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Efektivitas E-Book Fisika Terintegrasi Virtual Laboratory terhadap Kemampuan Multirepresentasi dan Pemahaman Konsep Mahasiswa

(Effectiveness of an Integrated Physics E-Book with Virtual Laboratory on Students' Multiple Representation Skills and Conceptual Understanding)

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Keywords: conceptual understanding; multi-representation; physics learning; virtual laboratory.

ABSTRACT. This research aims to determine the effectiveness of a physics e-book integrated with a virtual laboratory in improving students' multi-representation skills and conceptual understanding. The study applied a nonequivalent control-group design involving 27 second-semester physics education students. The experimental class (11 students) used a multi-representation e-book integrated with a virtual laboratory, while the control class (16 students) used only the multi-representation e-book. Pretest and posttest data were analyzed using normalized gain (N-gain) and Mann-Whitney tests. Results show that the experimental class achieved an N-gain of 0.23 for multi-representation (low category) and 0.48 for conceptual understanding (medium category). The control class achieved 0.19 (low) and 0.39 (medium), respectively. Statistical analysis revealed no significant differences between groups, likely due to the small sample size and the limited use of the virtual laboratory during lessons. Nevertheless, the integrated e-book showed higher average gains than the e-book alone. These findings suggest that integrating virtual laboratory components in e-books can enhance learning outcomes, though implementation factors must be optimized.

INTRODUCTION

Physics is a branch of science that studies the natural phenomena of matter and energy. To facilitate the explanation and analysis of these phenomena, physicists use various forms of representation, or multi-representation. This approach is essential for 21st-century learning. Proficiency in multi-representation can enhance conceptual understanding, reduce cognitive load during problem-solving, and improve overall cognitive abilities. It is a versatile tool that can be integrated effectively for students with low, medium, or high proficiency in physics. For prospective physics teachers, the ability to represent concepts in multiple forms is crucial, as the representation a teacher finds most suitable may not always be the one most easily understood by every student.

The reality is that prospective physics teachers' multi-representation ability and conceptual understanding [1] are low. This finding is reinforced by previous research indicating that the multi-representational skills and conceptual understanding of physics students at Khairun University are low. The use of physics e-books provides a supportive learning solution for the use of science and technology. However, the use of e-books has not significantly improved multi-representational skills or conceptual understanding. Therefore, the researcher aims to implement an e-book that integrates a virtual laboratory, enabling access anytime, anywhere, and enabling 21st-century learning. Virtual laboratories complement e-books because they have been proven to enhance creativity, problem-solving skills, and conceptual understanding.

The reality is that prospective physics teachers' multi-representation ability and conceptual understanding [2][3] are low. Previous research confirms this finding, showing low multi-representational skills and conceptual knowledge among physics students at Khairun University. The use of physics e-books provides a supportive learning solution for the use of science and technology. However, the use of e-books has not significantly improved multi-representational skills or conceptual understanding. Therefore, the researcher aims to implement an e-book that integrates a virtual laboratory, enabling access anytime, anywhere, and enabling 21st-century learning. Virtual laboratories complement e-books because they have been proven to enhance creativity, problem-solving skills, and conceptual understanding.

RESEARCH METHOD

This study uses a *nonequivalent control-group design*, involving 27 second-semester students from the Physics Education Study Program at Khairun University for the 2024/2025 academic year. In this study, which employs a just comparable control-group design, 27 second-semester students from Khairun University's 2024–2025 academic year Physics Education Study Program participated. The experimental class (n=11) used a multi-representational e-book integrated with a virtual laboratory, while the control class (n=16) used a multi-representational e-book without a virtual lab. The instruments used were nine reasoning multiple-choice questions (for multi-representation) and 10 concept comprehension questions, adapted from the R-FCI and presented via Google Forms. Data analysis includes calculating N-gain and performing the Mann-Whitney test with a significance level of 5%.

RESULT AND DISCUSSION

This study uses a *nonequivalent control-group design*, involving 27 second-semester students from the Physics Education Study Program at Khairun University for the 2024/2025 academic year. In this study, which employs a just comparable control-group design, 27 second-semester students from Khairun University's 2024–2025 academic year Physics Education Study Program participated. The experimental class (n=11) used a multi-representational e-book integrated with a virtual laboratory, while the control class (n=16) used a multi-representational e-book without a virtual lab. The instruments used were nine reasoning multiple-choice questions (for multi-representation) and 10 concept comprehension questions, adapted from the R-FCI and presented via Google Forms. Data analysis includes calculating N-gain and performing the Mann-Whitney test with a significance level of 5%.

