for designing a teaching module to enhance the conceptual understanding about plane mirror reflection. The teaching module was then administered only to the EG, whereas the CG was taught using the traditional method. However, the two groups were not informed that they were going to be taught using two different techniques. The implementation of the teaching module took almost 2 weeks. After this period, the same test used as the PrT was administered to both groups as the post-test (PoT). The PrT and PoT scores were analyzed using statistical methods to check whether the EG had shown significant improvement over the CG in their PoT performance. The actual size of the EG was 37 and that of the CG was 52. This was cut to 26 and 44 because the researchers included only those learners who appeared for both pre-test (PrT) and post-test (PoT).

Data collection instrument

The questionnaire used in this study was a slightly-modified version of the standardised two-tier questionnaire designed by Chen et al. (2002). The slight modifications were done to the structure of the questionnaire by incorporating some ideas of Caleon and Subramaniam (2010a & 2010b). In the two-tier, multiple choice questionnaire designed by Chen et al. (2002), the first tier of each question was a multiple choice content-based question. The second tier was a multiple choice question in which participants were asked to choose a reason to justify their answers for the first tier. Space was also provided with each tier of each question if none of the given alternatives fitted the learners' understanding. On the other hand, the first tiers in the questionnaire for this paper were content-based, multiple choice questions as in the two-tier questionnaire of Chen et al. (2002). The second tier of the questionnaire in this study asked about the participants' confidence levels in their responses to the first tier. The confidence rating for the answer to the first tier was a four-point scale starting from A to D as follows:

A) Certain B) Almost certain C) Almost a guess D) A totally-guessed answer

The four questions which were relevant to this report are given in Appendix 1. In addition, all the four questions selected for the present study were of non-covariation type (Millar & Kanari 2004). Millar and Kanari (2004: 749) proposed as follows:

> In the case of continuous variables, covariation means that a gradual increase in one variable results in a steady increase [or decrease] in the

other. Non-covariation means that a change in one variable results in no change in the other.

In a study done to explore the understandings of data and measurement that school students draw upon, and the ways that they reason from data, Millar and Kanari (2004) concluded that there was a statistically-significant difference in the proportion of students reaching the correct conclusion in covariation and non-covariation cases. Koslowski (1996) argues that if a person can imagine a plausible reason why two variables might covary, then a small amount of data showing non-covariation is unlikely to make them reject the hypothesis that the variables covary. Because of the use of non-covariation type questions in the current study, the researchers made the following assumptions for the present study:

1. If the participants respond by stating that the two variables covary in a non-covariation case, it should be assumed that the learning-teaching process was not effective enough for the learners to think about a plausible reason why the two variable do not covary; and
2. If the participants respond by stating that the two variables do not covary in a non-covariation case, it should be assumed that the learning-teaching process was effective enough for the learners to think about a plausible reason why the two variables do not covary.

All four questions in the questionnaire of the current study sought to test whether or not the participants could identify whether the two variables (either object size or image size) did not covary with variables such as observer postion, position of the light source and so on. The content validity of the questionnaire was established by two experts in the field: one holds a PhD in Education and the other one, a PhD in Physics. The questionnaire assumed its final form after piloting the original version and making necessary changes thereafter.

Ray diagram teaching module

In the traditional instructions (including Grade 11 Physical Sciences textbooks), the object is shown as a point object in the ray diagram for the image formation by a plane mirror. (See Figure 1.)

The drawback of such a ray diagram in which the object is a point object is that such a ray diagram is not able to prove one of the important properties of the image formed by a plane mirror: the image size is equal to object size. A brief outline of the traditional teaching module using the ray diagram given in Figure 1 is shown in Figure 2.

