the CG remained very poor in both the PrT and the PoT as far as their Tier 3 responses are concerned.

8. Discussion of the findings

To evaluate the effectiveness of the designed teaching module in improving secondary school learners' conceptual understanding of the characteristics of the image formed by a convex lens, the current study incorporated a quasi-experimental research design. The two-tier optics diagnostic instrument used to collect the data before and after the implementation of the teaching module was designed in such a way as to collect both quantitative and qualitative data.

8.1. Discussion of the findings based on Tier 1 responses

The data collected from the participants' responses from the first tiers of the questionnaire suggest that the designed teaching module can be considered to be successful in enhancing learners' conceptual understanding regarding certain characteristics of the image formed by a convex/converging lens. The PrT results showed that the participants from both the EG and the CG had a variety of alternative conceptions about the concept of image formation by a convex lens. There were many learners who strongly believed that when a lens of larger diameter is used, the size of the image increases without a change in brightness. It was identified that a large majority of the learners from both groups strongly believed that without a screen, a convex lens cannot form an image. This finding was found to be consistent with that of [9] in which the respondents claimed that without a screen, the image cannot be seen.

The number of learners who strongly believed that the upper half of the image disappears when the upper half of the lens is covered was very high. This was also found in agreement with the previous studies [18] [19].

The findings reported in this study, combined with similar findings from the previous literature (as listed above) suggest that the image formation by a convex lens has been an area in which learners experience many conceptual difficulties. This has been so for many years and in many parts of the world.

The findings emerged from the PoT indicated that the first part of the teaching module was effective in correcting learners' alternative conceptions (Questions 1,2 and 4); however, the second part of the teaching module was not much effective in doing so. Several attempts ave been made by previous researchers to improve learners' conceptual understanding regarding the optical phenomena. Some of them have been collaborative learning mediated by multimedia, computer-assisted learning programs [9], converging lens simulations [12] and conceptual change texts [20].

Computer-assisted learning programs were used to enhance learners' conceptual understanding regarding image formation by convex lenses [9]. It was claimed that such an approach was particularly helpful to students who were comfortable with peer collaboration and were prepared to engage intensively in the learning tasks (and with each other) and tried to test out their ideas on the multimedia CAL programs. A similar approach was tried by [12] focusing on the same topic, that is, image formation by convex lenses. The authors integrated computer simulations into their instructional practices and examined the effects of different simulations on students' predictions and subsequent understanding of how images are formed by converging lenses, specifically in relation to outcomes when portions of the lens or the object are covered. Their results indicate that changing the number of rays (depicted in the lens simulations) had little effect on student predictions, but the point (s) of origin of the rays did influence student predictions.

To eliminate misconceptions about "propagation of light", "reflection of light" and "refraction of light", [20] prepared conceptual change texts. Through a quasi-experimental approach, the study showed that the conceptual change texts were more effective than the traditional method of instruction in eliminating learners' misconceptions about geometric optics.

The current study is in agreement with the previous literature in that conceptual change texts (similar to the sequentially-arranged worksheets in the present study) and practical experiments supported by such worksheets can work effectively in the remediation of alternative conceptions/misconceptions; however, the computer simulations did not work well in improving learners' conceptual understanding of the image formation by convex lenses.

7.2 Discussion of the findings based on Tier 3 responses

It is evident from the findings that the designed teaching module helped in developing a deep conceptual understanding amongst the EG learners. The learners did, not only present the correct answers to the questions of the PoT, but they also succeeded in justifying their answers using scientifically-acceptable arguments. Such an evaluation would not have been possible if the researchers had used multiple-choice questionnaire as the data collection instrument. Thus, apart from the increase in the number correct responses to different questions, more effective attempts at justifying those correct responses with scientifically-acceptable arguments were identified

in the PoT. The EG learners were therefore found to have gained a clearer conceptual understanding during the PoT than during the PrT.

Instead of giving pre-set options in the second tier as in the traditional two-tier multiple-choice type questionnaires [15], the learners were given the freedom to respond, in their own words to the reason tier of the 4ODI by answering an open-ended question. The advantage of using such an open-ended question in the 3rd tier is that the researchers did not delimit the conceptions of the learners by giving pre-set options. The use of the open-ended third tier could capture some of the advantages of the interviews because the learners had first been given an opportunity to present their answer or choose their answer from among the given options, and, secondly, to explain their answers in their own words. Thus, by the use of open-ended questions in the 3rd tier of each question of the 4ODI, and analysing qualitatively the learners' responses, the researchers could obtain an in-depth understanding of the learners concecptions/alternative conceptions.

The analysis of the learners' responses to the 3rd tiers of the PrT revealed that even though the learners' responses to some questions were incorrect, the arguments presented by some of these learners were scientifically acceptable. This might be an indication of the weak understanding of certain scientific concepts and of the lack of ability to apply the scientific conceptions correctly to different situations. Such situations were identified when the learners used scientifically-acceptable arguments to support the incorrect answers in Question 3 of the PrT. For example, a few learners from both the groups believed that when a larger lens is used, more light rays will be refracted. Even though the above argument is scientifically acceptable, it was noted that the learners failed to understand that it is the brightness of the image which is affected when more light rays are refracted and not the size of the image.

The explanations given by the participants indicated that some learners were confused about certain terminologies in optics, such as, reflection and refraction. Participants from both the groups were found to have used the terms reflection instead of refraction to explain the image formation by a convex lens; this happened more often during the PrT with the EG than during the PoT. This reminds educators the importance of implementing careful strategies in optics classrooms when dealing with closely-related science concepts such as reflection and refraction.

8. Conclusion

Our research paper explores South African Grade 11 learners' conceptual understanding of the image formation by a convex lens and then evaluates the effectiveness of the designed optics teaching module in improving learners' conceptual understanding of the topic. The use of 4ODI enabled the researchers to collect both the quantitative and qualitative data simultaneously. The mixed-method mode of data collection employed in the 4ODI (using the 1st tier as the quantitative and the 3rd tier as the qualitative) helped the researchers to go deeper into the learners' conceptual understanding of the image formation by a convex lens. Moreover, the quasi-experimental research design adopted in this study helped the researchers to compare the designed teaching module with the traditional teaching module by administering PrT and PoT to both the EG and the CG.

The findings that emerged from this study suggest that the participants had a variety of alternative conceptions regarding the characteristics of the image formed a convex lens. However, a variety of teaching strategies such as worksheets and laboratory experiment, when carefully integrated, could improve learners' conceptual understanding of converging lens image formation. The hands-on and real-life experience which made possible in the laboratory experiments still dominate over modern technologies such as computer simulations in bringing about meaningful conceptual change among science learners. The findings from this study thus point to the importance of integrating practical experiments properly in the science learning and teaching process. In short, the optics bench practical experiment supported by the sequentially-arranged worksheets was found to be more successful in improving learners' conceptual understanding of image formation by lenses than the converging lens computer simulation (even though it was also supported by worksheets of a similar nature).

9. References

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