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THE EFFECT OF USING PHET APPLICATIONS IN PJBL-BASED E-LKPD ON IMPROVING LEARNING OUTCOMES OF GRADE IV STUDENTS IN SCIENCE LEARNING AT STATE ELEMENTARY SCHOOL 14 BANDA ACEH

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ABSTRACT

Elementary education in Indonesia plays a crucial role in establishing the foundation of knowledge, skills, and attitudes that students will use throughout their lives. Therefore, innovative learning strategies are needed to improve students' understanding of difficult concepts, particularly in Natural and Social Sciences learning. This study aims to investigate the effect of using Electronic Student Worksheets based on Project-Based Learning (PjBL) integrated with the PhET application on the learning outcomes of fourth-grade students at State Elementary School 14 Banda Aceh. The research method employed an experimental approach with a pretest-posttest control group design. Tests were administered to both the experimental and control groups. The findings showed a significant increase in the experimental group compared to the control group. The average pretest score of the experimental group was 70, which increased to 94 in the posttest, resulting in a 24-point improvement. This significant gain indicates that integrating PjBL-based E-LKPD with the PhET application is effective in helping students comprehend abstract concepts through engaging interactive simulations. Furthermore, students became more active, motivated, and enthusiastic in participating in the learning process. These findings demonstrate that the integration of technology into IPAS learning can provide positive impacts not only on students' learning outcomes but also on their engagement and motivation. Therefore, the integration of technology, particularly the PhET application, is highly recommended to improve the quality of elementary education in Indonesia.

Keywords: *PhET Application; E-LKPD Based on Project Based Learning; Student Learning Outcomes*

INTRODUCTION

Education in Indonesia, especially at the elementary school level, plays a very important role in forming the foundation of knowledge and skills that students will use throughout their lives. Elementary education is the first stage where students begin to build not only cognitive abilities but also attitudes, values, and essential skills that will support lifelong learning (Alawiyah & Fajriyah, 2022). Among various subjects, Natural and Social Sciences, especially science learning, is one of the main focuses in the Indonesian curriculum. The aim of science learning is not only to provide basic knowledge that can be applied in everyday life but also to train students' abilities in critical thinking, creativity, collaboration, and communication which are highly needed

in the 21st century (P. Lestari & Wulandari, 2021). However, in practice, science learning in elementary schools often faces challenges. Students frequently perceive science as a difficult subject, especially when it deals with abstract concepts such as force, energy, and changes in matter. This perception leads to decreased motivation and engagement in learning, resulting in suboptimal academic achievement (Mulyani & Setiawan, 2023). Therefore, educators need to develop more innovative and effective approaches to make science learning meaningful and enjoyable. One approach that has been widely implemented in recent years is Project-Based Learning (PjBL) (Arifin & Saputra, 2023).

PjBL is a student-centered learning model that emphasizes active involvement in projects that are directly related to real-life contexts. Through PjBL, students are encouraged to explore, investigate, and produce project outputs collaboratively. This process enables the development of problem-solving skills, creativity, collaboration, and communication (S. Astuti & Ningsih, 2019). In Indonesia, several studies have reported the effectiveness of PjBL in improving students' conceptual understanding and learning motivation (Firmansyah & Lestari, 2022). Hidayat & Rahmawati (2021) found that PjBL strengthens students' ability to link theory with practice, particularly in science experiments. Similarly, Iskandar (2020) explained that the project-based approach provides opportunities for students to enhance higher-order thinking skills (HOTS) because they are challenged to analyze problems, generate hypotheses, and evaluate results. Furthermore, PjBL also contributes to the development of collaborative attitudes among students. Research by Ningsih & Handayani (2019) shows that students who are involved in project-based learning demonstrate stronger teamwork and communication skills compared to those in conventional classrooms. In addition, PjBL helps reduce the cognitive load when learning abstract science materials because students are guided to construct concepts through practical experiences (Pratama & Anwar, 2020). Thus, PjBL not only increases student engagement but also improves the quality of their learning outcomes.