1. Multi-representation Ability

The results of the pretest and post-test on students' multi-representation ability are presented in the form of a diagram in Figure 1 below.

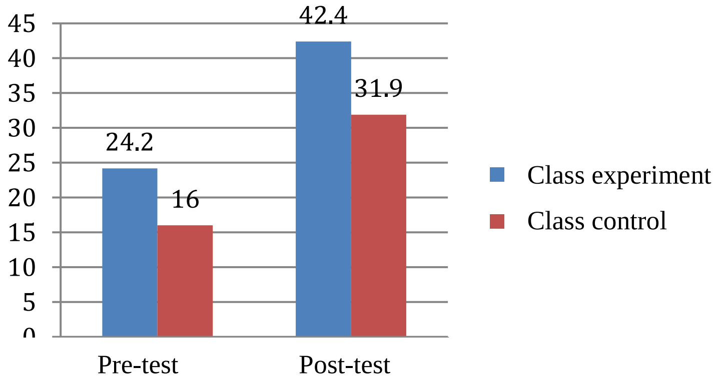

Figure 1. Pretest and Post-test Scores of Students on Multi-representation (MR) Ability

The diagram in Figure 1 above shows that students' multi-representational ability in the Physics Education study program at Khairun University, in the experimental class, has increased. The average test results after the learning process, which used an integrated physics e-book with a virtual laboratory (post-test), are 42.4, indicating an increase from the pre-test score of 24.2. The multi-representational ability of physics students in the control class increased, as evidenced by the average pre-test score of 16 and the post-test score of 31.9. The increase in scores from pre-test to post-test was higher in the experimental class than in the control class, at 18.2.

To test the significance of the improvement in physics students' multi-representational abilities, a Mann-Whitney U test for independent samples is required. This non-parametric test was chosen considering the small sample size. The results are shown in Table 1.

Table 1. Mann-Whitney test results for data gain in multi-representation ability

Data Source (Gain)	**Class**	**Sig.**	**Description**
Multi-representation ability	Experimen	1,000	There was no significant difference in improvement.
	Control		

Based on the results of the Mann-Whitney test, the multi-representation ability of Khairun University Physics students in both the experimental and control classes, using SPSS 24, showed that Sig. (2-tailed) The value was greater than the significance level alpha (1.000 > 0.05), so it can be concluded that there was no significant difference in improvement between the experimental and control classes. This result is supported by the pretest and post-test data analysis, which shows that the improvement difference between the two classes is indeed minimal. This is due to two factors: an insufficient sample size and the use of the virtual laboratory LKM in only a small portion of the learning process in the experimental class. The sample sizes in each experimental group are tiny, with fewer than 30 per group. Remember that 30 is a common magic number for the number of participants per group, as it affects variability and differences between the two groups [4]. The variability between the experimental and control groups in this study is considerable, as evidenced by the small standard deviation values. In the experimental class, the multi-representation ability standard deviation is 0.12, which is lower than the group's average of 0.19. Similarly, in the control class, the standard deviation is 0.20, which is lower than the group's average of 0.23. The best measure of data dispersion in a sample is the standard deviation, which indicates how close the data are to the mean. Therefore, the sample dispersion in this study was poor, leading to negative findings.

The use of the virtual laboratory LKM in a small portion of the learning process in the experimental class significantly impacts the success of the research. The LKM virtual laboratory is used by students using the PhET application. This study uses PhET, an interactive simulation for science and mathematics learning, to enhance physics learning. This simulation can be used on computer devices or smartphones. Using PhET and the virtual laboratory LKM for two meetings with something new requires adaptation and adjustment in their use, resulting in less-than-optimal outcomes. Next, to assess the magnitude of the increase in students' multi-representation abilities, we examined the results of the normalized N-gain test, shown in Figure 2.

