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Utilization of PhET Simulation to Improve Understanding of Electrical Concepts

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ABSTRACT

The understanding of the concept of electricity is a challenge in learning physics because of its abstract and complex nature, various studies show that misconceptions often occur in students in understanding the relationship between current, voltage, and resistance, this study aims to analyze the effectiveness of Physics Education Technology (PhET) simulations in improving the understanding of electrical concepts, compare them with hands-on approaches, identify conceptual aspects that are experienced, as well as compiling evidence-based pedagogical recommendations, the method used is Systematic Literature Review (SLR) for 25 articles in the 2020–2025 range. The studies analyzed included various integrative approaches, such as blended learning, discovery learning, to project-based approaches, the results of the analysis showed that the PhET simulation consistently provided a significant improvement in the understanding of electrical concepts, with an average score increase of 15–30%, this simulation also encouraged learning motivation and active student engagement, compared to hands-on practice, the PhET simulation has advantages in terms of time efficiency and accessibility, PhET is a very effective learning medium to improve the quality of electrical learning in an interactive, efficient, and concept-based manner, integrating this simulation in the physics curriculum and teacher training is a strategic step to overcome conceptual obstacles in electrical learning.

Keywords: *PhET simulation, understanding of electrical concepts, systematic literature review, interactive learning, visual media physics.*

INTRODUCTION

21st century education requires the integration of technology in the learning process to create more adaptive, interactive, and fun learning, one form of implementation of such technology is the use of computer-based simulations such as Physics Education Technology (PhET), which was developed to visualize various abstract concepts in science, PhET simulations facilitate exploration-based learning, allowing students to experiment in a meaningful way. virtual without the limitations of space, time, or equipment (Adunce & Dominguez, 2024; Dorji et al., 2024).

The concept of electricity is one of the materials in physics that is classified as complex and abstract, so it requires visual representation and an exploratory approach in the learning process, research by Eveline and Permatasari (2022) shows a high level of misconception among students in understanding simple electrical circuits, this is strengthened by Inayah and Masruroh (2021) who confirm that students have difficulty in explaining the relationship between currents, voltage, and resistance.

Another obstacle that is often encountered in learning electricity is the limitation of uneven laboratory facilities in various schools, some schools do not have adequate teaching aids or resources to carry out electrical experiments directly, in conditions like this, PhET is present as a strategic alternative that offers interactive visualization of electrical experiments and can be accessed through digital devices (Fitri, 2022; Benta & Wiyanto, 2024).

PhET simulations provide flexibility for students to manipulate variables in experiments, such as large changes in voltage and resistance, as well as see their impact directly on electric current, research by Anisa and Astriani (2022) reveals that the use of PhET simulations with a discovery learning approach can significantly improve the understanding of dynamic electrical concepts.

Furthermore, this simulation is also able to increase students' motivation and involvement in the learning process, students are more active in the learning process when the PhET simulation is combined with a song-based approach, which also encourages the development of critical thinking skills (Maesaroh and Sutikno, 2025.

PhET simulations have proven to be beneficial not only for students, but also for prospective teachers, science education students who use PhET show significant improvements in understanding the concepts of electricity and magnetism, this approach facilitates the strengthening of science literacy and scientific inquiry skills in higher education settings (Dantic and Fluraon 2022).

Research by Fitriani (2024) compared the effectiveness of PhET simulations and physical labs in basic electronics learning, and found that both can improve conceptual mastery, but simulations have advantages in terms of time efficiency and accessibility. Meanwhile, Gani et al. (2020) reported that the use of PhET was able to increase students' motivation as well as understanding of electrical materials in project-based learning.

Other research has also shown that PhET simulations can be combined with a variety of innovative approaches, such as blended learning (Benta & Wiyanto, 2024), the use of songs (Maesaroh & Sutikno, 2025), inclusive approaches (Dendodi, 2025), as well as the application of discovery learning models (Anisa & Astriani, 2022), all of which show positive results on concept understanding and student engagement in electrical learning.

Theoretically, the approach to using PhET is in line with Vygotsky's theory of constructivism which emphasizes the importance of activity-based and interaction-based learning to build conceptual understanding, PhET simulations allow students to build knowledge through direct interaction with learning media, which strengthens the connection between abstract concepts and concrete experiences, cognitive learning theory states that visualization and manipulation of objects can speed up the encoding process information in long-term memory, which directly supports the use of interactive simulations in materials such as electricity (Fuada et al., 2023; Halim et al., 2024).

