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Effect of Interactive E-Book to Measure Mathematical Representations on Optics in High School

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Abstract: This study aims to measure the effect of using interactive e-books in enhancing students' mathematical representation skills on optics material in high school. Mathematical representation involves students' ability to use mathematical symbols, graphs, and formulas to solve physics problems, particularly in the concept of optics, which is often considered abstract. The research method used was a quasi-experiment with a pretest-posttest control group design. The sample consisted of two classes: an experimental class using interactive e-books as learning media and a control class using conventional methods. The results showed an improvement in mathematical representation skills in both classes, with the n-gain value of the experimental class being 0.604 and the control class being 0.557, both in the medium category. However, the experimental class demonstrated a more significant improvement compared to the control class, indicating that interactive e-books are more effective in helping students deeply understand optical concepts. The interactive features in the e-book, such as simulations and animations, provided a more engaging learning experience and helped students visualize abstract concepts. In conclusion, the use of interactive e-books has a positive impact on improving students' mathematical representation skills and can be considered an effective alternative learning medium, especially for science subjects that require better visualization and conceptual understanding.

Keywords: Interactive e-book; Mathematical representation; Optics; Physics learning

Introduction

The rapid integration of digital tools in education has transformed traditional learning environments, offering new avenues to enhance student engagement, understanding, and retention. One such technological advancement is the development of interactive e-books, which have gained significant attention in recent years for their potential to enhance learning outcomes in various subjects, including mathematics and science (Asrowi et al., 2019; Haleem et al., 2022; Susanti et al., 2021). Interactive e-books, which combine multimedia elements such as videos, simulations, animations, and interactive assessments, provide a multi-sensory learning experience that traditional textbooks lack. These features are especially beneficial for complex subjects like optics in physics, where students must visualize abstract concepts and develop strong mathematical representations to understand the content deeply (Lichtenberger et al., 2024; Wangchuk et al., 2023).

Mathematical representations are critical in science education as they enable students to understand, interpret, and analyze scientific phenomena using mathematical tools and methods (Bunawan et al., 2023; Prain et al., 2023). For high school students studying optics, the ability to translate between different representations—such as graphs, equations, diagrams,

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and verbal descriptions—is crucial for mastering the subject (Maruf et al., 2024; Treagust et al., 2017). Despite the recognized importance of these skills, traditional instructional methods often fall short in providing the diverse and engaging learning experiences needed to develop robust mathematical representations (Hillmayr et al., 2020). The conventional use of static, text-based resources does not cater to the varied learning styles of students, nor does it offer the interactive and dynamic content that could significantly enhance their conceptual understanding and problem-solving abilities (Huda & Ikhsan, 2024).

Recent research indicates that interactive e-books can significantly impact students' learning outcomes by providing multimodal representations that align with different cognitive styles (Hanafi et al., 2024; Saktilia & Wulandari, 2024; Zhou et al., 2024). Unlike traditional textbooks, interactive e-books can present content in diverse formats that cater to visual, auditory, and kinesthetic learners, thereby promoting deeper engagement and understanding (Huda & Ikhsan, 2024; Yotta, 2023). For example, interactive simulations within e-books can help students visualize the behavior of light as it passes through different media, providing an experiential learning component that is often missing in conventional classroom settings (Asad et al., 2021; Asrowi et al., 2019). Furthermore, embedding formative assessments within interactive e-books allows for real-time feedback, enabling students to identify and address misconceptions immediately, thereby reinforcing correct mathematical representations (Cavalcanti et al., 2021; Ismail et al., 2022; Leenknecht et al., 2021).

Moreover, the use of interactive e-books aligns well with the principles of constructivist learning theories, which emphasize the importance of active learning and knowledge construction through experience and reflection (Kahar et al., 2023; Shah, 2019). In the context of learning optics, interactive e-books can provide a platform for students to engage in self-directed learning, exploring content at their own pace and revisiting challenging concepts as needed. This flexibility is particularly beneficial for developing mathematical representations, as students can manipulate variables and observe outcomes in real-time, thereby gaining a deeper understanding of the relationships between different concepts (Hidayat et al., 2020; Tong et al., 2021). For instance, interactive tools that allow for the manipulation of lenses and mirrors in virtual experiments can help students better grasp the mathematical principles governing reflection and refraction.