In line with the pedagogical shift toward student-centered learning, the rapid advancement of technology in education also provides new opportunities to enhance science instruction. Digital learning tools, particularly interactive simulations, are increasingly being integrated into classrooms to make science learning more engaging and accessible. Technology can help students understand abstract material by visualizing scientific phenomena in an interactive way (Rahman & Sari, 2021). One popular technological tool in science learning is the PhET (Physics Education Technology) simulation developed by the University of Colorado Boulder. PhET provides virtual laboratories where students can conduct experiments, manipulate variables, and directly observe the impact of changes in real-time (Santoso & Widodo, 2022). This application has been widely adopted in Indonesia as a supplementary tool in science learning. Research by Siregar & Lubis (2020) shows that the use of PhET can significantly

improve students' understanding of scientific concepts because it transforms abstract theory into visible and interactive phenomena. In addition, Susanti & Putra (2021) highlighted that digital simulations like PhET increase student engagement and concentration, Wibowo & Prasetyo (2019) reported that students achieve better learning outcomes when PhET is integrated into the curriculum. Similarly, Andini (2021) emphasized that PhET supports the creation of student-centered classrooms, while Haryanto (2023) found that simulation-based learning helps foster a more enjoyable and motivating atmosphere.

The integration of PjBL with technology has the potential to produce even greater impacts on learning. One promising strategy is the development of PjBL-based electronic student worksheets (E-LKPD) that are integrated with PhET simulations. E-LKPD provides structured guidance for students to conduct projects, while PhET simulations supply the interactive environment needed to deepen conceptual understanding. According to Putra, (2021), PjBL-based E-LKPD helps students stay focused and organized in conducting projects, ensuring that learning objectives are achieved effectively. Utami (2021) further argued that E-LKPD encourages independent learning and project management skills, while Kurniawan (2022) found that the use of digital worksheets combined with simulations enhances students' critical thinking abilities. Meanwhile, Rahmadani (2024) discovered that the integration of E-LKPD increased student participation and created a more collaborative classroom atmosphere. In Indonesia, the application of PjBL-based E-LKPD supported by PhET has become an innovative breakthrough, especially in addressing the challenges of science learning in elementary schools. This model combines the advantages of project-based learning with technological innovation, thereby not only improving students' academic achievement but also preparing them with 21st-century skills. Sari (2020) emphasized that integrating digital media into classroom projects can foster meaningful learning experiences. Similarly, Utami (2022) argued that technology-based science learning creates more interactive and dynamic class environments. In addition, Andini (2020) highlighted that the use of digital tools supports inclusivity by accommodating students' diverse learning styles.

Based on these studies, it is evident that integrating PjBL and technology is a promising approach to overcome difficulties in science learning. However, empirical research specifically focused on the combination of PjBL-based E-LKPD and PhET simulations at the elementary level is still limited, particularly in the Indonesian context. This study, therefore, aims to test the effectiveness of using PjBL-based E-LKPD integrated with the PhET application in science learning for grade IV students at State Elementary School 14 Banda Aceh. The expected outcome of this study is an improvement in students' conceptual understanding and motivation in learning science. Furthermore, this research is expected to contribute to the development of more

effective and innovative teaching methods that align with current educational technology advancements. Ultimately, the findings of this study are anticipated to provide valuable insights into how technology can be systematically integrated into project-based learning to create meaningful, enjoyable, and future-oriented learning experiences for elementary school students.

In addition, the results of this research are also expected to serve as a reference for teachers, policymakers, and curriculum developers in designing learning strategies that not only meet academic targets but also respond to the demands of the 21st century. With the rapid growth of digital tools, including simulation-based applications, it becomes increasingly important for educational institutions to adopt innovative practices that can bridge the gap between traditional teaching and modern learning needs. By integrating PjBL-based E-LKPD and PhET, teachers can foster a more dynamic classroom environment where students are empowered to explore, experiment, and reflect critically on their learning experiences. Such practices are crucial to nurturing scientific literacy from an early stage, thereby equipping students with the ability to analyze problems systematically, collaborate effectively with peers, and communicate their findings with confidence.

