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Effectiveness of the PhET Simulation Assisted by Song to Improve Students' Critical Thinking Skills in Electrical Circuits

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Abstract: Critical thinking is a fundamental skill in science education, yet many elementary students struggle to develop it due to conventional teaching methods that limit active participation. Electrical circuit concepts are often presented theoretically without hands-on application, making it difficult for students to grasp them fully. As a result, they face challenges in understanding electric current flow, series and parallel circuits and assembling circuits correctly. This study investigates the effectiveness of integrating PhET simulations with songs to enhance students' critical thinking skills in learning electrical circuits. A quasi-experimental design with a Nonequivalent Control Group was used, involving 40 students selected through total sampling. The control group (Class VA) received conventional instruction supplemented with videos, while the experimental group (Class VB) engaged in learning through PhET simulations combined with song and project-based learning. Data collection included written tests based on critical thinking indicators, interviews, and documentation. Statistical analysis comprised independent t-tests and N-Gain calculations. The t-test analysis, with a calculated t-value of 9.367, showed that students in the experimental group experienced significantly higher improvements in critical thinking skills than those in the control group. The experimental class achieved an average N-Gain score of 0.83 (high category), whereas the control class reached only 0.22 (low category). This finding shows that integrating PhET simulations with songs can improve students' critical thinking skills. In addition, supporting the Project Based Learning method allows students to apply their knowledge to real-world projects, encouraging deeper exploration and problem-solving skills. This research presents an innovative method for fostering critical thinking through interactive learning. Further research can investigate its implementation in different subjects to refine and expand effective teaching strategies.

Keywords: Critical Thinking; PhET Simulation; Project-Based Learning; Song in Learning; Electrical Circuits.

Introduction

Critical thinking is an ability that students must have in the 21st century. Critical thinking encourages students to have the courage to express logical thinking to make the decisions needed when faced with problems [1]. Critical thinking skills develop students' habits in seeking information, adjusting, dexterity, and perseverance in finding relevant information in the investigation. This study assessed students' critical thinking skills based on five modified indicators from Angelo and Facione: analysis, problem recognition and resolution, evaluation, inference, and synthesis. These indicators are important in helping students understand and develop scientific concepts. Especially in science learning, students must observe, examine a problem, and draw conclusions based on available data and evidence.

In elementary school science education, students are encouraged to naturally foster curiosity, hone questioning skills, and seek answers based on evidence of various natural phenomena to develop a scientific way of thinking [2]. Referring to the 4 elements of the nature of science, which include the aspects of products, processes, attitudes, and applications, the four dimensions need to be integrated into the science learning process [3]. Science learning not only emphasises the mastery of facts, concepts, and principles about nature but also forms skills in problem-solving, working together, appreciating other people's views, improving critical thinking skills, and making decisions objectively.

However, in the implementation of science learning at SDN 02 Botekan, especially the material on electrical circuits, the learning objectives of science have not been achieved. Learning problems were found. Namely, students lack mastery of electrical circuits, such as not understanding the flow of electric current, how series and parallel circuits work, and how to make series and parallel circuits. These problems are in line with the findings of Hindriyani et al that students' understanding of concepts in electrical circuit material is low because the material is abstract and cannot be observed directly through the eyes [4]. In addition, teacher-centred learning by applying conventional models. Monotonous learning, such as the lecture method without student involvement, will cause boredom and a lack of interest in learning that hinders understanding of the learning material [5]. Additionally, a strong enthusiasm for learning plays a significant role in enhancing students' critical thinking skills [6].

Another problem is the limited learning media for electrical circuits. Teachers utilise blackboards, student books, and videos as learning media. The limited practical equipment makes it difficult for teachers to facilitate students in developing their thinking because there are no practical activities in learning. Implementing science

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learning should focus on mastering knowledge and developing students' problem-solving ability. In science learning, students are directed to conduct explorations that encourage active student involvement in the discovery process [7]. Practical activities in science learning have a crucial role because they can develop scientific attitudes while obtaining new knowledge from within students [8]. Through the implementation of practicum, students' critical thinking skills can develop because students will analyse, interpret, and evaluate the results of experiments that have been carried out.