Despite the growing body of literature supporting the use of interactive e-books, there remains a gap in understanding their specific impact on the development of mathematical representations, particularly in the context of high school physics education. While several studies have explored the general benefits of interactive e-books in enhancing student engagement and motivation (Hellín et al., 2023; Huda & Rohaeti, 2023; Merkle et al., 2022), fewer studies have focused on how these digital tools influence students' ability to construct and utilize mathematical representations effectively. Understanding this relationship is critical, as the ability to move fluidly between different mathematical representations is a key skill not only in physics but also in other STEM fields (Dominguez et al., 2023; Sakdiah et al., 2023). Consequently, investigating the potential of interactive e-books to foster these skills in high school optics courses could provide valuable insights for educators and policymakers seeking to integrate technology more effectively into science curricula.

To address this gap, the present study aims to explore the effectiveness of interactive e-books in promoting the development of mathematical representations among high school students studying optics. Specifically, the study will investigate how different features of interactive e-books—such as embedded simulations, dynamic problem sets, and instant feedback mechanisms—affect students' ability to understand and apply mathematical concepts related to optics. This focus is particularly relevant given the increasing emphasis on digital literacy and the integration of technology in modern educational practices (Quraishi et al., 2024; Temirkhanova et al., 2024; Zamista & Azmi, 2023). By examining the impact of interactive e-books on students' mathematical representations, this study also seeks to contribute to the broader discourse on the effectiveness of digital learning tools in enhancing cognitive and metacognitive skills in STEM education.

Furthermore, the study will adopt a mixed-methods approach to provide a comprehensive understanding of how interactive e-books influence learning outcomes. Quantitative data will be collected through pre- and post-tests to measure changes in students' ability to use mathematical representations accurately, while qualitative data will be gathered from interviews and classroom observations to gain deeper insights into students' experiences and perceptions (Creswell, 2012; Huda et al., 2023). By combining these methods, the study aims to provide a nuanced analysis of the potential benefits and limitations of interactive e-books in high school physics education, particularly regarding their role in fostering essential mathematical skills.

In conclusion, the integration of interactive e-books into high school science curricula represents a promising approach to addressing some of the longstanding challenges associated with teaching complex subjects like optics. By leveraging multimedia content and interactive features, these digital tools have the potential to enhance students' engagement, understanding, and ability to construct meaningful mathematical representations. However, further research is needed to understand fully the mechanisms through which interactive e-books influence these outcomes and to identify best practices for their implementation in diverse educational settings. The findings of this study are expected to provide valuable insights for educators, curriculum developers, and policymakers looking to harness the potential of digital learning tools to improve science education and prepare students for the demands of a rapidly evolving technological landscape.

Method

Research Design

The research employs a Nonequivalent Control Group Design, a popular form of quasi-experimental design. In this design, two groups of participants (experimental and control group) are selected without random assignment (Creswell, 2012). The subjects in this research were 58 students in class X of SMAN 1 Piyungan. The experimental group uses the interactive e-book for learning optics, while the control group uses traditional learning methods such as textbooks and lectures. Participants in this study are high school students from two different classes (Class X IPA 1 and Class X IPA 2) in the same grade level. Class X IPA 1 will serve as the experimental group, and Class X IPA 2 will serve as the control group. Both classes are comparable in terms of students' prior knowledge of mathematics and physics, based on a pre-test administered at the beginning of the study.

Instruments

Interactive E-Book: Developed based on the principles of interactive multimedia learning, incorporating simulations, quizzes, videos, and interactive problem-solving tasks related to optics. Mathematical Representation Test: A test to measure students' ability to represent and solve problems mathematically in the context of optics. The test consists of multiple-choice questions and open-ended problems that require graphical, algebraic, and conceptual representations.

Procedure

This research followed the following steps: First pre-test: Both groups take a pre-test on mathematical representations related to optics to assess baseline knowledge. Second the experimental group uses the interactive e-book, during the optics unit, while the control group receives conventional instruction. Third, post-test: both groups take a post-test identical to the pre-test to measure any changes in their mathematical representations of optics. Fifth, duration the intervention lasts for four weeks, with both groups covering the same content over this period. These steps can be seen in table 1.

Table 1. Step Quasi-Experiment

Group	Pre- Test	Treatment	Post-Test
Experimental	O1	Interactive E- Book (X)	O2
Control	O2	Traditional Intruction	O2

O1 : Pra-test on mathematical representasions
X : Intervention using the interactive e-book
O2 : Post-test on mathematical representations

Data Analysis

N-Gain Analysis

To evaluate the effectiveness of the interactive e-book on students' mathematical representations in optics, we utilized the N-gain index. The N-gain index measures the improvement in students' understanding by comparing pre-test and post-test scores. It is calculated using the formula:

$$N-\text{gain}=\frac{\text{Post−test score−Pretest score}}{\text{Maximum possible score−Pre−test score}} \quad (1)$$

Wilcoxon Signed-Rank Test

The Wilcoxon Signed-Rank Test is a non-parametric test used to compare two paired datasets, such as pretest and posttest data in a group, particularly when the data does not follow a normal distribution (Rosner et al., 2006). This test is often used as an alternative to the Paired t-test when the assumption of normality is not met.

