



Indonesian Science Education Research (ISER)

Available online

<https://jurnal.unimed.ac.id/2012/index.php/iser>

e-ISSN: 2715-4653

p-ISSN: 2797-6262



The Effect of Problem Based Learning Assisted by PhET on Students' Critical Thinking Skills on the Material of the Earth and Solar System

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Accepted: Month 28th, 2025. Published: Month 28th, 2025

Abstract

This research investigates the impact of using the Problem-Based Learning (PBL) model supported by PhET simulation media on students' critical thinking skills, specifically in enhancing each indicator of critical thinking on the Earth and Solar System topic for Grade VII students at SMP Negeri 13 Medan during the 2024/2025 school year. Based on observations made, it is known that students have not been thinking critically, as indicated by their inability to interpret tables or images, analyze problems, and explain issues. The study adopts a quasi-experimental approach with a pretest-posttest control group design. The participants included two classes: class VII-2 as the experimental group receiving PBL with PhET, and class VII-6 as the control group receiving conventional instruction. Cluster random sampling was employed to determine the sample. Data were gathered through tests and observational methods, and analyzed using the Independent Sample t-test for hypothesis testing. The experimental group had an average pretest score of 12.9 and a posttest score of 77.7, while the control group scored 15.7 and 65.6, respectively. The results confirmed a significant influence of the PBL approach aided by PhET media on students' critical thinking development. Furthermore, the N-gain analysis revealed that the experimental class showed a higher average percentage gain across all indicators compared to the control class.

Keywords: Problem Based Learning, PhET, Critical Thinking Skills, Earth and Solar System

Introduction

The 21st century is characterized by major changes in various sectors, including education, driven by technological advances and the shift from human labor to machines (Yusmar & Fadilah, 2023). These shifts demand adaptability and competency development to create superior human resources. In education, technology plays a vital role in supporting flexible and accessible learning, particularly for Generation Z students who are more accustomed to digital devices like smartphones than printed books (Janattaka & Putri, 2021; Salsabila & Riadi, 2022).

A major issue in today's education is not just understanding concepts, but also enhancing critical thinking to elevate human resource quality (Temuningsih et al., 2023). Critical thinking skills are a crucial aspect in shaping students who are able to face life's problems logically and systematically. Various studies show that students with high critical thinking skills tend to have better learning outcomes (Khairinaa et al., 2023). These skills encompass analysis, understanding, problem-solving, evaluation, and drawing conclusions (Cynthia et al., 2023). In developing instruments and learning, the critical thinking framework formulated by Facione is widely used as a reference due to its comprehensive scope, including the critical thinking disposition dimension that is crucial in the learning process (Facione in Cynthia et al., 2023). Nonetheless, findings from global assessments like Trends in Mathematic and Science Study (TIMSS) indicate that Indonesian students continue to demonstrate limited critical thinking abilities, particularly when tackling high-level cognitive questions (Rahayu & Dewi, 2022). This indicates the need for improvements in the science learning process that does not yet support the optimization of critical thinking skills, because teachers tend to still emphasize mastery of concepts without in-depth exploration of the scientific thinking process (Zulfiana et al., 2023; Wahyudi & Purwanto, 2024).

A similar situation was found at SMP Negeri 13 Medan, where science learning was still teacher-centered, with minimal use of learning media, and low student engagement in the exploratory process. Pre-study results showed that most students were unable to interpret images, classify information, or critically evaluate arguments. Students showed low levels of activity and reflection regarding their learning, even when it came to self-regulation indicators (Slameto, 2019). Meanwhile, science as a science subject is actually a vehicle for developing the ability to reason, discover, and explain natural phenomena logically (Dewi et al., 2023; Sinambela & Setiawan, 2024).

The Earth and Solar System is a science topic that demands in-depth conceptual understanding and the ability to analyze natural phenomena such as rotation, revolution, and the characteristics of celestial bodies (Inabuy et al., 2021). Based on pre-study by researchers, science teacher interviews revealed that students have difficulty recognizing and describing issues using their own language, reflecting weak critical thinking in this area.