However, practicum tools and materials still constrain the implementation of practicum activities. In this digital era, PhET simulation is the solution to these problems. PhET simulation is proven to be effective for virtual practicum activities. Students can still do practicum like a real practicum without any obstacles, and can foster student interest in learning [9]. Other research shows that PhET simulations can strengthen students' understanding of the material through the features provided [10]. PhET simulations are also able to foster students' creative thinking skills, which are very important in solving problems in physics [11]. In the PhET simulation, students will analogise abstract physics concepts to foster their creative thinking skills. In the PhET simulation, students will analogise abstract physics concepts to foster creative and critical thinking. In the electrical circuit material, students will assemble the electrical circuit components to light the lights. They will try to solve the problems that occur so that the lights in the electrical circuit can light up. Thus, students' understanding of the material and critical thinking skills increase.

To optimise the application of PhET simulation, learning is supported by Project Based Learning, which aims to increase student involvement in developing projects. Project Based Learning is learning that places the project at the core of the learning process [12]. Project Based Learning can develop critical thinking skills, improve the achievement of learning outcomes, and encourage active student involvement in the learning process [13].

In addition, with the actual practicum, students will be more adept at connecting between electrical circuit components, not only connecting electrical circuit components virtually. Students' initial understanding of the electrical circuit is obtained from exploring the PhET simulation, and then they will assemble it in real life. However, to overcome the limited practical equipment, researchers took the initiative to facilitate independent practicum activities with simple materials. Thus, learning will be more effective and comprehensive because students can do actual practicum.

While Project Based Learning has been applied, further research is necessary to investigate how combining PhET simulations with other methods can further enhance students' critical thinking skills. Numerous studies have shown that PhET simulations greatly improve conceptual understanding, yet their effect on critical thinking remains underexplored. Additionally, integrating PhET simulations with song has not been widely studied. Therefore, this research aims to fill this gap by assessing the effectiveness of song-assisted PhET simulations in developing students' critical thinking skills, with Project Based Learning as a supporting learning method.

Considering the identified research gaps, this study investigates how integrating PhET simulations with songs enhances elementary school students' critical thinking skills. This research's uniqueness lies in using song-assisted PhET simulations as the primary learning medium, supported by the Project Based Learning approach. This combination has rarely been explored in previous studies.

Research Methods

This research adopts a quantitative approach utilizing the Quasi-Experimental, specifically implementing the Nonequivalent Control Group Design [14]. The study design is outlined as follows:

Table 1. Experimental and control class treatment

Class	Pretest	Treatment	Postest
Eksperiment	Y_1	X_1	Y_2
Control	Y_1	X_2	Y_2

The initial step of this research is that students are given a pretest (Y_1) in the two classes to test students' initial ability in critical thinking. The experimental class will receive treatment in the form of PhET simulations and songs about electrical circuits with Project Based Learning (X_1). Songs about electrical circuits are applied to make it easier for students to understand the difference between series and parallel circuits, the flow of electric current, and how it works. The control class will get video media treatment with conventional methods (X_2). After the 2 classes got treatment, they were given a posttest (Y2) to analyse the increase in critical thinking in the 2 classes.

This study involved a population of 40 students at SDN 02 Botekan Pemalang. 20 students from class VA as the control class and 20 from class VB as the experimental class. The sample determination in this study refers to Roscoe's opinion in the book Research Methods for Business that in simple experiments with control and experimental groups, the ideal sample size is in the range of 10 to 20 students per group [15]. In addition, the theory of Gay and Diehl (1992), as cited in A'izah and Dewi [16], argues that "in experimental research, the minimum sample is 15 subjects per group.". From these 2 expert opinions, the author used 20 samples in the experimental class and 20 samples in the control class. The sample selection technique uses saturated samples by making all members of the population into samples [17]. The selection of saturated samples is because researchers want to make generalisations with the smallest possible error with a population of less than 100 [18].

Data collection techniques were carried out by interviews, documentation, and written tests consisting of 10 multiple choice questions and 5 description questions adjusted to the critical thinking indicators used. Critical thinking indicators refer to the theory developed by Angelo and Facione, which is then adjusted to the research needs.

