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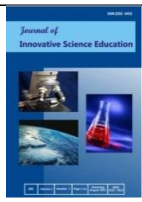

Implementation of Project Based Learning Assisted by PhET Simulation in Science Learning to Improve Students' Science and Digital Literacy

Arfilia Wijayanti✉, Khusnul Fajriyah, Mira Azizah, Kiswoyo

Primary School Teacher Education Study Program, Faculty of Education, Universitas PGRI Semarang Indonesia

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Mastering scientific and digital literacy is essential for prospective teachers to meet the demands of modern science education. This study specifically aims to analyze the effectiveness of Project-Based Learning (PjBL) assisted by PhET simulations in improving students’ scientific and digital literacy. A quasi-experimental design with a pretest–posttest control group was conducted involving 80 undergraduate students, and the data were analyzed using N-Gain and comparative statistical tests. The results show that the implementation of PjBL supported by PhET simulations significantly outperformed conventional learning, with the experimental group achieving a higher N-Gain across all indicators of scientific and digital literacy. These improvements were also reflected in students’ project performance, demonstrating stronger conceptual understanding and more proficient use of digital tools during inquiry-based activities. These findings highlight the potential of integrating interactive simulations within PjBL to strengthen essential competencies in teacher education programs and support the development of innovative science learning practices aligned with 21st-century educational demands.

✉ correspondence:
Primary School Teacher Education Study Program,
Faculty of Education, Universitas Persatuan Guru
Republik Indonesia Semarang
E-mail: arfiliawijayanti@upgris.ac.id

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INTRODUCTION

Project Based Learning (PjBL) is a student-centered learning method, where students are actively involved in the learning process through real and relevant projects. The application of Project Based Learning in higher education aims to develop critical thinking skills, problem solving, and collaborative and communication skills (Hartono & Asiyah, 2019; Artama et al., 2023). Basic education is an important foundation in the formation of children's character and knowledge. As prospective educators at the Elementary School level, students are expected to not only have in-depth knowledge of various disciplines, but also the ability to integrate technology into the learning process. Scientific and digital literacy are two crucial aspects that must be mastered by prospective elementary school teachers in order to create a relevant and adequate learning environment in today's digital era (Nuraini et al., 2023).

Research on the implementation of PjBL assisted by PhET simulations shows that this method is effective in improving students' scientific and digital literacy. Scientific literacy includes understanding scientific concepts, scientific thinking skills, and skills in applying scientific knowledge in real contexts. Meanwhile, digital literacy involves the ability to use information and communication technology effectively and ethically.

The implementation of PjBL assisted by PhET simulation is carried out through several stages. First, the lecturer prepares a project that is relevant to the learning material and designs activities that involve the use of PhET simulation. Second, students are divided into small groups to work on the project collaboratively. During this process, students are required to identify problems, design experiments, collect data, and analyze the results. Third, students present the results of their projects and get feedback from the lecturer and their peers.

The results of the study showed that students who studied with the Project Based Learning model assisted by PhET simulation experienced a significant increase in scientific literacy (Aina & Hariyono, 2023). They were better able to understand abstract scientific concepts and apply them in real situations. In addition, their digital literacy also increased, as seen from their ability to use simulation software, search for scientific information online, and communicate and collaborate through digital platforms (Ritonga, 2021).

PjBL is a project-focused learning model that provides students with hands-on experience in solving real problems (Hartono & Asiyah, 2019; Artama et al., 2023). In PjBL, students are actively involved in the learning process by working on projects that are relevant to the material being studied. The main characteristics of PjBL include project orientation with learning centered on complex and realistic projects, collaboration where students work in teams to complete projects, skill development with critical thinking, problem solving, and collaboration skills training, and performance-based assessments conducted based on the final product and project work process (Nuraini et al., 2023).

The PjBL syntax involves a series of systematic stages to guide the project-based learning process. The first stage is determining the basic questions that are challenging and relevant to be answered through the project. Then, the project design is carried out by designing the learning objectives, activities, and expected final results. Furthermore, the preparation of the work plan includes the activity schedule, task division, and teamwork methods. The project implementation stage involves students in collecting information, conducting experiments, and developing project products. Monitoring and guidance are carried out by lecturers to monitor progress and provide support to students. Project assessment is carried out both formatively and summatively to assess the process and results of the project based on predetermined criteria. Finally, students present their project results to a wider audience and evaluate the learning process that has been passed. This syntax ensures that PjBL is structured and focused on achieving the desired learning objectives (Li et al., 2023; Krajcik et al., 2023; Utaminingsih et al., 2023).