An option to address this issue is implementing the Problem-Based Learning (PBL) model supported by Physics Education Technology (PhET). The PBL model is very suitable for enhancing students' critical thinking skills because this model provides problems that are relevant to the real world, stimulates curiosity, helps students identify issues, communicate their opinions, and encourages them to think critically. This model also enables students to identify the strengths and weaknesses of their arguments. Meanwhile, the PhET media is very easy to use and accessible. This media offers a variety of features that facilitate students in studying the material to be covered. The simulation of the Earth and solar system material is very difficult to implement in real life because the tools and materials are hard to assemble or design, but through this media, we can learn about the planet Earth and the Solar System, celestial objects within the solar system, the processes of revolution and rotation of planets, and the processes of solar and lunar eclipses virtually and in an easy-to-use manner. The PBL model emphasizes contextual problem-solving, encouraging students to think critically, express opinions, and build arguments based on data (Delfiza & Fuadiyah, 2024). Meanwhile, PhET media provides interactive simulations that visualize abstract concepts such as the solar system in a realistic and easy to understand manner, even overcoming limitations in direct practicum implementation (Muzana et al., 2021). The research conducted by Novita et al. (2023) found that the use of PhET simulation media in PBL

model learning greatly assists students in understanding the material because students can see and directly experiment with the simulations; students can also independently try the experiments available in the PhET simulations. Research integrating the PBL model and PhET media has shown positive results in improving students' critical thinking skills in understanding science material. Students become more active, able to analyze, evaluate, and draw conclusions using structured logic (Fransiskus et al., 2023).

Based on this background, this study was conducted to explore the effect of the implementation of the PBL model assisted by PhET media on the critical thinking skills of seventh grade students on the Earth and Solar System material. This study examined how integrating problem-based learning with digital simulations influences students' critical thinking, assessed using six specific indicator by Facione: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The investigated subtopics included "solar energy and its effects on Earth's life", "the consequences of Earth's rotation and revolution", and "the Moon's revolution and its influence on living beings". Conducted during the second semester, the study applied a quantitative method using an experimental design to compare critical thinking outcomes between experimental and control groups. In both groups, a pretest was conducted to determine the initial abilities of the students; once it was established that the abilities of both classes were the same, treatment could be administered. The experimental class received treatment using the PhET-assisted PBL model, while the control class was treated with direct instruction. After four sessions of learning, a posttest was conducted to assess the critical thinking abilities of the students after the treatment had been provided. Based on the analysis of the posttest data, it will be determined whether the PhET PBL model has an effect or not.

Research Method

This study explores how using a Problem Based Learning (PBL) model integrated with Physics Education Technology (PhET) simulations influences the critical thinking skills of seventh grade students at SMP Negeri 13 Medan, specifically on the topic of the Earth and Solar System included "solar energy and its effects on Earth's life", "the consequences of Earth's rotation and revolution", and "the Moon's revolution and its influence on living beings".

A quasi-experiment was conducted using a control group design with both pretest and posttest. Rather than randomly choosing individual participants, entire classes were randomly chosen through cluster sampling from the broader population. Two groups were involved in the research: the experimental group was taught using the PBL method with PhET simulations, while the control group received standard teaching methods. Both groups took a pretest before the learning sessions and a posttest after to evaluate their academic performance and the growth of their critical thinking abilities (Sugiono, 2016).

The research took place at SMP Negeri 13 Medan, located on Jalan Sampali No. 47, Pandau Hulu II, Medan Area, North Sumatra, during the second semester of the 2024/2025 school year, specifically in April 2025. The study population comprised 224 seventh-grade students across seven parallel classes, each with 30 students. Two of these classes were randomly selected as samples using cluster sampling one experimental and one control. The study's independent variable involved implementing problem based learning (PBL) integrated with PhET simulations, whereas the dependent variable focused on learners' critical thinking abilities. These skills were evaluated using Facione's six criteria: interpreting, analyzing, evaluating, inferring, explaining, and self-regulation (Facione, 2011). The PBL method began with real-world problems to guide students' learning, while PhET simulations offered a visual representation of abstract science concepts related to space.

Data collection included both testing and non-testing methods. A test composed of 12 expert-validated essay questions was used for both the pretest and posttest, with scoring based on a scale of 0–4, later converted to a 0–100 scale. Non-test information was obtained via classroom activity documentation, teacher and student interviews, and observation. Instrument validation was conducted by three experts in physics education, and the test's construct validity was

analyzed through item validity, question difficulty, discrimination index, and reliability, using the Anates software.