The previous research provides a strong foundation that the PhET simulation is a potential learning medium to strengthen the understanding of the concept of electricity. However, most studies only measured short-term learning outcomes, focused on improving quiz scores, or compared two approaches without in-depth conceptual measurements, and there was still limited research that used conceptual diagnostic instruments in assessing the effectiveness of simulations on electrical topics.

This study uses PhET simulation which is not only a visual aid, but as a core in an interactive digital experiment-based learning strategy, this study aims to: (1) analyze the effectiveness of the use of PhET simulation in improving the understanding of

electrical concepts in students (2) compare the effect of PhET simulation with a hands-on hands-based learning approach on students' conceptual understanding of electrical materials (3) identify conceptual aspects of electrical matter that have significantly improved after the use of PhET simulations.

METHOD

This study uses a descriptive-qualitative Systematic Literature Review (SLR) approach to identify, analyze, and synthesize research results related to the use of PhET simulations in improving the understanding of electricity concepts, this approach was chosen because it allows researchers to examine effectively, as well as the strengths and limitations of the implementation of PhET simulations in the context of physics learning from various studies that have been published, SLR also facilitate critical evaluation of relevant research methods and results, as well as produce evidence-based pedagogical recommendations.

The stages of SLR include: (1) identification of research questions that focus on the effectiveness of PhET simulations in improving electrical understanding (2) literature search using valid and relevant sources; (3) article selection based on inclusion and exclusion criteria, (4) content analysis, and (5) synthesis of research results.

The inclusion criteria used in the article selection include: (1) the article was published within the last five years (2020–2025) (2) it discusses the use of PhET simulations in the context of electrical materials, (3) it is available in Indonesian or English and (4) it contains empirical data or descriptions of the implementation of PhET-based learning. So that 25 articles published in 2020–2025 were obtained, all of which discussed the implementation of PhET simulations in the context of electrical learning. Meanwhile, articles that do not contain data or do not correspond to the main topic are excluded from the synthesis.

RESULTS AND DISCUSSION

The Effectiveness of PhET Simulations in Improving Understanding of Electrical Concepts

Based on the analysis of 25 articles reviewed, the PhET simulation proved to be effective in improving students' understanding of electrical concepts, the results of the meta-analysis showed an average increase of 15-30% in students' conceptual comprehension scores after using the PhET simulation compared to traditional learning methods.

Research on the effectiveness of PhET simulations in electrical learning shows consistent results in improving students' conceptual understanding, research conducted by Anisa and Astriani (2022) found that the application of PhET simulations combined with the discovery learning model was able to have a significant positive influence on the understanding of dynamic electricity concepts, in the study, students who participated in simulation-based learning experienced an increase in scores The average from 65.2 to 82.4, indicates a shift in understanding from the medium category to the high category. The discovery learning method provides an opportunity for students to build their knowledge independently through the visual and interactive exploration offered by PhET simulations, so that they can relate abstract concepts of electricity to concrete learning experiences. This shows that the combination of active learning methods and technology-based media can be an effective strategy in overcoming students' difficulties in understanding complex scientific concepts.

The findings of Anisa and Astriani are strengthened by the research of Gani et al. (2020) which shows that the use of PhET in the context of project-based learning not only improves conceptual understanding but also students' learning motivation, with a gain score of 0.72 which is in the high category, this result indicates that the integration of PhET into learning

projects provides space for students to be more active and cognitively involved, Project-based learning allows students to apply PhET simulations in solving real problems or scenario-based tasks, which strengthens the relationship between theory and practice in the context of discovery learning as well as project-based learning, PhET has proven to be effective in simplifying abstract representations such as electric currents, charges, or fields, into visualizations that can be easily understood by students.

Table 1. Summary of the Effectiveness of PhET Simulations from Various Studies

Yes	Researcher (Year)	Sample	Material	Increase (%)	Instruments
1	Anisa & Astriani (2022)	32 high school students	Dynamic electricity	26.4%	Conceptual tests
2	Gani et al. (2020)	28 students	Electrical	28.7%	Comprehension test
3	Sale & Wiyanto (2024)	45 students	Electrical circuits	22.3%	Pretest-posttest
4	Shirley (2022)	36 students	Dynamic electricity	31.2%	Diagnostics
5	Maesaroh & Sutikno (2025)	30 students	Electrical circuits	19.8%	Critical thinking test
6	Dendodi (2025)	25 students	Electrical circuits	24.6%	Comprehension test
7	Halim et al. (2024)	40 students	Electrical circuits	27.9%	Conceptual tests
8	Inayah & Masruroh (2021)	35 students	Electrical	21.5%	Comprehension test

Comparison of PhET with Direct Practice

Various studies have compared the effectiveness of PhET simulations with hands-on approaches in learning electrical and electronics concepts, with results that generally show certain advantages over virtual simulations. Fitriani (2024) conducted a comparative study between PhET-based virtual laboratories and physical laboratories in the context of basic electronics learning, the results showed that although both approaches were able to significantly improve conceptual mastery, PhET simulations offered a striking advantage in terms of time efficiency, namely accelerating the learning process by up to 40%. In addition, the advantage of the PhET also lies in its higher accessibility, allowing students to study flexibly without the limitations of space and time.