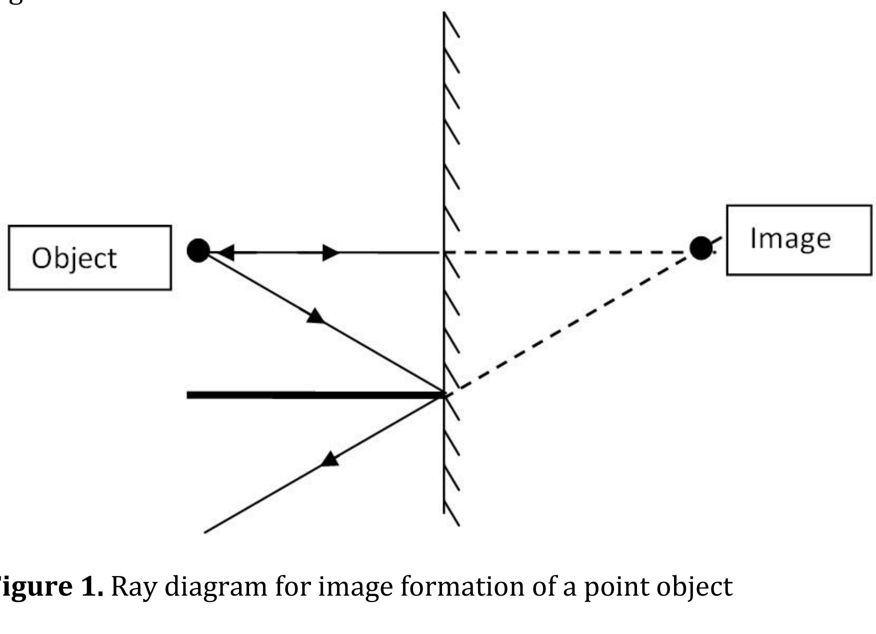

Figure 1. Ray diagram for image formation of a point object

It can be noted from Figure 2 that one cannot find a suitable situation in the learning-teaching process according to the traditional teaching method in order to draw the relationship between image distance and object distance. This drawback was addressed in this study by using 'ray diagram of an extended object' as the learning-teaching tool to enhance the conceptual understanding of 'image formation by a plane mirror'. (see Figure 3.)

In the design of the interactive ray diagram teaching module, three ray diagram tasks were included in which the learners were supposed to complete 2 ray