Once the learning process was completed, the collected data was analyzed through prerequisite tests, including the normality and homogeneity tests, to ensure that the data followed a normal distribution and had uniform variance. Next, the hypothesis was tested using an

independent sample t-test to analyze the variation in average scores between the experimental and control groups. The N-Gain test was also employed to assess the enhancement of students' critical thinking skills after administering the treatment.

The division of the category of results uses a modified Normalised Gain index interpretation [19].

Table 2. Normalised Gain Categories

Normalised Gain Value	Interpretation
$0.70 \leq g \leq 1.00$	High
$0.30 \leq g \leq 0.70$	Medium
$0.00 \leq g \leq 0.30$	Low
G = 0.00	No improvement
$-1.00 \leq g \leq 0.00$	There is a decrease

The findings from this analysis serve as the foundation for concluding the effectiveness of song-assisted PhET simulations in enhancing students' critical thinking skills, with Project-Based Learning as a supporting approach, compared to video media within conventional teaching methods.

Results and Discussion

Effective learning depends not only on the material but also on how it is delivered. According to Piaget's (1936) constructivism theory, as cited in Ratna [20], 'students build understanding through active interaction,' making fun and interactive learning more effective, especially for elementary school students.

As a solution, multimedia theory emphasises that a combination of visual and auditory elements can improve comprehension [21]. Interactive simulations aid concept exploration, while educational songs strengthen memory and make learning more enjoyable. Thus, using innovative media can improve the effectiveness of science learning.

PhET simulations and educational songs are innovative learning media that can improve students' critical thinking skills. PhET simulations allow students to conduct interactive virtual experiments to analyse, evaluate, and draw conclusions from the experiment results. Integrating PhET simulations into learning contributes to enhancing students' engagement, fostering independent concept comprehension, and strengthening their critical thinking abilities [22].

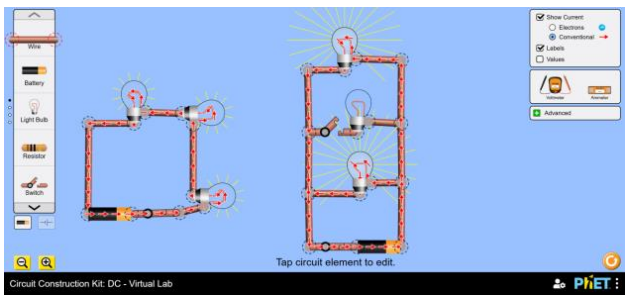

Figure 1. Simulasi PhET

Meanwhile, song as a learning medium helps students understand concepts in a more enjoyable and memorable way [23]. Through rhythm and lyrics, the songs can simplify scientific terms and improve students' memory. By combining PhET simulations and educational song, students get a more engaging learning experience and are better trained in critical thinking. Students can explore concepts in depth, connect theory with practice, and be more active in solving problems in science learning. The display of PhET simulations and songs used in learning (Figure 1).

Lagu Rangkaian Listrik

Rangkaian seri lampu disusun, secara berderet atau berurutan.
Hemat kabelnya mudah pasangnya, arus listriknya di satu jalur.
Nyala lampu lebih redup, jika satu padam yang lain padam (2x)

Rangkaian paralel lampu disusun, secara sejajar atau bercabang.
Perlu banyak kabel pasangnya rumit, arus listriknya di banyak jalur.
Nyala lampu lebih terang, jika satu padam yang lain menyala (2x)

Figure 2. Song Lyrics
The figure presents song lyrics in Indonesian, which are used as a learning aid

Figure 3. Song Display
The song about the electrical circuit above can be accessed through the link
https://youtu.be/w9P38U_qlIs?si=OvuuuIGikl9qp-Ap

Description of Learning in the Experimental and Control Classes

This study's experimental class underwent four learning sessions, utilizing Project-Based Learning as a supporting approach. Students were introduced to open and closed circuits using PhET simulations during the first session. After that, they were given a project to create the circuit concretely. In the second meeting, students learnt the characteristics of series and parallel circuits by exploring the PhET simulation and then created a virtual electrical circuit project. In the third meeting, students are trained to analyse and solve problems in electrical circuits by identifying errors in the preparation of the circuit and finding solutions to improve it through PhET simulations. In the fourth meeting, students apply the concepts they learned by applying simple electrical circuits to actual systems, such as traffic and twinkling lights.