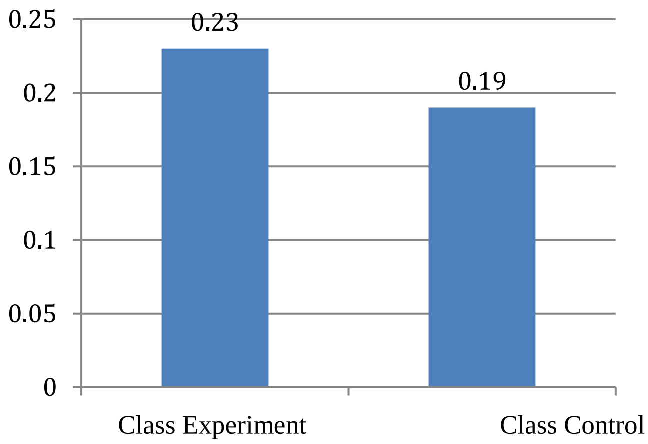

Figure 2. N-gain Value of Students' Multi-representational Ability

The N-gain results shown in Figure 2 indicate that the multirepresentational ability of Unkhair Physics students in both the experimental and control classes has increased. The increase for the experimental class is 0.23, which falls into the low category, and for the control class, it is 0.19, also in the low category. Multi-representational ability is the ability to apply multiple representations to physics concepts. The multirepresentational ability of physics students increased after learning using a virtual laboratory-integrated physics ebook. This is because the virtual laboratory-integrated physics ebook provides various representations such as text, images, diagrams, and equations. The virtual laboratory in the physics ebook consists of experimental activities using the PhET application, supported by the LKM (Student Worksheet). Students learn physics concepts as they complete the LKM using the PhET application. The presence of a virtual laboratory in the physics ebook can facilitate students' learning of physics concepts by providing experimental activities to test hypotheses and develop theories virtually. Thus, this material has a positive impact on students. This aligns with the findings in [5] that multi-representation in learning materials can have a positive effect on students. If only one representation is used, the ability to use multiple representations does not improve students' understanding of physics concepts. For example, if students receive only mathematical concepts, they will struggle to represent them graphically, verbally, and visually.

The ability to engage in multirepresentation can support students' cognitive processes, reduce the likelihood of misinterpretation, and deepen their understanding of concepts [6]. This representational ability is supported by Johnson-Laird's cognitive framework theory, which outlines three main categories of mental representations. First, the mental representation of propositions consists of a series of symbols, such as equations, formulas, numbers, and definitions of abstract and meaningful syntactic structures. Perception, imagination, and analogical representations build two tentative mental models, whose results can be refined by existing knowledge. The third mental image is based on real-world observation and experience, and is a coherent, unified representation of events or objects from the observer's perspective [7].

2. Understanding of Concepts

Data on prospective physics teacher students' understanding of Newton's laws were collected using 10 concept understanding questions via a Google Form, making it more suitable for current educational technology developments. The results of the pretest and post-test on students' conceptual understanding are presented in the diagram in Figure 3 below.

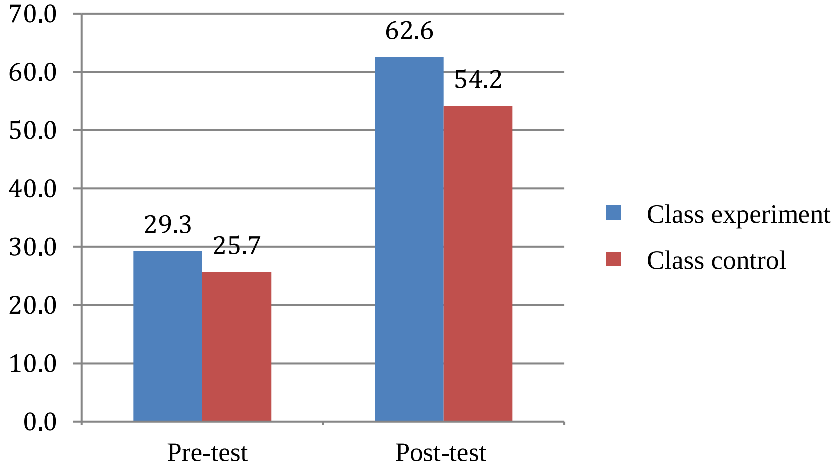

Figure 3. Pre-test and Post-test Scores of Students' Conceptual Understanding

The diagram in Figure 3 above shows that the conceptual understanding of Khairun University Physics students in the control class has improved. The average test results after the learning process using a physics e-book (71.7) indicate an increase compared to the pretest scores (35.3). The average pretest score (54.9) and post-test score (94.6) show that the conceptual understanding of physics students in the experimental class using a physics e-book integrated with a virtual laboratory increased. Next, researchers need to conduct a Mann-Whitney U test for independent samples to assess the significance of the increase in conceptual understanding. This non-parametric test was chosen considering the small sample size. The results are shown in Table 2.

Table 2. Results of the Mann-Whitney test analysis

Data Source (Gain)	**Class**	**Sig.**	**Description**
Conceptual understanding	Experimen	0,212	There was no significant difference in improvement.
	Control		

The results of the Mann-Whitney U test analysis of the concept-understanding data for Khairun University physics students in both the experimental and control classes, using SPSS 24, show that Sig. (2-tailed) value is greater than the significance level alpha, or 0.212 > 0.05. Therefore, the improvement in students' concept understanding is not significant.