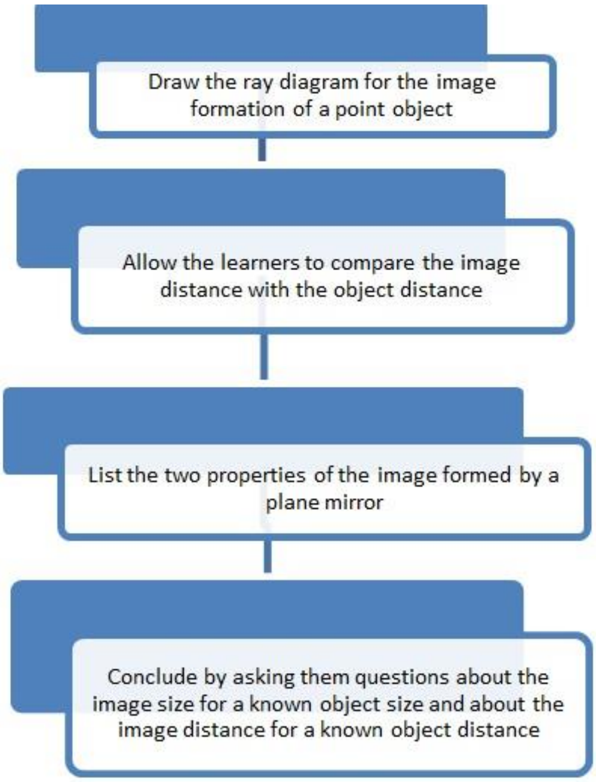

Figure 2. Traditional teaching method using ray diagram for a point object

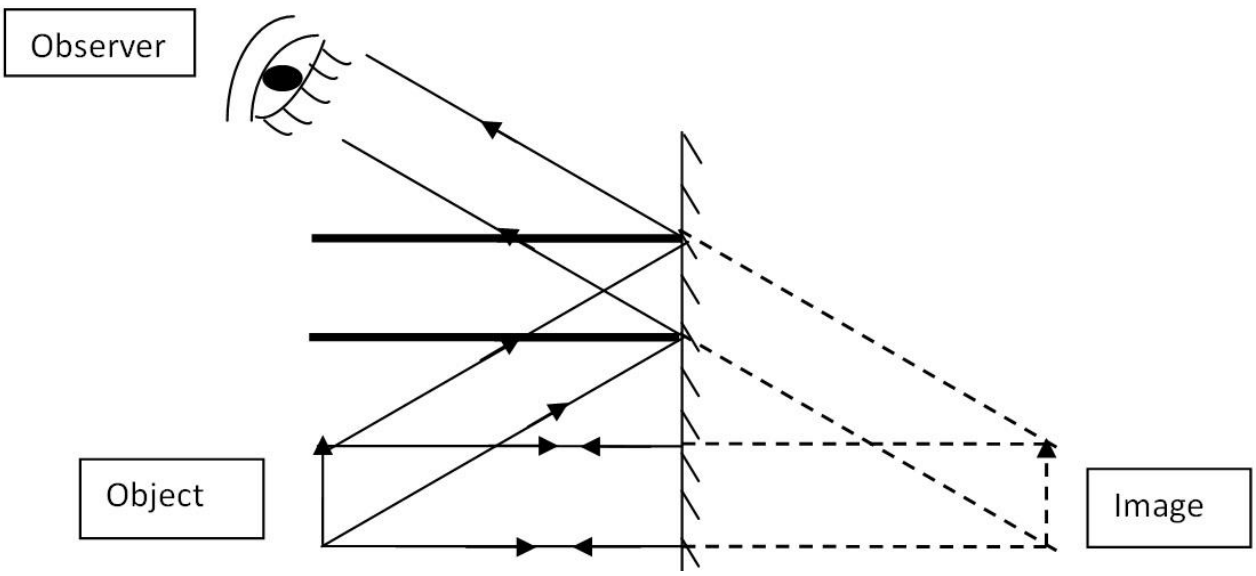

Figure 3. Ray diagram for image formation of an extended object

diagrams (using the ray diagram given in Figure 3 as a guideline) in each task. The information about the learners' prior knowledge, which was obtained from the PrT, was also included in the teaching module, thereby allowing an appropriate environment to create cognitive conflict among the learners. Moreover, the teaching module was designed in such a way as to ensure continuous interaction among the learners in addition to that between the learners and the educator. The teaching module was implemented by issuing worksheets which incorporated the above ideas. A brief outline of the interactive ray diagram teaching module is shown in Figure 4.

The learners thus used the three ray-diagram tasks to determine the relationships between:

1. object size and image size
2. object size and image distance.
3. object distance and image size.
4. object distance and image distance.
5. observer position and image size.
6. observer position and image distance.

It should be noted that covariation between the variables exists only in relationships 1 and 4 of the above and the remaining relationships are of non-covariation type. The researchers thus made sure that the ray diagram tasks included situations in which two variables covary and also that in which two variables do not covary. Thus, after completing the above ray diagram tasks, learners were expected to draw the following conclusions regarding the image formed by a plane mirror:

- Image size is equal to object size; and
- Image distance is equal to object distance.

Learners could use these ray diagrams as strong scientific proofs to reach the following conclusions:

- Image size changes only when object size changes; and
- Image distance changes only when object distance changes.