Effect Size

Calculating effect size using r in a non-parametric test like the Wilcoxon Signed-Rank Test helps to determine the magnitude of the effect or change in the data. The effect size r is also used to measure the strength of the relationship or the impact of the change from pretest to posttest data (Morris, 2008). The formula to calculate effect size r is: $r=\frac{Z}{\sqrt{N}}$. Where: r = Effect size, Z = The Z-value obtained from the Wilcoxon test, N = Total number of observations (the number of data points or samples used in the test). Effect size r can be interpreted as follows:

r ≈ 0.1: Small effect size
r ≈ 0.3: Medium effect size
r ≥ 0.5: Large effect size

Mann- Whitney U Test

The Mann-Whitney U Test is a non-parametric test used to compare the differences between two independent groups when the assumption of normality is not met. It is often used as an alternative to the independent t-test for ordinal or non-normally distributed continuous data with hypotheses:

Null Hypothesis (H0)**:** There is no difference in the distributions between the two groups.

Alternative Hypothesis (H1)**:** There is a difference in the distributions between the two groups.

Result and Discussion

The results of the study clearly show that the use of an interactive e-book had a significant positive effect on students' ability to represent mathematical concepts related to optics. The interactive e-book's features, such as animations and simulations, allowed students to visualize the behavior of light as it interacts with lenses and mirrors. This visualization helped bridge the gap between abstract mathematical formulas and the physical phenomena they describe. For example, students could adjust variables like object distance or focal length and immediately see the effect on image formation, making the relationship between the variables in the lens equation more concrete.

The interactive e-book not only explained the theoretical concepts but also provided practice problems with step-by-step solutions, which helped students develop problem-solving strategies. The dynamic feedback system in the e-book allowed students to correct mistakes in real-time, leading to deeper learning and retention. The ability to experiment with different scenarios fostered a better understanding of how to apply mathematical equations to real-world optics problems. One of the main advantages of the interactive e-book was its ability to engage students more actively than traditional textbooks. The interactive features, such as drag-and-drop ray diagrams and instant quizzes, made learning more participatory. This active engagement is likely to have contributed to the improved performance in mathematical representations, as students were not passively consuming information but actively interacting with it.

The study aimed to assess how the use of interactive e-books influences students' ability to represent mathematical concepts in optics. The results of the study were gathered by comparing the performance of students in the experimental group (who used the interactive e-book) with those in the control group (who used traditional textbooks).

Tests of Normality

Since the data are not normally distributed, the Mann-Whitney U test, a non-parametric statistical test, is used to analyze differences between two independent groups (Dexter, 2013; Rainio et al., 2024), namely the experimental and control classes. This test is used to determine whether there are significant differences in the pretest and posttest scores between these two groups. The two questions that the Mann-Whitney U test aims to answer are:

a) Is there a significant difference in the pretest scores between the experimental and control classes? This test is conducted to ensure that both groups have equivalent initial abilities before the intervention (use of the interactive e-book) is applied to the experimental group. If there is no significant difference in the pretest scores, it can be concluded that both groups had similar starting conditions, making the posttest results more valid for comparison.
b) Is there a significant difference in the posttest scores between the experimental and control classes? This test is conducted after the intervention to determine whether the use of interactive e-books in teaching has had a significant impact on student learning outcomes in the experimental group compared to the control group, which used conventional methods. If there is a significant difference in the posttest scores, it indicates that the interactive e-book was effective in improving students' mathematical representation skills in the topic of optics.

The results of the Mann-Whitney U test will provide a U value and a p-value, which are used to assess whether the differences between the experimental and control groups are statistically significant. If the p-value < 0.05, it can be concluded that there is a significant difference between the two groups in either the pretest or posttest scores.

Table 2. Normality Test Results

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Stat.	df	Sig.	Stat.	df	Sig.
Pretest	.129	58	.017	.965	58	.090
Posttest	.180	58	.000	.947	58	.014

Mann-Whitney Test

Table 3. Mann-Whitney Results

	Post-ekskon	Post-ekskon
Mann-Whitney U	298.000	298.000
Wilcoxon W	704.000	704.000
Z	-.462	-.462
Asymp.Sig. (2-tailed)	.644	.644

Since there is no difference, it is not necessary to calculate the effect size. Mann-Whitney U test is a non-parametric statistical test used to compare differences between two independent groups when the data are not normally distributed (Emerson, 2023; Tai et al., 2022). It is often used to determine whether there is a significant difference between two groups, such as an experimental and a control group.