SPSS version 21 was utilized to analyze the gathered data. Before conducting the primary analysis, assumption testing was carried out, utilizing the Shapiro-Wilk method to evaluate data normality and Levene's approach to examine homogeneity of variances. A t-test for independent samples was used to assess differences in critical thinking skills between students in the experimental and control groups following the intervention. A conclusion was drawn using a significance threshold: when the p-value is under 0.05, the null hypothesis (H_0) is dismissed in favor of the alternative hypothesis (H_a), suggesting the intervention produced a significant effect. The improvement in students' critical thinking abilities was measured using the normalized gain (N-gain), which evaluates the difference between pretest and posttest scores relative to the maximum possible score.

The research procedure is carried out in three main stages: preparation, implementation, and completion. The preparation stage includes the preparation of research instruments and question outlines. Pretest and posttest, as well as teaching modules. The level of implementation includes giving pretest, implementation of learning according to the model in each class, and provision of posttest. The final stage includes data processing, statistical analysis, interpretation of results, and drawing conclusions.

Result and Discussion

1. Pretest and Posttest Data of the Experimental and Control Classes

Critical thinking skills students's data through pretest and posttest given to the experimental class and control class can be seen in Figure 1.

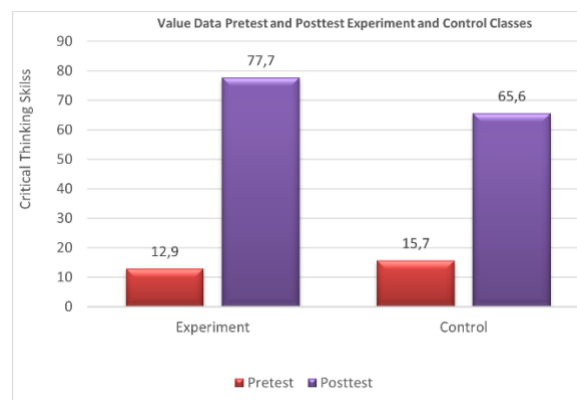


Figure 1. Pretest and posttest value data experimental and control classes

Figure 1 presents the pretest results, revealing that students in the control group had an average critical thinking score of 15.7, compared to 12.9 in the experimental group. Following the instructional activities, posttest scores rose to 65.6 in the control group and 77.7 in the experimental group. These findings suggest improvement in critical thinking skills across both groups, with the experimental group taught using a PBL model supported by PhET simulations showing a more notable gain.

2. Results of Hypothesis Testing

This research employed a t-test to examine differences in students' critical thinking abilities between the control and experimental groups, both prior to and following the intervention. The test was administered after fulfilling the requirements for normality and homogeneity.

Normality test using with Shapiro-Wilk shows that all pretest and posttest data in both classes have significance values (Sig.) between 0.064 and 0.544, all of which are greater than $\alpha = 0.05$. This means that the data is normally distributed.

The Levene Test results indicate that the significance values for both classes' pretest and posttest scores exceed 0.05, suggesting that the variances between the groups are homogeneous.

Once the requirements are fulfilled, an independent t-test is performed using SPSS. The pretest data yields a significance value of 0.24 (> 0.05), indicating no notable difference between the experimental and control groups prior to the intervention. This means that the initial abilities of students in both classes are the same.

However, the t-test results for the data posttest show a Sig. value = 0.00 (< 0.05), which means there is a significant difference between the control and experimental classes after treatment. The average value posttest increased from 65.62 (control class) to 77.7 (experimental class).

3. Normalized-gain Test Result Data

The results of the normalized-gain test for the control and experimental classes can be seen in Table 1.

Table 1. Results of the N-gain test of the experimental class and the control class

No	Indicator	Experiment			Control		
		N-gain	N-gain (%)	Cat.	N-gain	N-gain (%)	Cat.
1	Interpretation	0,73	73	high	0,57	57	moderate
2	Analysis	0,82	82	high	0,60	60	moderate
3	Evaluation	0,69	69	moderate	0,58	58	moderate
4	Inference	0,72	72	high	0,56	56	moderate
5	Explanation	0,75	75	high	0,57	57	moderate
6	Self-regulation	0,72	72	high	0,62	62	moderate

Based on Table 1 of the N-gain test results of students' critical thinking skills, the experimental class shows that the analysis aspect is the highest, with a score of 0.82 (high), and the evaluation aspect is the lowest, with a score of 0.69 (moderate). Meanwhile, in the control class, the self-regulation aspect is the highest with a score of 0.62 (moderate) and the inference aspect is the lowest with a score of 0.56 (moderate).