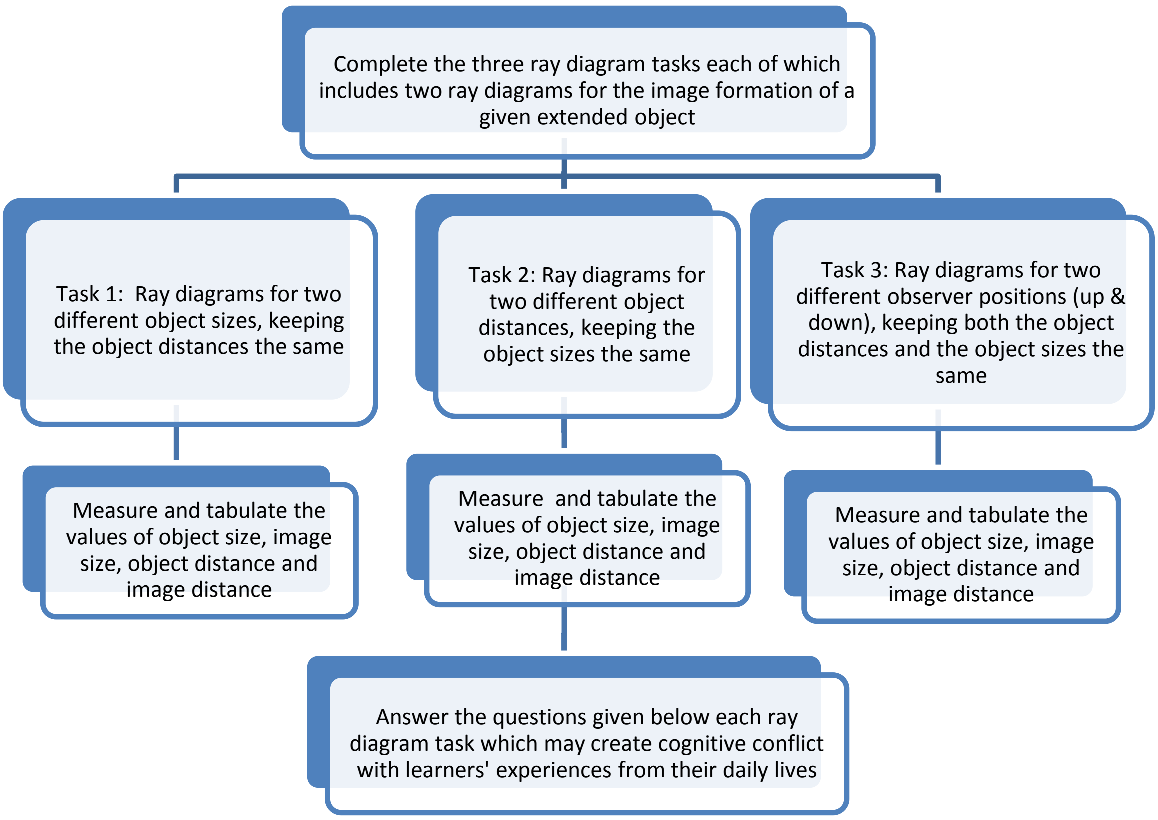

Figure 4. The interactive ray diagram teaching module for the image formation in a plane mirror

The researchers made sure they created situations where the learners felt dissatisfaction (Posner's 1st condition for conceptual change) with their existing conceptions (which were identified from the pre-test results) by asking probing questions (based on the conclusions they had drawn from each ray diagram task) at appropriate points. The PrT results were used as a guideline to the researchers having a prior idea about the alternative conceptions held by the learners regarding the situation corresponding to each ray diagram task; for example, the PrT results showed that the majority of the learners held an alternative conception that 'object size decreases as the object or observer is moved away from the mirror'. After the learners completed the ray diagrams to prove the relationship between image size and object distance and image size and observer position, the researcher probed in the following way:

- Suppose you are viewing the image of a 5 cm pen in a plane mirror. What can you say about the image size when
  - the pen is 2 cm from the mirror?
  - the pen is 8 cm from the mirror?
- Suppose you are viewing your own image in a plane mirror. What will happen to your image size when you move further away from the mirror?

The experiences of the learners guided them to a conclusion, 'image size decreases when the object/observer is moved further away from the mirror' - even though they were a bit confused when they saw that their experience contradicted the scientific proof they had formulated from the ray-diagram tasks. The researcher then presented another situation in the form of a question:

- Do you see the distant objects like stars in their actual size?

The learners responded that stars do not appear in their actual size. The learners could then relate this experience to the experience of feeling an apparent decrease in the image size when either the object or the observer moves further away from the mirror. Such probing questions were included in the worksheet after each ray diagram task to relate their findings from the ray diagram to their experiences in daily lives. The learners drew conclusions after completing each ray diagram and answering the supporting questions given after each ray diagram. This approach could help the learners to accept the new conception as intelligible, plausible and fruitful (Posner et al., 1982).

