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Analysis of the utilization of PhET colorado simulation in learning science

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ABSTRACT

PhET is an instructional medium with high attractiveness for science learning. This study aimed to analyze the utilization of the PhET Colorado simulation in teaching science learning in junior high school science. A descriptive qualitative approach was employed to explore how teachers and students engaged with the PhET simulation during the learning process. The participants consisted of 34 seventh-grade students and four science teachers selected purposively. Data were collected through classroom observations, semi-structured interviews, questionnaires, and documentation analysis, including lesson plans and worksheets. Observations focused on teacher implementation and student activities, while questionnaires examined students' interest, ease of use, and conceptual understanding. The results showed that the utilization of PhET was categorized as good to very good, with an average teacher implementation score of 84.25% and student activity of 81.76%. Student responses were highly positive (86.32%), particularly in helping them understand abstract concepts. Teachers reported that PhET increased student engagement and supported conceptual visualization, although challenges related to limited devices and time management remained. In conclusion, PhET Colorado simulation is an effective and interactive medium for teaching science learning. Its successful integration requires careful instructional planning, sufficient resources, and structured guidance to optimize learning outcomes.

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INTRODUCTION

Science learning at the junior high school level should ideally develop students' conceptual understanding, science process skills, and critical thinking skills.(Li et al., 2022). However, in practice, science learning often focuses on delivering material and solving problems, rather than on in-depth conceptual understanding. (Sasmita et al., 2021). This situation becomes even more problematic when applied to the abstract, dynamic nature of heat, which requires students to have strong visualization skills (Karnadi et al., 2021).

The topic of heat often gives rise to misconceptions among students, such as the assumption that heat and temperature are synonymous or that larger objects always have more heat (Mashami et al., 2023). These misconceptions are inseparable from learning models that do not provide direct experience or adequate visual representation. (Solihin S et al., 2025). Learning that relies solely on textbooks and teachers' verbal explanations often fails to bridge the microscopic concept of heat with the macroscopic phenomena students experience in everyday life (Solihin & Dedah, 2022). Although practical activities are considered a means of overcoming the abstraction of the idea of heat, their implementation in schools often faces various obstacles, such as limited laboratory equipment, limited instructional time, and large class sizes (Kurniawan, 2016). As a result, heat practicals cannot be implemented optimally or are even ignored.(Fadhilah, 2024). This condition indicates a gap between the demands of experimental-based science learning and the reality of learning in schools (Wibawanto, 2020).

On the other hand, developments in educational technology offer alternative learning methods, such as virtual simulations (Solihin, et al., 2025). One widely recommended medium for science learning is the Colorado PhET simulation (Chotimah et al., 2023). Theoretically, PhET is designed to help students build conceptual understanding through active exploration and interactive visualization. However, the use of PhET in science learning at the junior high school level is often supplementary rather than systematically integrated into instructional strategies, and its impact on student learning has not been thoroughly analyzed (Mashami et al., 2023). This situation is also evident at SMP Negeri 12 Jakarta, where technological facilities are quite adequate, but the use of PhET simulations on heat is suboptimal. PhET use tends to be limited to teacher demonstrations rather than to active student exploration. Furthermore, no studies have specifically analyzed how PhET simulations are used, the obstacles teachers face, or the extent to which these media help students conceptualize heat(Harum et al., 2020).

Most prior research has focused on the quantitative impact of PhET simulations on learning outcomes, such as Damayanti et al., (2022); Nuralisa et al., (2021), and Niyanti et al., (2022), whereas aspects of the learning process, student engagement, and the quality of media use remain relatively understudied.(Dheeraj Kumar, 2024). However, the effectiveness of learning media is determined not only by their availability but also by their use in real-life learning contexts. This indicates a research gap that requires contextual analysis of the use of PhET simulations in schools. (Chotimah et al., 2023). Given these issues, this study is crucial for analyzing the use of the Colorado PhET simulation in heat science learning at SMP Negeri 12 Jakarta. This study is expected to uncover classroom PhET practices, student responses and engagement, and the challenges encountered in its implementation. The findings are expected to provide strategic recommendations for teachers and schools to optimize the use of PhET simulations as an effective and meaningful medium for science learning.