PhET simulation is a technology-based learning tool that is very effective in teaching natural science. Developed by the University of Colorado Boulder, this simulation offers interactive visualizations that help students understand complex and abstract scientific concepts through a more concrete and practical approach. In science learning, PhET simulations allow students to conduct interactive virtual experiments, such as simulating Newton's laws, chemical reactions, or concepts of electricity and magnetism. Students can change variables and see the impact directly, which provides a deeper and more meaningful learning experience (Rosadi, 2023; Mashami et al., 2023). In addition, PhET simulations provide direct feedback that helps students evaluate their understanding in real-time. By using PhET simulations, science learning becomes more interesting, effective, and encourages independent exploration and problem solving (Putra et al., 2023; Rianti et al., 2024; Nguyen et al., 2024).

PhET simulation is a technology-based learning tool developed by the University of Colorado Boulder. This simulation offers interactive visualization of scientific concepts that are difficult to understand through conventional methods. The main benefits of PhET simulation include interactivity that allows students to interact with scientific concepts directly, concept visualization that helps students understand abstract concepts in a more concrete way, independent exploration which encourages independent exploration and experimentation, and providing direct feedback on student actions (Kumullah et al., 2023; Samitra et al., 2023; Almadrones, & Tadifa, 2024).

Scientific literacy refers to a person's ability to understand and use scientific concepts and processes in everyday life. Scientific literacy involves understanding scientific concepts as demonstrated by the ability to explain scientific concepts and phenomena; scientific processes, namely by understanding scientific methods, including observation, experimentation, and data analysis; and the application of science, namely applying scientific knowledge to solve real-world problems (Seprianto & Hasby, 2023; Nurhayati et al., 2023; Akerson & Bartels, 2023).

Digital literacy includes the ability to use digital technology effectively. This involves technical skills demonstrated by the ability to operate digital devices and use software; digital problem solving, namely the ability to use technology to solve problems; digital ethics, namely understanding the ethics of using digital technology, including data privacy and security (Ervianti et al., 2023).

The implementation of PjBL assisted by PhET simulations in science learning has been shown to enhance students' scientific and digital literacy. This improvement occurs because students gain direct hands-on experience, allowing them to learn by doing and develop a deeper understanding of scientific concepts. In addition, the PjBL approach encourages collaboration and communication, as students work in teams and practice expressing ideas while solving problems together.

PhET simulations also provide opportunities for virtual experimentation, enabling students to perform interactive scientific investigations that strengthen both their technical skills and conceptual understanding. Throughout the learning process, students receive feedback and opportunities for reflection, allowing them to analyze simulation outcomes, evaluate their project results, and refine their understanding based on immediate, meaningful input.

The implementation of PjBL assisted by PhET simulation in science learning is an effective approach to improve students' scientific and digital literacy. By combining project-based learning and interactive technology, students can develop relevant skills to face real-world challenges and become more competent in science and technology.

METHODS

This study uses a quasi-experimental method with a pretest-posttest control group design, there are two groups that are compared, namely the experimental group and the control group. The population in this study were students of the Elementary School Teacher Education Study Program in the odd semester of 2024/2025 at Universitas PGRI Semarang who took the Science Learning course in Elementary School. This design allows researchers to measure changes in science and digital literacy before and after implementing PjBL assisted by PhET Simulation in the experimental group, and to compare it with the control group that did not receive intervention.

The logical scheme of the steps taken in the research methodology can be seen in Figure 1.