To conclude, the worksheets in the interactive ray-diagram teaching module were not merely aimed at answering some structured questions; they consisted of a series of activities (focused mainly on ray diagrams), clear instructions on how to approach the activities, the drawing of conclusions from the activities, situations which illustrated the activities and situations which created cognitive conflict among the learners and those which helped the learners in accepting that the new conceptions were more intelligible, plausible and fruitful than the already-existing conceptions (Posner et al. 1982). The authors believe the following are some of the advantages of the interactive ray diagram teaching module over the traditional teaching module:

- In the traditional textbooks and instructions, properties of the image formed by a plane mirror were simply listed without presenting any scientific activities or experiments which could be used to arrive at these properties; however, in the designed teaching module, the learners listed the properties of an image formed by a plane mirror from the scientific proof that emerged from drawing the ray diagrams. As a result, the learners could view the new knowledge as more intelligible, plausible and fruitful when they approached different situations in the teaching module.

- This worksheet did not incorporate any hands-on experiments to prove the properties of the image formed by a plane mirror. Even though this in itself is not considered an advantage, the researchers are of the view that hands-on experiments are more effective as a learning and teaching aid when learners lack hands-on experience regarding the scientific phenomena under consideration. Reflection and image formation in a plane mirror are those phenomena about which learners have rich experience from their daily lives. Most of the alternative conceptions are also derived from their daily-life experiences. To contradict such alternative conceptions that learners gain from daily-life experiences, the researchers found the plane mirror ray-diagram tasks done in different situations to be more effective than hands-on experiments.

Data-analysis methods

The research question was addressed by comparing the learners' responses to the questionnaire before and after the implementation of the interactive teaching module. Following the arguments of Caleon and Subramaniam (2010a & 2010b), the incorrect responses in the 1st tiers associated with low levels of confidence (corresponding to options C and D in the 2nd tiers) were categorized as 'errors due to lack of knowledge (ELK) instead of 'alternative conceptions' and those with high levels of confidence (corresponding to options A and B in the 2nd tiers), the 'alternative conceptions' (AC). On the other hand, the correct responses in the 1st tier with low levels of confidence were categorized as 'scientifically-accepted weak conceptions (SAWC) and those with high levels of confidence, the scientifically-accepted strong conceptions (SASC). An analysis procedure which is usually used for the Likert type questionnaires was used to categorize the conceptions into each of the above 4 types. Any option in the first tier coupled with option A (which corresponds to 'certain') in the corresponding 2nd tier was allocated a score of 4, the one coupled with option B was allocated a score of 3 and so on. This was done to calculate the average confidence level for each of the first-tier options (both the correct and the incorrect) of each of the four questions. A cut-off value of 3 was used to categorize a particular conception as ELK (incorrect conception with an average confidence level below 3), AC (incorrect conception with an average confidence level greater than or equal to 3), SAWC (correct conception with an average confidence level less than 3) and SASC (correct conception with an average confidence level greater than or equal to 3).

In order to compute the statistical t-tests, the 1st tier responses of each participant from both the groups were marked by allocating a score of 1 to the correct responses to the first tiers and 0 to the incorrect 1st tier responses. Since there were a total of 4 questions which were used for the data collection for this report, the total score was calculated out of 4 for each student. This was followed by performing paired samples t-test and independent samples t-test to determine if the two groups differed significantly in their performance during the PrT and the PoT. The level of significance was determined mainly by comparing the p-value obtained from each test with a pre-set alpha value of 0.05.

RESULTS

Types of conceptions the learners held about the characteristics of the image formed in a plane mirror

Table 1 indicates the frequency distribution of the participants' responses to the first tiers of the PrT. It should be noted that the two variables mentioned in each of the four questions of the questionnaire do not covariate; in other words, the changes

Table 1. Percentage occurrence of different types of participants' responses to the PrT

QN	Fractional occurrence of various types of responses (%)								
	The two variables covariate				The two variable do not covariate				
	[1]ELK		[2]AC		[3]SASC		[4]SAWC		[5]NR
	EG (N=26)	CG (N=44)	EG (N=26)	CG (N=44)	EG (N=26)	CG (N=44)	EG (N=26)	CG (N=44)	CG (N=44)
1	38	23	46	41	4	25	12	11	-----
2	42	34	39	45	4	14	15	5	2
3	38	25	58	48	0	14	4	14	------
4	50	36	19	39	15	18	15	7	------

[1]Errors due to lack of knowledge [2]Alternative conceptions [3]Scientifically-accepted strong conception [4]Scientifically-accepted weak conceptions [5]Not responded

in the independent variable do not affect the independent variable. Any response which corresponds to covariation between the two variables therefore belongs either to 'errors due to lack of knowledge' or to 'alternative conceptions' depending on the mean confidence level of the learners for the responses (as calculated from the 2nd tiers). Conversely, the responses which correspond to the non-covariation between the two variables belong either to 'scientifically-accepted strong conceptions' or to 'scientifically-accepted weak conceptions'.