Figure 4. PhET Simulation Exploration

Figure 5. Sing the electric circuit song

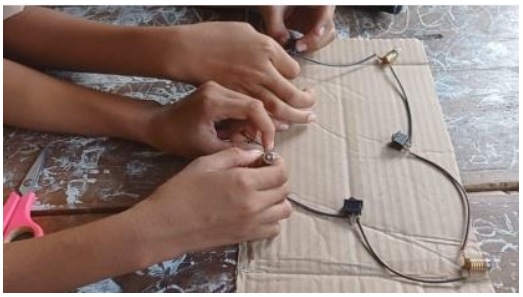

Figure 6. Project Creation

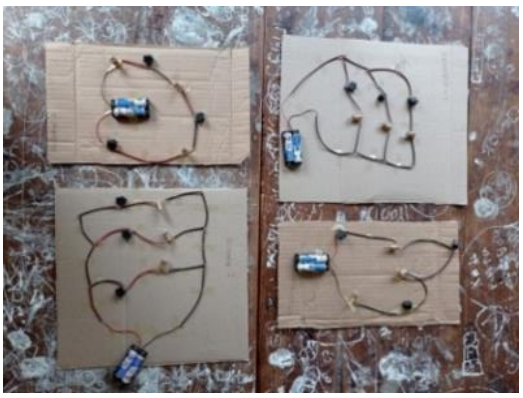

Figure 7. Student Project

In addition, educational songs strengthen students' understanding through lyrics that explain important concepts more memorably. This approach has a positive impact on students' activeness and critical thinking. They are more involved in discussions, actively seek solutions, and show improvement in critical thinking. Simulations provide first-hand experience in understanding concepts, while songs help strengthen their memory.

In the control class, using conventional methods, learning was done through video media. Teachers delivered material related to electrical circuits through lectures and video presentations. Students listened to explanations, took notes, discussed, and answered questions from the teacher. This method was more teacher-centred, with student interaction limited to discussion, question and answer, and exercises.

Although videos can help visualise concepts, students are more passive than the experimental class. They tend to rely on information provided directly without much exploration. Their understanding continues to develop, but they lack the in-depth learning experience compared to using song-assisted PhET Simulations with Project Based Learning to support the learning process.

Pretest and Posttest Score

The pretest was given before the treatment to measure students' initial critical thinking skills, while the posttest was conducted after the learning ended to see the changes. The results of the average pretest and posttest scores are presented in Table 3.

Table 3. Grade Averages

Class	Average Pretest	Averages Pretest
Experiment	34	89
Control	34,7	49

The pretest results indicate that students' average critical thinking skills in both classes were comparable. After learning, there were changes in the value of each class. Following the implementation of learning using song-assisted PhET simulations, the experimental class showed a more substantial improvement than the control class.

A significant improvement has occurred because the use of digital media has been proven to be effective in improving students' critical thinking skills through concept visualisation, increased engagement, and learning motivation [24]. In line with this study, the PhET simulation, with the help of song, provides a more interactive learning experience, allowing students to analyse, evaluate, and create electrical circuits, thus understanding the concepts in depth. In addition, the use of song in learning can create fun learning, which can improve the quality of learning [25]. The combination of PhET and song makes learning more effective than conventional methods.

Normality Test Result

A normality test assessed whether the collected data followed a normal distribution. The Shapiro-Wilk test was utilized for both pretest and posttest results in both groups. The analysis indicated that all significance values > 0.05, confirming that the data met the normality assumption.

Table 4. Normality Test Result

Normality Test	Number of Samples	Sig.	Information
Control pretest	20	0.535	Normal
Control posttest	20	0.141	Normal
Experimental pretest	20	0.478	Normal
Control posttest	20	0.173	Normal

Homogeneity Test Result

A homogeneity test was conducted to ensure that the data from both groups had similar variances, and the results are presented in Table 5. The significance value based on the mean section is 0.758. Since the value is > 0.05, it can be concluded that the two groups have uniform variance or are homogeneous.