Moreover, this study underscores the broader significance of educational innovation in shaping the future of learning in Indonesia. The integration of PjBL and PhET is not merely a technical enhancement but a strategic effort to transform learning culture at the elementary school level. By moving away from rote memorization toward interactive and inquiry-based experiences, students can develop both cognitive and socio-emotional competencies essential for lifelong success. The results of this study are thus expected to inform future research and practical applications in other schools and regions, ensuring that the benefits of technological integration in education can be scaled and sustained. In the long term, the adoption of such approaches has the potential to raise the overall quality of science education in Indonesia, foster student-centered classrooms, and prepare young learners to become active, creative, and resilient participants in a knowledge-driven society.

RESEARCH METHOD

This study uses a quantitative approach with a quasi-experimental design of one-group pretest-posttest design to test the effectiveness of using E-LKPD based on Project-Based Learning (PjBL) that integrates the PhET application on improving the learning outcomes of fourth-grade students in Natural and Social Sciences learning at Elementary School 14 Banda Aceh. The population of the study was fourth-grade students at the school, with the research sample taken by purposive sampling from one class consisting of 25 students. The instruments used in this study included learning outcome tests (pretest and posttest), observation sheets to observe the learning process, and student

response questionnaires to determine their perceptions of the use of this method. Similar designs have also been applied in several studies to evaluate the effectiveness of innovative learning models in elementary schools (L. Astuti, 2022).

The research procedure began with a pretest to measure students' initial abilities, followed by learning using E-LKPD based on PjBL and the PhET application. After the learning was completed, a posttest was given to measure student learning outcomes after the treatment. In addition, observations were made on student involvement during the learning process and students filled out questionnaires to determine their responses to the use of the method. This procedure is in line with the recommendations of recent studies that highlight the importance of combining quantitative tests with observation data in order to obtain comprehensive results (Fadilah, 2021). Other studies also emphasize that triangulation of test, observation, and questionnaire data strengthens the validity of classroom research (A. Haryanto, 2021).

The data obtained will be analyzed using a paired sample t-test to determine the differences in learning outcomes before and after learning, while observation and questionnaire data will be analyzed descriptively to describe student involvement and perceptions. The use of mixed analysis like this is considered more effective in capturing not only cognitive improvement but also students' affective and behavioral responses during learning. In addition, the use of quasi-experimental methods has been proven effective in measuring the impact of innovative learning models in science subjects. Recent research also confirms that the integration of digital-based applications such as PhET provides significant positive effects on student learning outcomes (Indrawan, 2022).

RESULTS AND DISCUSSION

Result

This study was conducted to evaluate the impact of using E-LKPD based on Project-Based Learning (PjBL) that integrates PhET application on student learning outcomes in grade IV of Elementary School 14 Banda Aceh in Natural and Social Sciences subjects. This study involved 25 students who were divided into two groups: an experimental group using E-LKPD based on PjBL and PhET application, and a control group using conventional learning methods.

a. Improving Student Learning Outcomes

The results of the pretest and posttest analysis showed a significant increase in the experimental group. In the pretest, the average student score was 70, but after implementing PjBL-based E-LKPD with the PhET application, the average posttest score increased to 94. The increase in the average score was 24 points, which shows the effectiveness of using the PhET application in improving understanding of the concept

of science and science. The paired t-test conducted to test the significance of the difference in pretest and posttest scores produced a p-value of 0.000 ($p < 0.05$), which indicates that the difference between the pretest and posttest is statistically significant. The following is a comparison of the results of the students' pretest and posttest:

