Electronic Journal of Education, Social Economics and Technology
Vol. 6, No. 2, (2025), pp. 1~7, Article ID: 861
ISSN 2723-6250 (online)
DOI: https://doi.org/10.33122/ejeset.v6i2.861

SAINTIS publishing

Research Article

The Implementation of PhET Simulation Media to Improve Junior High School Students' Understanding of Heat and Heat Transfer Concepts

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ABSTRACT

This study aims to determine the effect of using PhET (Physics Education Technology) simulation media on enhancing students' conceptual understanding of heat and heat transfer at SMP Negeri 1 Cot Girek. The research employed a quantitative approach using a quasi-experimental design with a non-equivalent control group type. The sampling technique used was purposive sampling, involving a total of 50 students—Class VII A as the experimental group and Class VII B as the control group, each consisting of 25 students. The instrument used was a multiple-choice test administered as both a pretest and a posttest to measure students' conceptual understanding. The results showed that the average posttest score in the experimental class was 71.4, while in the control class it was only 52.8. Hypothesis testing using an independent sample t-test on the posttest data revealed a significance value of 0.001 (< 0.05), indicating a significant difference between the two classes after the treatment. Meanwhile, the N-gain scores showed an improvement of 71% (high category) in the experimental class and 54% (medium category) in the control class. Thus, it can be concluded that the use of PhET simulation media is effective in improving students' conceptual understanding of heat and heat transfer, especially in schools with limited laboratory facilities.

Keywords: PhET simulation; heat; conceptual understanding; interactive learning

1. INTRODUCTION

Education in the 21st century demands adjustments to align with the developments of the times, especially in preparing students to face global challenges. One form of such adaptation is the implementation of learning that emphasizes scientific analytical skills and the use of modern technology in the teaching and learning process (Fatikasari et al., 2020). In line with the rapid development of information and communication technology, the paradigm of science education has also undergone significant changes, particularly through the integration of interactive digital media in the learning process (Rizaldi et al., 2020). The use of various learning media not only changes the way teachers deliver material but also influences how students access and understand information. Moreover, digital media opens up broad opportunities for educators to apply various innovative and creative learning strategies (Pranowo et al., 2017).

Physics is a part of the natural sciences (IPA) subject developed to help students focus more deeply on understanding scientific concepts. One topic that often causes misconceptions among students is the topic of heat and heat transfer, which includes the concept of heat affecting changes in the state of matter, Black's principle, and mechanisms of heat transfer (Sofianto & Irawati, 2020). One particularly impactful innovation is the use of interactive simulations as an alternative to overcome the limitations of access to conventional laboratories, especially in physics learning which is rich in abstract concepts such as heat, energy, and heat transfer (Muzana & Astuti, 2017). The concept of heat plays an important role in physics because it is closely related to its applications in various fields of science and technology. However, students still often struggle to understand this concept comprehensively (Reyza et al., 2019).

Every student needs to have a strong conceptual understanding in learning physics (Nur & Arif, 2024). To achieve learning goals, several alternative interactive learning solutions can be implemented, including project-based learning (Cintya Bupu et al., 2025), demonstration-based learning (Irawati et al., 2024), video-based learning (Faiza et al., 2023), simulation-based learning (Nurulhidayah et al., 2020), and animation-based learning (Margaret Pandaleke, Munzil, 2020).

As an alternative solution, learning can be conducted using interactive simulation media such as PhET (Afrianti et al., 2022; Fathurohman et al., 2018). The use of PhET can improve conceptual understanding of thermodynamics by up to 40% in urban school contexts (Wieman et al., 2008). Digital media such as PhET (Physics Education Technology) simulations function as cognitive bridges that connect theoretical content with concrete and engaging learning experiences. Learning becomes more effective when information is presented both visually and verbally, as it reduces cognitive load and helps form stronger mental representations (Mayer, 2009). In addition, PhET simulations not only support individual learning but can also be integrated into group learning to strengthen conceptual understanding. PhET Colorado simulations are designed as discovery-based media that are enjoyable and effective in explaining physics concepts and phenomena typically practiced in laboratories (Mubarrok et al., 2014).