Table 5. Homogeneity Test Results

Student Learning Outcome	Levene Statistics	df1	df2	Sig.
Based on Mean	0.097	1	38	0.758
Based on Median	0.080	1	38	0.779
Based on the Median and with adjusted df	0.080	1	36.678	0.779
Based on trimmed mean	0.086	1	38	0.770

Hypothesis Test Results

To determine whether there is a difference between student learning outcomes in the experimental and control groups after the treatment is given, an independent sample t-test is conducted.

Table 6. T-Test Results

Variable	t	df	Sig. (One-Sided)	Sig. (Two-Sided)
Equal variances assumed	-9.367	38	< 0.001	<0.001
Equal variances not assumed	-9.367	28.264	< 0.001	<0.001

The t-test analysis shows a calculated t-value of 9.367 with a significance value (2-tailed) of < 0.05, so Ha is accepted, and H0 is rejected. This signifies a notable disparity in the average posttest scores between the experimental and control groups. Consequently, using PhET simulations integrated with song, reinforced by Project Based Learning, effectively enhances students' critical thinking abilities.

Students in the experimental class can analyse electrical phenomena directly in a virtual environment through PhET Simulation. The learning song also helps reinforce concept recall, making it easier for students to connect theory with practice. This combination creates more meaningful learning and encourages students to explore concepts actively. electrical circuit.

N-Gain Analysis Result

N-Gain analysis was applied to assess the extent of improvement in students' critical thinking skills after the learning process. The results are in the table below.

Table 7. N-Gain Calculation Results

Class	N-Gain	Category
Eksperiment	0.8360	High
Control	0.2287	Low

The analysis results indicate that the experimental group's average N-Gain surpasses that of the control group, implying that incorporating song-assisted PhET simulations has a stronger impact on improving students' critical thinking skills. In the experimental class, where the song-assisted PhET simulation was implemented, the N-Gain value reached 0.8360, falling within the high normalized Gain category ($0.70 \leq g \leq 1.00$). In contrast, the control class, which utilized video-based conventional methods, had an N-Gain value of 0.2287, placing it in the low improvement category ($0.00 \leq g \leq 0.30$). These findings confirm that integrating PhET simulations with songs effectively develops students' critical thinking skills.

The PhET simulation allows students to explore, test, and find solutions in virtual experiments, providing an interactive experience in understanding electrical concepts. Songs act as a tool that strengthens students' memory of electrical concepts, helping them connect theory with practice and improving their understanding of analysing, evaluating, and creating electrical circuits. In this learning, Project Based Learning is a supporting method that encourages students to apply their understanding in real projects so that learning becomes more structured and meaningful.

Critical Thinking Indicator Analysis

Based on Angelo and Facione's theory, critical thinking includes several main components. According to Angelo, critical thinking consists of five main skills, namely analysis (breaking down a concept into smaller parts), synthesis (combining various elements into a new form), recognising and solving problems (using concepts in various contexts), inferring (drawing conclusions based on available information), and evaluating (assessing a concept based on certain criteria) [26].

Conversely, Facione outlined six key critical thinking skills: interpretation (comprehending and deriving meaning from information), analysis (identifying connections between concepts), evaluation (determining the reliability and accuracy of information), inference (drawing conclusions based on evidence), explanation (logically articulating thoughts), and self-regulation (monitoring and adjusting one's thinking process) [27].

In this study, the critical thinking indicators used result from modifications from these two theories, which are adjusted to the needs in measuring students' critical thinking skills. The critical thinking indicators are:

- Analysis: Students are asked to analyse the difference between open and closed circuits, the function of electrical circuit components, the difference between series and parallel circuits, and the characteristics of series and parallel circuits.
- Recognise and Solve Problems: Students are given a picture of an electrical circuit that does not turn on and asked to find the cause and repair solution.
- Evaluation: Students evaluate the switching on or off of lights in series and parallel circuits and the application in everyday life.
- Inference: Students conclude from the results of experiments conducted in PhET simulations.
- Synthesis: Students synthesise the various components of an electrical circuit to create a functioning series or parallel circuit.

This critical thinking indicator is then used to assess student performance in the posttest. After the treatment was administered, the posttest results were analyzed to classify students based on their critical thinking levels according to the predetermined score range [28]. The distribution of students across each category is presented in the table below.