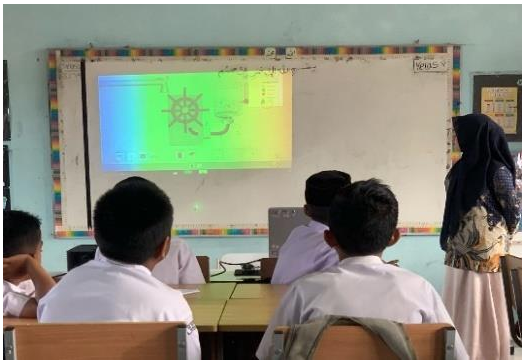
Table 1. Comparison of Pretest and Posttest Results

Test Type	**Average Score**	**Improvement (%)**
Pretest	70	-
Posttest	94	24

These improvements indicate that students are learning better, and the PhET application is helping them understand more complex concepts in science, such as energy, forces, and changes in matter. Beyond numerical improvement, the data also highlight a transformation in students' ability to apply knowledge rather than simply memorizing facts. Students who previously struggled with abstract scientific principles became more capable of explaining relationships between variables, identifying cause-and-effect patterns, and using evidence from virtual experiments to support their reasoning. Furthermore, the increased posttest results signify that integrating simulations into project-based tasks gives students multiple learning pathways. They do not only rely on teacher explanations but also engage actively in inquiry and experimentation. This multidimensional approach reduces misconceptions, reinforces key concepts, and promotes deeper understanding, which is often a challenge in conventional classroom practices.

b. Student Engagement and Perception

One indicator of successful learning is the level of student involvement in the learning process. Based on observations during the learning process in grade IV of Elementary School 14 Banda Aceh, students were very enthusiastic about using the PhET application. They actively participated in virtual experiments, simulated various scientific phenomena, and discussed with their friends to find solutions to problems. In terms of student responses, the questionnaire distributed after learning showed that most students felt more interested and found it easier to understand the material being taught.



Picture 1. students are listening to the phet application

The following are the results of the student response questionnaire regarding the use of the PhET application in learning:

Table 1. Results of Student Response Questionnaire on the Use of PhET Applications

Response Aspect	Percentage of Students (%)
Interest in learning	88%
Learning becomes more interesting	84%
Learning is easier to understand	80%
Desire to learn more	75%

The data indicate that the majority of students expressed positive perceptions of the use of PhET in their learning. A remarkable 88% reported increased interest in learning, suggesting that technology-based activities sustain attention better than traditional approaches. Similarly, 84% of students believed learning became more engaging, and 80% found the subject matter easier to comprehend. The fact that 75% wanted to learn more reflects that this approach not only enhances immediate learning outcomes but also builds intrinsic motivation for continuous exploration of science. Additionally, observations showed that students demonstrated higher levels of peer interaction during activities. They frequently collaborated to interpret results, compared observations, and debated hypotheses, which are all signs of active cognitive and social engagement. This change in behavior illustrates that the combination of project-based learning and simulations shifts the classroom culture from passive listening to active participation.

c. Understanding of Science Concepts

The main objective of this study was to determine the extent to which the use of the PhET application can help students understand science concepts that were previously considered difficult to understand. Based on the results of observations and

pretest-posttest, students involved in PjBL-based learning with the PhET application showed a significant increase in their understanding of several key concepts in science, such as force, energy, and changes in matter.