However, exploration of the effectiveness of PhET simulations in schools with limited infrastructure, particularly in rural areas of Indonesia such as Aceh, is still very limited. Preliminary findings at SMP Negeri Cot Girek indicate that the physics learning process, particularly on the topic of heat and heat transfer, is still dominated by lecture methods (around 92% of learning activities), without laboratory facilities. Interviews with science teachers revealed that students have difficulty understanding the processes of heat conduction and convection through verbal or text-based explanations alone. As a result, 85% of students did not meet the Minimum Mastery Criteria (KKM), with an average score of only 34.7 out of 100.

In the context of this problem, this study aims to examine the effect of implementing PhET simulations on students' understanding of heat and its transfer in Grade VII students at SMP Negeri Cot Girek. This research specifically explores the effectiveness of using PhET simulations in rural school environments in Indonesia with limited technological infrastructure. Theoretically, the findings of this study are expected to enrich the discourse on the application of multimedia learning theory and digital scaffolding strategies in science education in resource-limited areas. Practically, the results of this study provide empirical contributions and actionable recommendations for physics teachers in remote areas to adopt simulation-based learning approaches as adaptive and effective alternatives to virtual laboratories.

2. RESEARCH METHOD

This study employed a quantitative approach using a quasi-experimental design, specifically the pretest-posttest nonequivalent control group design(Creswell, 2012). Two groups were involved as samples: Class VII A served as the experimental group, which utilized the PhET simulation "Energy Forms and Changes," while Class VII B functioned as the control group, receiving conventional instruction through lectures and student worksheets (LKS). The research design used is illustrated as follows:

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_2	-	O_4

Source: (Sugiyono, 2016)

The study was conducted at SMP Negeri 1 Cot Girek, North Aceh, using a purposive sampling technique. The sample consisted of 50 students, with 25 students in each group, selected based on the equivalence of their previous science (IPA) scores. The test instrument used was a multiple-choice questionnaire administered as both a pretest and a posttest to both groups. The data from the pretest and posttest were used to measure students' conceptual understanding of heat and its transfer. Data analysis was performed using SPSS version 25, which included prerequisite tests such as the normality test (Shapiro–Wilk) and homogeneity test (Levene's Test), as well as the hypothesis test using an Independent Samples t-test.

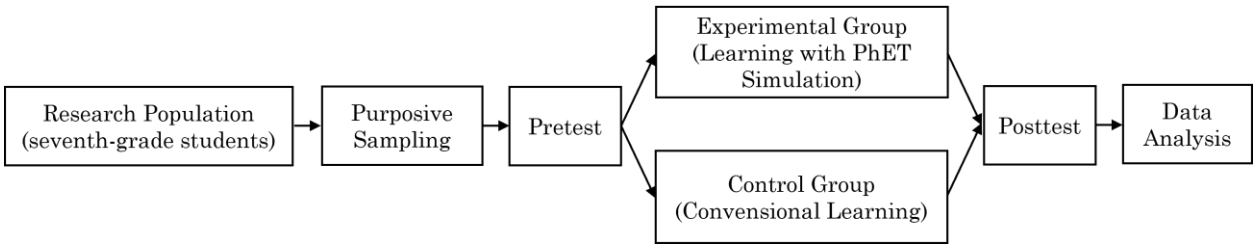

Figure 1. Research flow of quasi-experimental design with pretest-posttest nonequivalent control group model.

3. RESULTS AND DISCUSSION

3.1 Results

This study was conducted at SMP Negeri 1 Cot Girek with Grade VII students. The research sample consisted of Class VII A as the experimental group and Class VII B as the control group. The experimental group received instruction using PhET (Physics Education Technology) simulation media, while the control group did not use this media. Data were collected through pretest and posttest assessments to measure students' conceptual understanding of heat and its transfer. The instrument was previously tested on students from Classes VIII B and VIII C to evaluate its validity, reliability, level of difficulty, and discrimination index. The following are the pretest and posttest data from each group:

Table 2. Descriptive Statistics of Students' Conceptual Understanding

Descriptive Statistics						
	N	Minimum	Maximum	Mean	Students Achieving KKM	Std. Deviation
Experimental Pretest	25	20	45	36.80	0 %	9.341
Experiment Posttest	25	55	85	71.40	64 %	8.231
Control Pretest	25	15	45	32.60	0 %	5.612
Control Posttest	25	25	70	52.80	8 %	11.644

The descriptive statistical results in **Table 2**, Shown that the experimental group experienced an increase in the average score from 36.80 on the pretest to 71.40 on the posttest, with 64% of students achieving scores above the Minimum Mastery Criteria (KKM). Meanwhile, the control group showed only a slight increase from 32.60 to 52.80, with only 8% of students reaching the KKM. These results indicate a more significant improvement in conceptual understanding in the experimental group.