Table 5. Distribution of Students Based on Critical Thinking Ability Category

Score Range	Category	Experiment Class	Control Class
81.25 < X ≤ 100	Very High	15	-
71.5 < X ≤ 81.25	High	5	3
62.5 < X ≤ 71.5	Medium	-	1
43.75 < X ≤ 62.5	Low	-	7
0 < X ≤ 43.75	Very Low	-	9

Most students in the experimental group achieved scores within the high to very high range. Specifically, 15 students attained the very high category with scores between 81,25 < X ≤ 100, while 5 students fell into the high category with scores ranging from 71,5 < X ≤ 81,25. Conversely, in the control group, most students were categorized as low to very low scorers, with only a small number reaching the medium to high category.

For further analysis, the percentage of each critical thinking indicator is mapped in the diagram below.

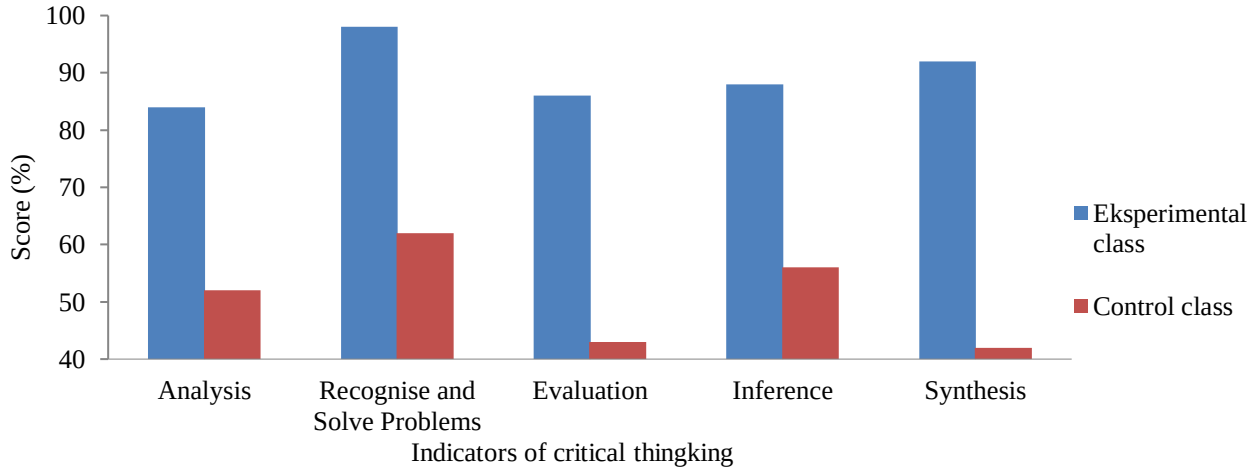

Figure 8. Critical Thingking Presentation

The critical thinking indicator analysis results show that the experimental class that used song-assisted PhET Simulation experienced a higher increase in all critical thinking indicators than the control class.

In the analysis indicator, the experimental class reached 84%, while the control class only reached 52%. Students in the experimental class could better distinguish the characteristics of electrical circuits because they could see the effects of changes directly in the PhET Simulation. In contrast, students in the control class only relied on the video.

The indicator of recognising and solving problems increased by 98% in the experimental class and 62% in the control class. Independent exploration in the PhET Simulation allowed students to identify and correct errors in electrical circuits, while the song helped them better remember the basic concepts of series and parallel circuits.

In the evaluation indicator, the experimental class reached 86%, much higher than the control class of 43%. The PhET simulation allows students to compare lights that are on in series and parallel when there is a change in the location of components or the condition of the switch, as well as to evaluate objects that apply series circuits in everyday life. Song lyrics act as guidelines, such as ‘in a series circuit, if one light goes out, the others go out too, while in a parallel circuit, if one light goes out, the others stay on’, helping students understand and apply this concept better.

The inference indicator is also higher in the experimental class, at 88%, compared to 56% in the control class. Students find it easier to draw conclusions based on experiments because the PhET simulation allows them to observe cause-and-effect relationships in electric currents. At the same time, the song reinforces their understanding of the concept. In addition, the song reinforces the understanding of the concept by reminding students that the lights in a series circuit are dimmer than in a parallel circuit. Through the song's lyrics, students find it easier to remember the difference in brightness of the lights in the two circuits.