Although in theory, the integrated Physics e-book with a virtual laboratory can influence students' multi-representational abilities and conceptual understanding, in practice, the virtual laboratory was used only in a small portion of the learning process in the experimental class. Therefore, while it was initially hoped that students' multi-representation abilities and conceptual understanding would increase significantly and show a significant difference, in reality, there was only a slight and insignificant improvement. Seeing the research results that did not align with the theoretical review, the researcher is confident that the theoretical review they conducted was correct. This is evident from the average scores of students' multi-representational ability and conceptual understanding using the virtual laboratory-integrated Physics e-book, which were higher than those of students who studied with the Physics e-book, specifically 10.5 points higher in multi-representational ability and 8.4 points higher in conceptual understanding. However, during the research implementation, the researcher imposed a small sample size due to the actual small number of students and the researcher's inaccurate provision of virtual laboratory-integrated physics e-books, resulting in negative findings that did not align with the research hypothesis. Next, to assess the extent of the students' conceptual understanding improvement, we examined the results of the normalized N-gain test, shown in Figure 4

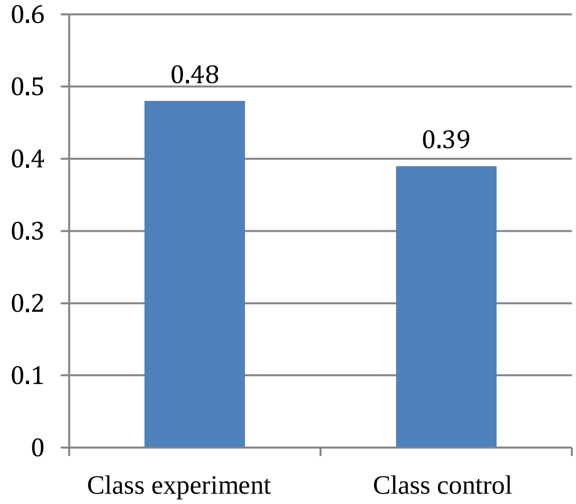

Figure 4. N-gain Value of Students' Conceptual Understanding

N-gain Value of Students' Conceptual Understanding. Based on the N-gain results shown in Figure 3, the conceptual understanding of prospective physics teacher students in both the experimental and control classes increased equally. The increase for the experimental class was 0.48, which falls into the moderate category, and for the control class, it was 0.39, also in the mild category.

The improvement in these physics students' understanding of the concepts is influenced by the physics e-book on Newton's laws. Student understanding of physics concepts can be enhanced by using multiple representations. This physics e-book is developed with various representations, including images, equations, diagrams, and text. This interpretation plays a significant role in physics and physics education, as it can substantially facilitate learning and understanding [8]. This aligns with the findings of [9], [10], [11], [12], and [13] that understanding of physics concepts can improve after learning using a multi-representational approach. The availability of multi-representational e-books that provide diagrammatic representations can help students easily understand and analyse physics problems, thereby improving the accuracy of their answers [14].

Additionally, the combination of concepts and symbolic reasoning in e-books can aid physics students' learning [15]. In particle dynamics, vectors are central to representation, typically used in three forms: algebraic representation as formulae, visual representation in vector plane diagrams, and graphical representation. Algebraic representations are useful for quantitative calculations, while vector plane diagrams help illustrate the components of a force in a plane. These two things complement each other: students first attempt to extract information from vector representations into algebraic representations, which is then followed by understanding physics concepts [16]. Image representation can visualize data, reducing working memory load during data analysis and helping students understand physics concepts [17].

Additionally, through a virtual laboratory, students can learn physics concepts through experimental activities to test hypotheses and develop theories. Experimental activities provide students with the opportunity to discover concepts through observation, creativity, and problem-solving [18]. This aligns with previous research, which found that virtual laboratories, as a supplement to e-books, are proven to improve multi-representational skills, creativity, problem-solving abilities, and conceptual understanding [19]; [20]; [21].

CONCLUSION

Analyze physics problems. The virtual laboratory-integrated physics e-book can improve prospective physics teacher students' multi-representation ability and conceptual understanding, although the improvement is not statistically significant. The small sample size and the limitations of the virtual laboratory implementation influence these results. The use of this integrated e-book has the potential to be more optimal if applied consistently and intensively.

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