Table 3. Normality Test Results for Pretest and Posttest

	Class	Shapiro-Wilk		
		Statistics	Df	Significant
Understanding Student Concepts	Experimental Pretest	0.944	25	0.185
	Experiment Posttest	0.945	25	0.210
	Control Pretest	0.955	25	0.129
	Control Posttest	0.935	25	0.154

Based on **Table 3**, the results of the normality test show that the significance value for the pretest data in the experimental group is 0.185, and for the control group is 0.129. Meanwhile, the significance value for the posttest in the experimental group is 0.210, and in the control group is 0.154. All of these values are greater than 0.05, indicating that the data in each group meet the assumption of normality.

Table 4. Homogeneity Test Results for Pretest and Posttest between Experimental and Control Groups

	Lavene statistic	df1	df2	Sig.
Based on mean Pretest	1.968	1	48	0.167
Based on mean Posttest	4.013	1	48	0.051

The results of the homogeneity test, as shown in **Table 4**, indicate that the significance value for the pretest data in the experimental and control groups is 0.167, which is greater than 0.05. This suggests that the variance of the pretest data from both groups is homogeneous. As for the posttest data, the significance value obtained is 0.051. Although this value is close to the 0.05 significance threshold, it still exceeds 0.05, indicating that the variance of the posttest data can also be considered homogeneous. Therefore, the homogeneity test results for both the pretest and posttest data confirm that the variances between the two groups are homogeneous.

Table 5. Independent Sample t-test Results for Pretest and Posttest between Control and Experimental Groups

	Equality of Variances			t-test for Equality of Means
	T	Df	Sig	Sig.(2-tailed)
Equal variances assumed Pretest	3.638	48	0.62	0.060
Equal variances assumed Posttest	2.319	48	0.045	0.001

The t-test on the pretest results showed no significant difference between the experimental and control groups, with a significance value of 0.060 > 0.05. However, the posttest results indicated a significant difference, with a significance value of 0.001 < 0.05, suggesting that the use of the PhET simulation had a meaningful impact on improving students' conceptual understanding. The N-gain calculation revealed that the improvement in learning outcomes for the experimental group reached 71%, which falls into the high category. In contrast, the control group showed only a 54% increase, categorized as moderate. These findings indicate that the use of PhET simulation media is more effective in enhancing students' conceptual understanding of heat and its transfer compared to conventional teaching methods.

3.2 Discussion

The results of the study show that the implementation of PhET simulation media significantly improves students' conceptual understanding of heat and its transfer. This is evidenced by the average posttest score of the experimental group, which reached 71.40, higher than the control group's score of 52.80. In addition, 64% of students in the experimental group achieved scores above the Minimum Mastery Criteria (KKM), far exceeding the 8% in the control group. This indicates that students who used interactive simulation media achieved better learning outcomes than those taught through conventional methods (Mawaddah et al., 2023). Accordingly, the use of PhET simulations in cooperative learning models significantly enhances students' conceptual understanding (Ginting et al., 2020). Furthermore, PhET media is also effective in improving cognitive, affective, and psychomotor learning outcomes (Sari, 2020).