Finally, the synthesis indicator shows that the experimental class achieved 92%, while the control class only achieved 42%. The PhET simulation helped students to construct and test series and parallel circuits, while the song made it easier for them to remember the circuit shapes, the arrangement of the lights, and the paths of electric current in both circuits. With the guidance of the song and exploration through the PhET simulation, students could create and understand the characteristics of series and parallel circuits more easily.

The significant difference between the experimental and control classes shows that using PhET Simulation and educational songs improves students‘ critical thinking skills. The song helps strengthen the understanding of the basic concepts of series and parallel circuits, making it easier for students to recognise their characteristics and differences. Meanwhile, PhET Simulation supports deeper exploration of electrical circuits to improve students’ critical thinking skills.

In the PhET simulation ‘Circuit Construction Kit: DC’, students are free to experiment by trying out various electrical circuits without the constraints of laboratory equipment. Students are also allowed to see first-hand electrical circuits that have failed. This ability to observe and correct errors helps students understand electrical concepts more deeply and encourages active involvement in learning. With its interactive features, PhET simulations enhance learning outcomes [29] and conceptual

understanding [30] by allowing direct exploration while also fostering critical thinking skills, including analysis, evaluation, inference, and problem-solving in virtual experiments [31]. Therefore, PhET simulation learning media align with science learning characteristics that require practical work.

In addition, using songs as learning tools can improve students' critical thinking skills. Songs designed to align with the subject matter help students retain key concepts more effectively and stimulate their cognitive abilities, including analysis, evaluation, and synthesis. Through lyrics containing subject matter information, students are invited to relate the concepts in the song to their learning experience, thus encouraging a deeper understanding of electrical circuit material.

Previous research has demonstrated that incorporating song into learning plays a crucial role in enhancing the cognitive abilities of elementary school students. The integration of singing activities in education has been proven to strengthen students' memory, boost motivation, and foster creativity by creating an engaging and stimulating learning environment [32]. Singing helps children retain information by reinforcing concepts through repeated lyrics while making learning more enjoyable, positively impacting their motivation. Additionally, singing activities stimulate students' creativity as they explore ideas while using PhET simulations for electrical circuits, making the learning experience more dynamic, meaningful, and engaging.

Furthermore, studies indicate that incorporating song into learning enhances students' academic performance by fostering an interactive and engaging learning environment [33],[34]. Educationally structured lyrics also support students in grasping learning concepts more effectively [35], enabling them to analyze, assess, and apply the material in a wider context, thereby strengthening their critical thinking abilities [36]. Consistent with these findings, this study demonstrates that combining PhET simulations and songs effectively enhances students' critical thinking skills by promoting active participation and deeper conceptual understanding in the study of electrical circuits.

In line with this, Project Based Learning allows students to apply their understanding in a real context while honing critical thinking skills. The application of Project Based Learning has been proven to encourage the development of high-level thinking skills in students [37]. This method also allows students to connect theory with practice in greater depth while training their independence and collaborative skills.

Thus, learning using PhET simulation media assisted by song with the support of Project Based Learning can improve students' critical thinking. This approach helps students understand the concept of electrical circuits in greater depth and encourages them to analyse, evaluate, solve problems, draw conclusions, and synthesise information independently in a more active and meaningful learning process.

Conclusion

This study confirmed that integrating PhET simulations with songs significantly enhanced students' critical thinking skills. The t-test analysis revealed a t-count value of 9,367 with a significance level of < 0,001, indicating a notable difference in posttest scores between the experimental and control classes. Furthermore, the N-Gain calculation showed that the average improvement in critical thinking skills in the experimental class reached 0,8360 (high category), whereas the control class only achieved 0,2287 (low category). These findings reinforce that combining PhET simulations and songs is more effective in developing students' critical thinking abilities than videos and conventional teaching methods.

Author's Contribution

Nur Maesaroh: designed research, data collection, and data analysis; reviewed the literature; managed communication with the journal; handled revisions, proofread and finalized the manuscript. Putri Yanuarita Sutikno: provided academic guidance, directed the research methodology, and provided input in the preparation and editing of the article.

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