The PrT analysis showed that the majority of both the EG and the CG learners believed that the two variables mentioned in each of the four questions in the questionnaire covariate. In reality, they do not covariate; that is, the image size/distance does not change with changes in variables such as the movement of the light source, observer and so on. This might imply that the traditional teaching module was not effective enough for the learners to think about a plausible reason why the two variables (in each of the situations corresponding to the four questions) do not covary.

It can also be deducted from the PrT analysis that not all the incorrect responses can be categorized as 'alternative conceptions' (Caleon & Subramaniam 2010a, 2010b). Some of the incorrect responses were identified as 'errors due to lack of knowledge' due to the low confidence level associated with such responses. The highest percentage occurrence of 'alternative conceptions' was observed for Question 3 for both the EG (58 %) and the CG (48 %). On the contrary, for the 'errors due to lack of knowledge' the highest occurrence was found to be associated with Question 4 for both the groups (50 % of the EG and 36 % of the CG). This shows that the learners from both the groups experienced similar conceptual difficulties when they appeared in the PrT.

The Extent to which the Ray Diagram Teaching Module Helped the Learners in enhancing their conceptual understanding of the image characteristics in plane mirror reflection

Table 2 displays the percentage occurrence of various types of responses of the participants in the PoT. It was noted from Table 2 that the percentage of the EG learners who held scientifically-accepted strong conceptions was very high for all the questions of the PoT, while it remained very low for the CG. This shows that the interactive ray-diagram teaching module was effective enough for the learners to think about plausible reasons why the image size/image distance do not covary when the variables such as observer position or light source position vary.

To determine if there was a significant difference between the performance of the two groups in the PrT and the PoT, statistical t-tests were performed. To perform the tests, the correct responses for the 1st tiers of the four relevant questions were allocated a score of 1 and the incorrect responses were allocated a score of 0. The results of the statistical tests are given in Table 3 and Table 4.

Table 2. Percentage occurrence of different types of participants' responses to the PoT

QN	Fractional occurrence of various types of responses (%)							
	The two variable covariate				The two variables do not covariate			
	[1]ELK		[2]AC		[3]SASC		[4]SAWC	
	EG (N=26)	CG (N=44)	EG (N=26)	CG (N=44)	EG (N=26)	CG (N=44)	EG (N=26)	CG (N=44)
1	4	27	19	50	73	14	4	9
2	4	18	15	59	65	11	15	11
3	8	36	27	39	62	16	4	9
4	12	23	8	27	73	30	8	20

[1]Errors due to lack of knowledge [2]Alternative conceptions [3]Scientifically-accepted strong conceptions [4]Scientifically-accepted weak conceptions

Table 3. Comparison of the PrT-PoT scores of the EG and the CG using independent samples t-test

Test	Group	N	Mean	Std. devn	df	t	Sig. (2 tailed) or p value
PrT	EG	26	0.69	0.838	68	-1.732	0.088
	CG	44	1.07	0.900			
PoT	EG	26	3.04	1.148	68	7.647	0.000
	CG	44	1.18	0.870			

Table 4. Comparison of the PrT-PoT scores of the EG and the CG using the independent samples t-test

Group	Test	N	Mean	Std. devn	df	t	Sig. (2 tailed) or p value
EG	PrT	26	0.69	0.838	25	-7.369	0.000
	PoT		3.04	1.148			
CG	PrT	44	1.07	0.900	43	-0.683	0.499
	PoT		1.18	0.870			

The results from Table 3 indicate that the performance of the two groups was almost similar in the PrT ($t = -1.732$, $p = 0.088$); however, the PoT results pointed to a significant difference between the performances of the two groups ($t = 7.647$, $p < 0.001$) in favour of the EG. This means that the interactive ray-diagram teaching module worked significantly better than the traditional teaching module in enhancing the learners' conceptual understanding of the image formation in a plane mirror. This is again evident from the results given in Table 4.