An increase in students' conceptual understanding is also reflected in the percentage of students meeting the KKM, which rose from just 15% (based on prior interviews) to 64%. This aligns with the findings of (Revvina et al., 2023), who reported an average score of 65.25, with many students achieving scores above 70. Thus, it can be concluded that implementing learning with the virtual PhET laboratory significantly contributes to student mastery in physics learning, particularly for Grade XI in senior high schools. Similarly, research by (Saputra et al., 2020) showed a notable improvement in students' physics learning outcomes, with an average increase of 50.47 points in the experimental class, compared to 42.40 in the control class. Other studies have also integrated PhET simulations with additional supports, such as student worksheets (Frans & Wasis, 2022; Mahardika et al., 2022), e-learning platforms (Suhardiman et al., 2022), the inquiry-based learning model (Fatikasari et al., 2020), and discovery learning (Widia, 2020), all of which demonstrated improved student learning outcomes. Throughout the learning process, students in the experimental group displayed high levels of enthusiasm. They appeared more active, engaged, and better able to grasp abstract concepts thanks to visual aids provided through PhET simulations. This improvement in conceptual understanding may also be influenced by student attitudes, as a positive correlation has been found between the two variables (Rizkita & Mufit, 2022). In today's digital age, the use of interactive media in learning is more likely to capture students' attention, especially when supported by videos and other multimedia tools (Barokah et al., 2024).

The application of PhET media in learning significantly enhances student engagement and conceptual mastery (Fitria et al., 2023; Ulfah, 2020). These simulations provide dynamic representations that help students connect theoretical concepts with real-world phenomena. However, during implementation, several technical challenges were encountered, such as students' lack of computer literacy and limited access to functioning computer equipment. These findings are important to consider, as in the digital era, the use of digital tools and platforms tends to increase students' engagement time beyond formal class schedules. This aligns with Giunchiglia et al. (2018), who found that the use of digital technology without sufficient control can lead to digital distractions and prolonged learning time without improving effectiveness. Similarly, a study by (Chang et al., 2023) found that media multitasking does not make students more efficient; instead, it fosters poor habits, highlighting the importance of establishing proper communication channels to manage such issues effectively. In contrast, the control group received instruction through conventional methods without the use of interactive media, relying solely on textbooks. Most students in this group demonstrated passive behavior. They were less likely to ask questions when confused and often completed the posttest carelessly. This contributed to their lower learning outcomes, as seen in their lower average posttest scores and fewer students meeting the KKM.

Beyond improving conceptual understanding, the use of PhET simulation media also contributes to enjoyable and motivating learning experiences, encouraging students to study independently (Prima et al., 2018; Susilawati et al., 2022). Interactive simulations help build more engaging and participatory learning environments. Through the visual and animated features offered by PhET, students can explore learning content directly, increasing curiosity and helping them connect theoretical concepts with everyday phenomena (Rayan et al., 2023). Therefore, this media holds great potential for integration into physics learning at the junior high school level, especially in schools with limited laboratory facilities. Several methods have shown significant impact, such as Contextual Teaching and Learning (CTL) through group discussions using PhET (Sukamto, 2022), Discovery Learning for science process skills (Rahmiyati et al., 2023), and Quantum Learning on pressure topics (Utami et al., 2024). Thus, the use of PhET simulation media can serve as an effective learning strategy to enhance students' conceptual understanding, particularly on the topic of heat and its transfer.

4. CONCLUSION

Based on the research findings, it can be concluded that the implementation of PhET simulation media significantly contributes to improving students' conceptual understanding of heat and its transfer. This is evidenced by the N-gain analysis results, which show a 71% improvement in the experimental group, compared to only 54% in the control group. The hypothesis testing using an independent samples t-test on the pretest data yielded a significance value of 0.060 (> 0.05), indicating no significant difference in initial ability between the two groups. However, the posttest results showed a significance value of 0.001 (< 0.05), indicating a significant difference between the experimental and control groups after the treatment. The average pretest score of the experimental group was 36.80, which increased to 71.40 on the posttest, with 64% of students achieving the Minimum Mastery Criteria (≥ 70). Meanwhile, the control group's average score increased from 32.60 to 52.80, with only 8% of students meeting the KKM. Thus, the use of PhET simulations is more effective than conventional teaching methods in enhancing students' conceptual understanding. This media provides a more interactive and visually representative learning experience, while also promoting active student engagement in understanding abstract physics concepts.

ACKNOWLEDGEMENTS

The author would like to express sincere gratitude to SMP Negeri 1 Cot Girek for granting permission and the opportunity to conduct this research at the school. Appreciation is also extended to all parties who contributed to the smooth implementation of this research.

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