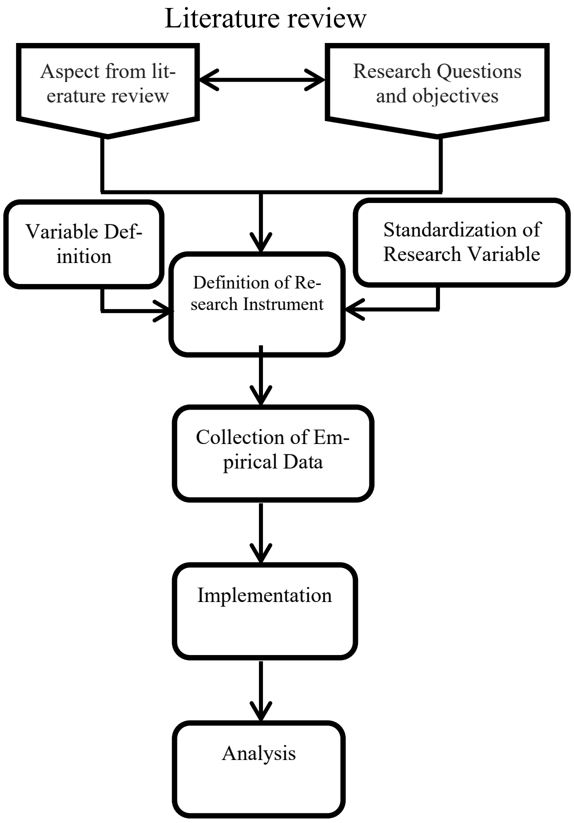

Figure 1. Logical Scheme of Research Steps

The instruments used in this study include scientific and digital literacy tests in the form of tests designed based on scientific and digital literacy indicators, a reflection questionnaire on students' mastery of scientific and digital literacy during the learning process.

Data analysis of increasing scientific and digital literacy through calculations using the following N-Gain formula (Hake, 2002):

The categorization of the N-gain score is determined from the N-Gain value. The distribution of N-gain values can be seen in Table 1 below:

$$N\ Gain = \frac{Skor\ Posttest - Skor\ Pretest}{Skor\ Ideal - Skor\ Pretest}$$

Table 1. Categorization of N-gain score acquisition values

N-gain score	Category
g > 0,7	high
0,3 ≤ g ≤ 0,7	medium
g < 0,3	low

The results of the questionnaire and observation data were analyzed descriptively quantitatively and calculated using the formula:

$$P = \frac{f}{N} \times 100\%$$

Description:

P = Percentage Score

f = Number of frequencies of each answer that has become the respondent's choice

N = Number of frequencies or number of individuals

RESULTS AND DISCUSSION

The implementation of PjBL assisted by PhET simulation to improve students' scientific and digital literacy has been carried out through a quasi-experimental method with a pretest-posttest control group design. Data collection was carried out in the odd semester of 2024/2025. There were two groups or study classes used as samples, each as an experimental class (Class 3A) and a control class (Class 3B). In class 3A, treatment was given in the form of implementing PjBL assisted by PhET simulation and in class 3B, lectures were held as usual. At the beginning of the lecture, students were given a pretest and at the end of the lecture, a posttest was given for scientific and digital literacy. The increase in students' scientific and digital literacy was calculated using the N-Gain formula (Hake, 2002).

The questionnaire was given at the end of the lecture and observations were made during the lecture in both the experimental and control groups. The results of the increase in scientific and digital literacy in the control and experimental groups were compared and analyzed based on the results of the tests, reflection questionnaires and observations during the lecture. The results of the questionnaire and observations were then described quantitatively to support the analysis of data on increasing students' scientific and digital literacy. The following presents the results and discussion of the research on the application of PjBL assisted by PhET simulations to improve students' scientific and digital literacy that has been carried out.

Improving Students' Science Literacy

The results of the increase or average N-Gain value of individual science literacy in the control and experimental groups are presented in Figure 2 below:

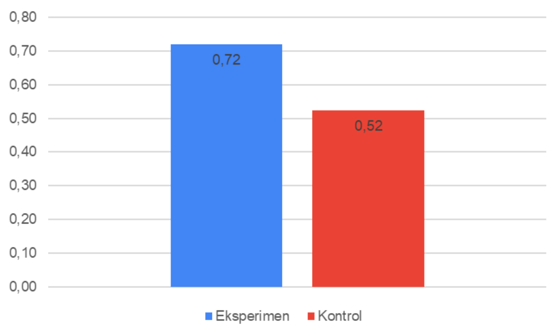

Figure 2. Average N-Gain value of individual scientific literacy in the control and experimental groups

Based on Figure 2, the average N-Gain value of individual scientific literacy in the control group was 0.52 (moderate category) and in the experimental group was 0.72 (high category). This shows that the implementation of the PjBL model assisted by PhET simulation is significantly more effective than conventional learning methods in improving students' scientific literacy.