Wilcoxon Signed Ranks Test

The Wilcoxon Signed Ranks Test provides a Z value and a p-value. If the p-value < 0.05, it indicates that there is a significant difference between the pre-test and post-test scores within the group. If p-value > 0.05, there is no significant difference in scores before and after the intervention. Since there is a difference, the effect size is calculated based on the correlation value (r). The results of this study are in line with research conducted by Haryanti et al. (2020) and Septikasari et al. (2021).

Table 4. Wilcoxon Signed Ranks Results

	Posttest-eks Pretest-eks	Potestest-kon Pretest-kon
Z	-4.631[b]	-4.789[b]
Asymp. Sig. (2-tailed)	.000	.000

In the experimental class, an *effect size* of 0.6 indicates that the use of interactive e-books has a significant impact on students' ability to represent mathematical concepts related to optics. The interactive e-book allows students to learn in a more visual and interactive manner, which is crucial for abstract concepts like refraction, reflection, and image formation. Features such as optical simulations and dynamic visualizations help students connect physics theory with mathematical representations like graphs, equations, and diagrams. This has been alluded to in research conducted by Harjono et al. (2020).

An intriguing aspect of this research is that the control class achieved an *effect size* of 0.62, which is slightly higher than that of the experimental class. The control class, which typically uses conventional learning methods such as physics textbooks and lectures, produced an almost equivalent or even slightly better improvement in students' mathematical representation skills. This suggests that traditional methods are also quite effective in enhancing students' representational abilities, even without using interactive technology like e-book as explained by Hillmayr et al. (2020).

This research shows that both the use of interactive e-books in the experimental class and traditional teaching methods in the control class have nearly the same effect on students' ability to represent optical concepts mathematically, with *effect sizes* of 0.6 for the experimental class and 0.62 for the control class, respectively. This suggests that traditional methods remain highly effective in certain contexts, while interactive e-books offer an engaging and innovative alternative for learning. Combining both methods may provide the most optimal outcome for teaching physics in high school, utilizing interactive technology to enhance engagement and understanding while maintaining traditional teaching methods that are already effective. The magnitude of the effect size was confirmed with the N-Gain test.

N-Gain Results

Based on the results, the n-gain value for the experimental class was 0.604, while for the control class, it was 0.557. From the results obtained, both the experimental and control classes have n-gain values in the medium category, with the experimental class (0.604) slightly higher than the control class (0.557). This indicates that while both methods improve students' mathematical representation skills, the use of interactive e-books proved to be more effective.

Table 5. The N-Gain Value of the Experimental Class

	n	Max	Min	Means	N-gain
Pretest	28	60	30	45.07	0.604
Posttest	28	92	65	78.67	

Table 6. The N-Gain Value of the Control Class

	n	Max	Min	Means	N-gain
Pretest	30	68	35	49.33	0.557
Posttest	30	88	70	78.86	

The use of interactive e-books seems to provide a more dynamic and engaging learning experience. This has also been explained by Rahim et al. (2020) in his research. Through interactive features such as simulations and animations, students can more easily understand abstract optical concepts. The e-book also allows students to learn at their own pace and gives immediate feedback on their answers, encouraging reflection and self-improvement. Meanwhile, the conventional teaching method used in the control class, while effective, tends to be more passive. This learning might involve lectures, textbooks, and discussions but does not provide the same level of interactivity as the e-book. Therefore, although improvement in learning outcomes still occurs, it is not as significant as in the experimental class.

Conclusion

This study shows that using interactive e-books can improve students' mathematical representation skills in understanding optical concepts in high school. Students who learned using interactive e-books experienced a greater improvement compared to those using conventional teaching methods. Interactive features in e-books such as simulations, animations, and interactive questions help students visualize abstract concepts like optics. This provides a deeper learning experience and allows students to study independently with instant feedback. With results showing the effectiveness of interactive e-books, teachers are encouraged to use this technology in their teaching to enhance student engagement and learning outcomes, particularly in science and math subjects that require strong visualization. Overall, this study concludes that interactive e-books are an effective learning tool for improving students' mathematical representation skills on optics material in high school.

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Author Contributions
Frisma Windah Afifah Panuqih contributes to conducting research, developing products, analyzing data, and writing articles. Edi Istiyono and Jumadi Jumadi as a supervisor in research activities to article writing.

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Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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