The results from Table 4 show that there was a significant increase in the performance of the EG during the PoT compared to their own performance during the PrT ($t = -7.369$, $p < .001$); however, there was no such significant difference between the performances in the PrT and the PoT for the CG ($t = -0.683$, $p = 0.499$). The designed ray diagram teaching module, therefore, worked significantly better than the traditional teaching method in developing the Grade 11 learners' conceptual understanding of the characteristics of the image formed in a plane mirror.

DISCUSSIONS AND CONCLUSIONS

The focus of this study was to test how the designed ray diagram teaching module was effective in enhancing Grade 11 South African learners' conceptual understanding of the characteristics of the image formed in a plane mirror. The study started with the identification of the prior knowledge of the sample, followed by the development of the ray diagram teaching module and then testing the effectiveness of the teaching module designed.

The analysis of the PrT showed that the responses of the majority of the participants were incorrect. The low value of the mean confidence level associated with most of such incorrect responses indicated that these responses should be considered as 'errors due to lack of knowledge' instead of 'alternative conceptions'. Only a few incorrect responses could be categorized as 'alternative conceptions'. The number of participants who held scientifically-accepted conceptions was very low and of these only a very few were found to have held scientifically-accepted, strong conceptions. Moreover, the traditional teaching module was not found to be effective in allowing the learners to think about a plausible reason why the two given independent variables do not covary (Koslowski 1996). This in turn resulted in most of the participants expecting a change in the variables (image size/distance) with change in some of the independent variables, such as observer position and position of the light source.

As revealed from the analysis of the PoT, the ray diagram teaching module designed and implemented was found to be effective in enhancing the Grade 11 learners' conceptual understanding of the image characteristics in plane mirror reflection ($p<0.001$). The teaching module resulted in a lower level of alternative conceptions and errors due to lack of knowledge among the EG learners whereas the CG learners, who were taught in the traditional teaching method, did not vary significantly in their performance in the PoT when compared with that in the PoT. It also led the EG learners to think about plausible reasons why the two given independent variables do not covary instead of associating a change in one variable with the change in an independent variable.

In the interactive ray diagram teaching module designed for the present study, the object was considered as an extended object. The purpose of using an extended object was to help the learners in identifying the relationship between object size and other factors such as image size, image position and observer position. Had a point object been used in these ray diagrams, the verification of the factors affecting the image size would not have been possible. In the traditional Physical Sciences textbooks and in the traditional teaching methods (according to the current South African high school Physical Sciences curriculum) used to teach plane mirror reflection, the properties of the image formed by a plane mirror are simply listed without presenting any scientific proof. Even though the learners are supposed to know how a correct ray diagram is to be drawn in this regard, the educators (and/or even the textbook writers) do not normally make an attempt to use these ray diagrams to prove different properties of the image formed in a plane mirror. Rather, it has been confined, as a small area, in which the properties of the image are simply listed. One then proceeds to the next optical phenomenon, 'refraction'.

The findings of this study have several potential implications for the teaching and learning of Physical Sciences, in general, and in particular, plane mirror reflection. First, the findings of this study with regard to the first sub-research question shed light on a large variety of errors due to lack of knowledge and alternative conceptions about the image characteristics in plane mirror reflection. These findings were found to agree with those from previous studies conducted in many parts of the world (Aydin 2012; Chen et al., 2002; Fetherstonhaugh, 1990; Galili & Hazan, 2000; Langley et al., 1997; Saxena 1991). This overwhelming number of alternative conceptions and errors due to lack of knowledge identified in the present study, along with those found in the literature, suggest that if prior knowledge of the learners regarding light and related phenomena are not identified and remedied, the teaching and learning process may be futile.