4. The Effect of Using PhET-Supported PBL Method on Students' Critical Thinking Abilities

The study showed that using problem-based learning combined with PhET simulations greatly enhanced seventh graders' critical thinking abilities regarding the Earth and Solar System. The posttest results revealed that the experimental group achieved an average score of 77.7, clearly surpassing the control group's average of 65.6. A significance level of 0.00 from the statistical test confirmed a substantial difference. These results demonstrate that using PBL combined with PhET media is more effective in fostering critical thinking than conventional instructional methods.

Ramadani and Nana (2020) state that the application of the problem-based learning model, aided by the PhET virtual laboratory as a learning innovation, can enhance students' thinking skills encountered in the teaching and learning process in the classroom. This learning model is capable of encouraging students to actively engage in higher-order thinking processes, as each stage of PBL is systematically designed to cultivate the six indicators of critical thinking, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation. At the start, learners face real world issues such as day night differences or global seasonal changes. Visual aids and videos foster interpretation skills, while PhET simulations realistically depict astronomical events, helping students identify key details. In the collaborative inquiry stage, students sharpen analytical skills by comparing simulation data with the Student Worksheet. Interactive simulations also guide them in evaluating cause effect relations, such as Earth's revolution causing seasons and its rotation affecting time, thereby supporting coherent and logical understanding in both experimental and control groups..

Evaluation skills are developed when students are asked to select, compare, and assess the accuracy of information from various sources. In this learning context, students learn to assess the validity of data from books, videos, or simulation results, as well as consider alternative solutions to problems they face. Although improvements in the evaluation indicator were not as high as other indicators, they remained in the moderate category and better than the control class, indicating that students are beginning to develop independent assessment skills.

Students' inference and explanation skills develop as they draw conclusions from simulation data, present them verbally in groups, and build arguments based on scientific evidence. They also explain concept relationships, respond to peers' questions, and practice conveying ideas clearly and logically.

Finally, self-regulation indicators are developed through reflective activities. Each student is asked to complete a reflection sheet to review their thinking process. Students evaluate their learning strategies, identify difficulties and develop improvement plans. In this way, students learn to control and develop their own metacognitive thinking.

5. Percentage of N-gain Increase In Critical Thinking Skills

The N-gain results quantitatively demonstrate enhanced critical thinking abilities. Most indicators in the experimental group showed significant growth, with the exception of evaluation, which saw a moderate improvement. The highest progress was found in the analysis aspect (N-gain = 0.82), followed by explanation (0.75), interpretation (0.73), inference and self-regulation (0.72), and lastly evaluation (0.69). Meanwhile, the control class only achieved moderate gains across all aspects. These results demonstrate that using PBL supported by PhET simulations is effective in enhancing students' critical thinking abilities.

These findings align with research by Rambe et al. (2024) which found that students learning using PBL achieved better results compared to conventional models. Furthermore, Nugroho et al. (2025) stated that PhET media is highly effective in science learning because it provides an engaging, interactive, and contextual learning experience. These findings are further supported by Rohmawati et al. (2023) who demonstrated that PBL syntax can guide students in systematically developing problem-based solutions and explanations with the aid of digital simulations.

In conclusion, using the PhET-supported PBL model in science education effectively improves students' understanding of Earth and the Solar System concepts while also fostering their overall critical thinking abilities. This approach encourages active participation, teamwork, and reflective learning, aligning well with 21st-century educational goals.

Conclusion

The application of PBL with PhET media significantly improves the critical thinking skills of seventh-grade students at SMP Negeri 13 Medan on the Earth and Solar System topic, as shown by a significance value of 0.00, which is below 0.05.

Based on Table 1 of the N-gain test results of students' critical thinking skills, the experimental class shows that the analysis aspect is the highest, with a score of 0.82 (high), and the evaluation aspect is the lowest, with a score of 0.69 (moderate). Meanwhile, in the control class, the self-regulation aspect is the highest with a score of 0.62 (moderate), and the inference aspect is the lowest with a score of 0.56 (moderate).

Future studies are encouraged to introduce PhET media through demonstrations prior to instruction, helping students become familiar with its use and promoting more effective learning. Researchers should also manage research time efficiently and ensure a supportive classroom atmosphere. Including hands-on activities regularly can enhance student achievement and foster science process skills. Schools are also advised to improve infrastructure and resources to support the smooth implementation of diverse instructional strategies.

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