The following is an increase in students' understanding of several basic concepts in science after participating in learning with the PhET application:

Table 2. Improving Students' Understanding of Science Concepts

Science Concept	Before Learning (%)	After Learning (%)
Force	72%	91%
Energy	71%	89%
Changes in Matter	73%	92%

The improvement shown in the table reflects not only higher scores but also deeper conceptual mastery. Students who initially viewed scientific concepts as abstract and disconnected from their everyday lives began to recognize practical applications through simulations. For example, when exploring the concept of force, students could manipulate virtual objects, vary applied pressure, and observe direct effects on motion. Similarly, the energy concept became clearer as students simulated energy transfer in different scenarios, reinforcing the principle of conservation of energy. Another important finding is that the PhET application provided a safe and repeatable environment for experimentation. Unlike physical experiments that may require special equipment or pose safety risks, virtual experiments allowed unlimited exploration with immediate feedback. This accessibility encouraged students to test multiple scenarios, compare outcomes, and learn from mistakes without fear of failure. Consequently, the learning process became more dynamic and student-centered, leading to sustainable comprehension of complex topics.

Picture 2. students carry out teacher assignments

d. Evaluation of Technology Implementation

This study shows that the use of PJBL-based E-LKPD integrating the PhET application has succeeded in improving learning outcomes and understanding of science concepts of students in grade IV of Elementary School 14 Banda Aceh. The use of the PhET application not only improves understanding, but also makes learning more interesting and interactive for students. D. Lestari (2020) shows that the application of technology in science learning can enrich students' learning experiences and help them understand the material in a more enjoyable way. Students who use the PhET application not only learn science concepts through theoretical explanations, but can also conduct virtual experiments that illustrate scientific phenomena, giving them the opportunity to learn more deeply and comprehensively. This supports the findings of Maulana (2021), who found that application-based learning such as PhET can improve students' understanding of complex science concepts.

Discussion

The results of this study provide strong evidence that the use of E-LKPD based on Project-Based Learning (PjBL) integrating the PhET application can significantly improve student learning outcomes in Natural and Social Sciences subjects in grade IV of State Elementary School 14 Banda Aceh. These results are in line with research conducted by Ningsih (2023) which shows that the PhET application helps students understand difficult concepts through interactive simulations. The average increase in students' scores of 24 points shows that the PhET application not only improves students' understanding of the material but also helps them connect theory with real practice in experiments. By using the PhET application, students can conduct virtual experiments on scientific phenomena, allowing them to more easily understand principles that are difficult to understand if only explained theoretically. Research by Putri (2022) also emphasized that integrating digital simulations with PjBL strengthens students' ability to connect abstract science theory with observable practice, especially in elementary education.

Another important finding of this study is that the learning atmosphere became more engaging and collaborative. The majority of students reported enjoying the lessons because they could experiment virtually, test their own ideas, and compare results with their peers. This resonates with the findings of S. Rahmadani (2020), who argued that technology-assisted PjBL enhances not only comprehension but also collaborative skills among students. Collaborative learning is essential in elementary schools since it trains children to share ideas, listen to others, and work toward a common goal. In this study, the integration of PhET within PjBL helped students engage in discussions, develop hypotheses, and test them, which reflects the essence of scientific inquiry.,The level of student engagement in learning also increased significantly.

For example, 88% of students felt more interested in learning after using the PhET application. This shows that the PhET application can increase student motivation in learning. Research by Sari (2021) shows that project-based learning (PjBL) can stimulate active student involvement in learning, and this has proven effective in the context of this study. Students' understanding of science concepts also increased significantly. Based on pretest and posttest data, students were better able to understand concepts such as force, energy, and changes in matter after participating in PjBL-based learning with the PhET application. Setiawan (2023) also found that the use of technology such as PhET applications in learning can make it easier for students to understand abstract concepts in science. Similarly, Syafitri (2022) explained that digital technology integration in PjBL makes students more creative in solving problems and encourages them to apply scientific reasoning in daily life.