Students in the experimental group showed a better understanding of scientific concepts, especially those related to abstract topics such as particle dynamics and thermodynamics. This was due to the interactive visualization of the PhET simulation which helped students understand the relationships between variables in a concrete way (Dy et al., 2024; Bahtiar et al., 2024; Acquah et al., 2024).

Students in the experimental group were better able to design, conduct, and evaluate virtual experiments using PhET than the control group. Complex scientific processes can be safely simulated, thereby improving data analysis and interpretation skills (Prihatiningtyas et al., 2024; Reyes et al., 2024).

The PjBL model encourages students to connect scientific concepts to real-world problems, such as renewable energy utilization. This results in significant improvements in their ability to apply scientific knowledge in relevant contexts (Ariza & Olatunde-Aiyedun, 2023; Rizki & Suprapto, 2024; Rahayu et al., 2025).

Figure 3. Classroom Activity

Improving Students' Digital Literacy

The results of the increase or average N-Gain value of individual digital literacy in the experimental and control groups are presented in Figure 4 below:

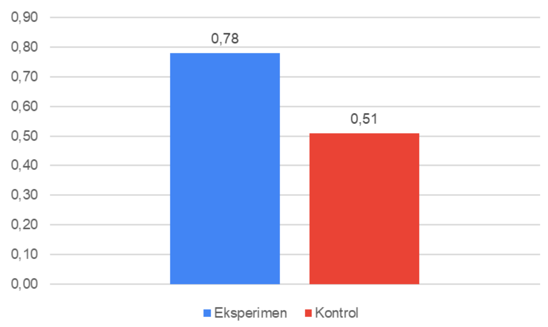

Figure 4. Average N-Gain value of individual digital literacy in the control and experimental groups.

Based on Figure 6, the average N-Gain value of individual digital literacy in the control group was 0.51 (medium category) and in the experimental group was 0.78 (high category). The PjBL model assisted by PhET simulations made a significant contribution to improving students' digital literacy.

Figure 5. Project Activity

Students in the experimental group showed better abilities in using technological devices and digital applications, especially in utilizing PhET simulations to conduct scientific exploration. PjBL trains students to solve problems independently through computer-based simulations, such as designing experiments to test hypotheses using virtual tools. The application of PjBL assisted by PhET Simulation can help improve critical thinking skills in a digital context (Sukarma et al., 2024; Singh-Pillay, 2024).

Collaborative activities carried out by students in digital-based projects help them understand the importance of digital ethics, such as sharing information in a safe way and respecting the copyright of digital materials. In the security of sharing information, students learn the importance of proper privacy settings, such as limiting access to only team members. Students also learn to understand the importance of avoiding the distribution of personal or sensitive information without permission, so as to avoid the risk of data theft or misuse of information. In digital communication ethics, students learn to maintain polite language, avoid hate speech and respect the opinions of other team members. Students also understand the importance of filtering information before sharing it, in order to avoid the spread of fake news or misleading information (Rakuasa et al., 2024; Chang & Kuo, 2025).

Student Reflection Response

The questionnaire was given at the end of the lecture and observations were made during the lecture for both the experimental and control groups. The results of the questionnaire and observations were then described quantitatively to support data analysis on improving students' scientific and digital literacy. The following presents the results and discussion of the research on the application of PjBL assisted by PhET simulations to improve students' scientific and digital literacy that has been carried out.

The results of the questionnaire indicate that students responded positively to the implementation of Project-Based Learning (PjBL) assisted by PhET simulations. Overall, students felt that the integration of PhET made science learning more engaging, interactive, and easier to understand. Their reflections highlight how simulations help visualize abstract concepts, provide meaningful hands-on experiences, and support clearer explanations from educators.

One student, MIK, expressed that using PhET offers "a new and exciting experience," noting that the animations make it easier for educators to explain scientific material. Similarly, JAP shared that PhET greatly simplifies the delivery of learning content and makes lessons more interesting and not monotonous. JAP described using the simulation to explore food chain concepts, observing how disturbances in one population affect others.

Other students emphasized how PhET helps them understand scientific phenomena that are usually abstract. IK noted that the simulation provides a highly interactive learning experience, explaining that the *Bouncing Ball* simulation made the concept of energy changes more concrete by allowing variable manipulation and direct observation of the outcomes. HW also shared a similar experience while exploring density concepts, stating that PhET made it easier to compare objects of different types and understand why objects with the same mass do not always have the same volume.