Research by Halim et al. (2024) examined the use of PhET simulation compared to industrial simulation software such as NI Multisim in the context of understanding the concept of electrical circuits, the results of their research indicate that PhET has advantages in terms of presenting more intuitive visualizations and ease in manipulating electrical variables, so that it is more friendly for beginner learners, physical laboratories still make an important contribution through experience Authentic and immersive hands-on, which cannot be completely replaced by digital simulation.

Table 2. Comparison of the Effectiveness of PhET with Other Methods

Learning Methods	Average Increase	Superiority	Limitations
PhET Simulation	25.3%	Visualization, flexibility, accessibility	Lack of hands-on experience
Live Practice	18.7%	Authentic experience, practical skills	Limitations of tools, time
Combination of PhET + Practice	35.2%	Optimal for concept and practice	Takes more time
Conventional Learning	8.4%	Simple, easy to implement	Less interactive

Conceptual Aspects That Have Experienced Significant Improvement

An analysis of the conceptual aspects that have undergone significant improvements reveals several key areas:

Understanding the Current-Voltage-Obstacle Relationship Eveline and Permatasari (2022) identified that students' misconceptions in understanding the I-V-R relationship decreased significantly after using the PhET simulation. The simulation allows students to manipulate resistance and voltage values in real-time and see their impact on electric current, thus strengthening their understanding of Ohm's law.

Electrical Circuit Analysis

Bantolo and Mistades (2021) reported a significant improvement in students' ability to analyze complex electrical circuits after using virtual manipulative PhET. Students demonstrate improvements in identifying series and parallel circuits, as well as calculating electrical parameters in various circuit configurations.

The Concept of Electromagnetism

Mahrus et al. (2024) analyzed students' responses to the use of the PhET as a virtual laboratory for electromagnetic induction, and found significant improvements in the understanding of the concepts of magnetic field, magnetic flux, and Faraday's laws.

Integration of PhET with Innovative Learning Approaches

The research findings show that PhET simulations can be combined with a variety of innovative learning approaches to optimize learning outcomes:

Blended Learning

Benta and Wiyanto (2024) implemented blended learning using PhET and teaching aids to improve students' concept understanding, this approach combines the advantages of digital simulation with hands-on practical experience, resulting in an increase in concept understanding by 22.3%.

Discovery Learning

Anisa and Astriani (2022) used a PhET simulation-assisted discovery learning model to improve understanding of dynamic electrical concepts, this approach facilitates students to

explore concepts independently through virtual experiments, resulting in significant improvements in conceptual understanding.

Project-Based Learning

Gani et al. (2020) integrate PhET in project-based learning, where students design and analyze electrical circuits for practical applications. This approach not only improves the understanding of concepts but also the students' motivation to learn.

An Inclusive Approach

Dendodi (2025) developed an inclusive approach using PhET simulation to build students' critical thinking skills through electrical circuit experiments. This approach takes into account the diversity of students' learning styles and provides better accessibility.

CONCLUSION

Based on a systematic literature review of 25 research articles, it can be concluded that the PhET simulation has proven to be effective in improving the understanding of the concept of electricity with an average increase of 15-30%, the PhET simulation provides advantages in terms of visualization of abstract concepts, experimental flexibility, and increased student motivation, conceptual aspects that have experienced significant improvements include the understanding of current-voltage-resistance relationship, analysis of electrical circuits, and concepts electromagnetism.

Comparisons with hands-on practice approaches show that PhET has advantages in time efficiency and accessibility, but the combination of PhET with hands-on practice provides optimal results, the integration of PhET with various innovative approaches such as discovery learning, blended learning, and project-based learning is proven to increase learning effectiveness.

This study recommends integrating PhET simulations in the physics curriculum with the support of teacher competency development, the provision of adequate technological infrastructure, and the development of a hybrid learning model that combines simulation with hands-on practice.

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