Furthermore, the findings of this study align with broader demands of the 21st-century education framework. Students are required not only to master knowledge but also to build 4C skills (critical thinking, creativity, collaboration, communication). By using PhET in PjBL, students are trained to analyze data, design experiments, and communicate findings with their peers. This is consistent with N. Utami (2020), who revealed that technology-enriched PjBL models foster critical thinking skills in science education. In addition, Wulandari (2021) found that the use of E-LKPD with interactive features significantly increases students' higher-order thinking skills (HOTS), particularly in understanding abstract science concepts. Another key implication is related to motivation. Putra (2021) emphasized that motivation is a critical factor determining student success. The data of this study confirmed that technology-enhanced PjBL increases intrinsic motivation because students feel more autonomous and competent when they can control experiments virtually. For example, when they manipulate variables in the PhET simulation, they feel empowered to explore "what if" scenarios, which makes learning personal and meaningful. Similarly, Rahmadani (2024) discovered that interactive media can elevate students' willingness to participate in science activities and sustain their attention throughout lessons.

The impact of this study also extends to teachers' roles. Teachers no longer act as sole knowledge transmitters but as facilitators who guide students in inquiry-based learning. Haryanto (2021) explained that teachers who adopt simulation-based applications are better able to create student-centered classrooms, which promotes higher engagement and deeper learning. This shift aligns with the modern paradigm of education that prioritizes active learning. Utami (2020) confirmed that students become more confident and engaged when PjBL is supported by structured digital worksheets such as E-LKPD. Finally, the broader implication of this study is that the integration of PjBL-based E-LKPD with PhET can be scaled and applied in other schools. However, this requires adequate infrastructure, teacher competence, and continuous support. Sari

(2021) stated that digital literacy among teachers is a crucial factor in ensuring the success of ICT-based learning. Wulandari (2021) further argued that with proper training and access to resources, the use of PhET and similar applications can help reduce educational inequality across regions in Indonesia, since students from various backgrounds can access high-quality interactive learning experiences.

Thus, the results of this study indicate that the use of PhET in science learning not only enhances students' conceptual understanding and motivation but also prepares them with 21st-century skills. Along with teacher professional development and infrastructure improvement, this model can be optimized to provide broader and more sustainable benefits for elementary education in Indonesia.

CONCLUSION

Based on the findings of this study in grade IV of Elementary School 14 Banda Aceh, it can be concluded that the use of E-LKPD based on Project-Based Learning (PjBL) integrating the PhET application has a significant impact on improving student learning outcomes in the Natural and Social Sciences (IPAS) subject. The results of the pretest and posttest showed a very meaningful difference, with the average score rising from 70 to 94, an increase of 24 points. This improvement indicates that the integration of interactive simulations through PhET is highly effective in helping students understand abstract science concepts such as force, energy, and changes in matter. Students were not only able to memorize concepts but also demonstrated deeper comprehension by connecting experimental results with theoretical explanations, which is a key aspect of meaningful learning.

Furthermore, the results also reveal that the use of PhET in PjBL-based learning has a positive influence on student engagement and learning motivation. During classroom activities, students showed active participation in conducting virtual experiments, collaborating with peers, and presenting their findings. The questionnaire distributed after the learning process supported these observations, with most students reporting that lessons became more enjoyable, easier to understand, and sparked their curiosity to explore scientific topics further. Such results demonstrate that the integration of technology into learning can foster not only cognitive development but also affective aspects, such as enthusiasm, confidence, and persistence in solving problems. This holistic impact is important to ensure that learning outcomes are sustainable and beneficial for the long-term development of students' competencies.

In conclusion, technology-based learning media such as the PhET application, when combined with student-centered approaches like PjBL, can be considered an innovative solution to improving the quality of education in elementary schools. Its interactive and experimental nature bridges the gap between theory and practice, making abstract science content more tangible and easier to understand. The success of this research

also underscores the urgency of integrating technology into education to prepare students with 21st-century skills, including critical thinking, collaboration, and digital literacy. Thus, the implementation of PhET-based PjBL learning not only enhances academic achievement but also strengthens student readiness to face the increasingly complex challenges of modern education and society.

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Additional Information	All data used in this study are completely presented within the article. No additional or undisclosed information was omitted from the publication. This reflects the author's commitment to transparency, accuracy, and adherence to academic ethical standards.

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