The interactive ray-diagram teaching module is unique in many aspects. Several studies investigated learners' conceptions/alternative conceptions regarding the area 'image formation in a plane mirror' (Goldberg & McDermott 1986; Galili & Hazan 2000; Chen et al. 2002), however, a teaching approach which included the ray diagram approach as in the present study could not be located in any of the previous studies. Moreover, the teaching module exposed the learners to experiences of investigating the effect of variables that do not covary with the outcome in addition to the variables that covary (Millar & Kanari 2004). The conclusions that were driven from the ray diagram tasks along with the sequentially-arranged questions designed to create cognitive conflict led the learners to create a stronger conceptual understanding of the characteristics of the image formed in a plane mirror.

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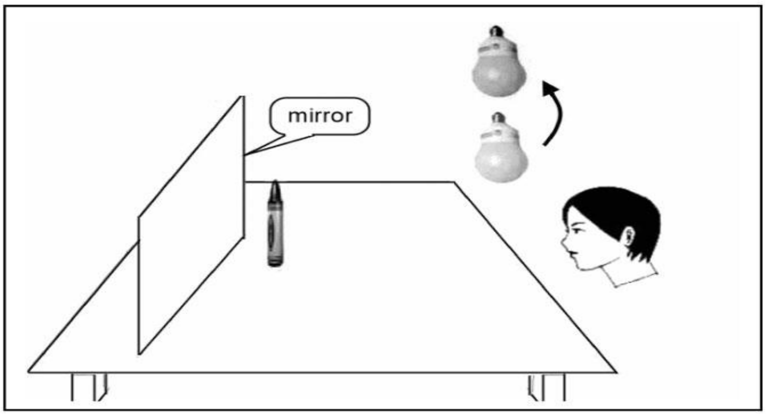
APPENDIX 1: FOUR-TIER QUESTIONNAIRE USED IN THE STUDY

Question 1

A plane mirror and a pencil are placed on a tabletop. An observer is looking into the mirror to observe the image of the pencil. The experiment is performed in a darkened room. A lamp is the only illuminant inside the room.



1.1. If the lamp is raised a little higher, what will happen to the location of the image of the pencil seen by the observer? Please check.

(A) It will move up.
(B) It will move down.
(C) It will stay in the same place*.
(D) ____________________

1.2. How sure are you of your answer?

A) Certain B) Almost certain C) Almost a guess D) A totally-guessed answer

Question 2

Regarding above question: If the lamp is raised a little higher, what will happen to the height of the image of the pencil as seen by the observer?

2.1. Please check:

(A) The image will become longer.
(B) The image will become shorter.
(C) The image will remain unchanged*.
(D) ____________________

2.2. How sure are you of your answer?

A) Certain B) Almost certain C) Almost a guess D) A totally-guessed answer

Question 3

Regarding the above question: The lamp stays fixed. The pencil is moved a little further from the mirror. What will happen to the height of the image of the pencil as seen by the observer?

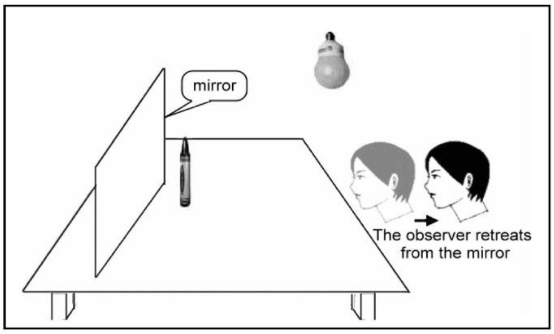
3.1. Please check:

(A) The image will become longer.
(B) The image will become shorter.
(C) The image will remain unchanged*.
(D) ____________________

3.2. How sure are you of your answer?

A) Certain B) Almost certain C) Almost a guess D) A totally-guessed answer

Question 4
Regarding the above question: Instead of moving the pencil, the observer moves a little further from the mirror while the lamp stays fixed. What will happen to the location of the image of the pencil as seen by the observer?



4.1. Please check:
(A) It will retreat from the mirror.
(B) It will approach the mirror.
(C) It will stay at the same location*.
(D) ____

4.2. How sure are you of your answer?
A) Certain B) Almost certain C) Almost a guess D) A totally-guessed answer

*Scientifically-acceptable answer