Students also highlighted the usefulness of PhET in understanding more complex physics concepts. WRP stated that simulations such as electrical circuits and light properties enabled direct interaction with abstract ideas. By adjusting variables—such as wire length, resistor types, and light intensity—WRP could immediately observe experimental changes and better understand relationships like those described in Ohm's law. Likewise, VSF explained that learning about lenses became more engaging through PhET, as the simulation allowed manipulation of object distance, focal length, and lens type to visualize how images form in convex and concave lenses.

Finally, DNA reflected on the PhET Magnets and Electromagnets simulation, noting that it effectively illustrates how electric currents generate magnetic fields and how these fields influence magnetic objects. DNA emphasized that the visual and interactive design of the simulation helps deepen understanding of both magnetic and electromagnetic principles. Together, these responses demonstrate that PhET-assisted PjBL not only enhances student engagement but also significantly supports the comprehension of complex scientific concepts through interactive, visual, and exploratory learning experiences.

The recapitulation of the results of student response reflection through eight questions related to the implementation of PjBL assisted by PhET simulations to improve students' scientific and digital literacy is shown in Figure 6:

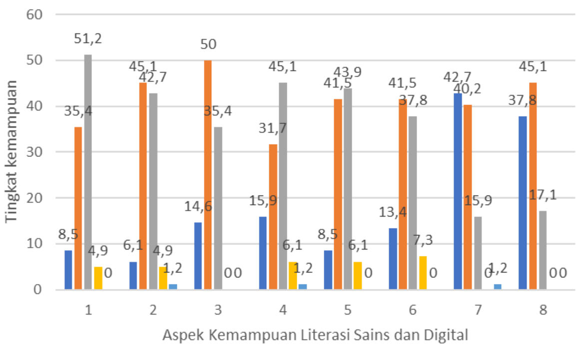

Figure 6. Diagram of Student Responses to Science and Digital Literacy Skills

Figure 6 shows the highest aspect of literacy and digital skills "Very capable or very understanding" is in aspect 7, namely understanding the importance of maintaining privacy and security when using digital technology by 42.7%, aspect 8, namely understanding how to use digital resources ethically, respecting copyright, and verifying information by 37.8%, aspect 4, namely being able to use science/science concepts to provide solutions to problems around me every day by 15.9%, aspect 3 is being able to conduct simple science/science experiments and analyze the results by 14.6%. This shows that 42.7% of students have a very high awareness of digital ethics and digital security.

The literacy and digital skills aspect at the level of "Quite capable or quite understand", in aspect 3, namely being able to conduct simple science/science experiments and analyze the results obtained a result of 50%, in aspect 2, namely being able to explain various science/science phenomena in everyday life correctly with the help of digital technology PhET Simulation and aspect 8, namely using digital resources ethically, respecting copyright, and verifying information obtained the same percentage of 45.1%. This shows that 50% of students have sufficient ability to conduct simple science/science experiments and analyze the results. No students in the category of "less capable or unable" showed the effectiveness of PhET simulation in improving experimental skills.

The aspect of literacy and digital skills at the "able or understand" level, in aspect 1, namely understanding the science/science concepts that I learned in project-based lectures assisted by PhET Simulation by 51.2%, but there are still students who are less able in aspects 1,2,4,5,6 and unable in aspects 2,4,7 by 1.2% which indicates that there are still challenges in explaining various science/science phenomena in everyday life correctly with the help of PhET Simulation digital technology, the application of science concepts in real life, the importance of maintaining privacy and security when using digital technology.

In general, the implementation of the PhET simulation-assisted PjBL model contributes to the understanding of science concepts, but still requires improvement in analytical skills and application of concepts in everyday life because there are still students who are categorized as underprivileged and unable. In the implementation of the next lecture, a practical session on the application of science concepts in everyday life can be added, providing further training in digital information searches by guiding students in finding valid sources of information, critiquing data, and applying it in solving science problems. In addition, it also encourages discussion and project-based problem solving to improve applicative understanding (Rianti et al., 2024; Alqawasmi et al., 2024).

CONCLUSION

The implementation of the PjBL model assisted by PhET simulations has proven to be more effective in improving students' scientific literacy and digital literacy compared to conventional methods. Each indicator of scientific and digital literacy showed a significant increase, with a higher N-Gain value in the experimental group. This model is recommended to be implemented more widely in technology-based science learning.

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