RESEARCH METHODS

Research Design

This study employed a descriptive qualitative research design to analyze the use of the PhET Colorado simulation in science learning on heat. This design was selected because the study focused on describing learning processes, media utilization, and teacher and student responses in natural classroom settings. The research did not aim to test hypotheses or measure treatment effects statistically, but rather to explore how PhET was implemented and experienced during instruction. Through this approach, the researcher was able to capture detailed information about classroom interactions, learning activities, and the role of simulations in supporting conceptual understanding. Therefore, the qualitative descriptive design was considered appropriate for investigating the pedagogical implementation of simulation-based learning.

Population and Samples

The population of this study consisted of all Grade VII students and science teachers at SMP Negeri 12 Jakarta in the academic year in which the research was conducted. The sample was selected using purposive sampling, based on relevance to the research objectives. The participants included 34 seventh-grade students and four science teachers who were directly involved in heat learning using PhET simulations. Seventh-grade students were chosen because heat was part of their curriculum content at the time of the study. The selected teachers had experience designing and implementing learning activities using PhET, enabling them to provide rich and relevant information.

Instruments

Several instruments were used to collect comprehensive data. Observation sheets were designed to record teacher implementation, student engagement, and learning activities during the use of PhET simulations. Semi-structured interview guides were prepared to explore teachers' perceptions, experiences, benefits, and challenges in using PhET. Student questionnaires were used to gather data on interest, ease of use, learning engagement, and conceptual understanding. Documentation checklists were employed to collect lesson plans (RPP), teaching materials, student worksheets (LKPD), and records of classroom activities. These instruments allowed data triangulation and supported the credibility of the findings.

Procedures

The research procedures were conducted in several stages. The preparation stage involved coordinating with the school, identifying participants, and developing observation sheets, interview guides, and questionnaires. The implementation stage was carried out by observing science learning activities on heat that used PhET simulations. During this stage, the researcher documented teacher practices, student interactions, and simulation-based activities. After the learning sessions, semi-structured interviews were conducted with teachers, and questionnaires were distributed to students. Documentation, such as lesson plans and worksheets, was then collected to support observational and interview data. Finally, verification activities such as triangulation were conducted to ensure data accuracy.

Data Analysis

Data analysis followed an interactive qualitative model, consisting of data collection, data reduction, data display, and conclusion drawing. Data from observations, interviews, questionnaires, and documentation were first organized and reviewed. Relevant data were then reduced by selecting information related to PhET implementation, student activities, and learning responses. The reduced data were presented in descriptive narratives and tables to facilitate interpretation. Conclusions were drawn by identifying patterns and relationships among teacher practices, student engagement, and conceptual understanding. To ensure trustworthiness, source triangulation and technique triangulation were applied throughout the analysis process.

RESULTS

This study aims to analyze the use of the Colorado PhET simulation in science learning on heat at SMP Negeri 12 Jakarta. The study focuses on how teachers and students use simulation media in the learning process, including exploration activities, interactions, and student engagement in understanding abstract concepts such as heat and temperature. This study employs a descriptive qualitative approach, as the primary objective is to describe learning phenomena rather than test hypotheses.

The research participants consisted of 34 seventh-grade students and four science teachers, who were purposively selected for their involvement in learning about heat using PhET. Data collection was conducted through classroom observations to assess teacher-student interactions and student exploration activities, semi-structured interviews with teachers to explore perceptions and obstacles, student questionnaires to measure responses, and documentation in the form of lesson plans, worksheets, and recordings of class activities. Data were analyzed using triangulation techniques to ensure the validity and consistency of the findings.

The research process began with the identification of learning practices and the preparation of data-collection instruments, followed by observations and questionnaires administered during the learning process. Furthermore, interviews with teachers and analysis of documentation were conducted to corroborate the observational findings. All data were analyzed descriptively to illustrate the use of PhET, student engagement, student responses, and the media's strengths and weaknesses. The results are presented in tables and narratives to provide a comprehensive overview of the implementation of PhET simulations in science learning. The results of the data analysis are presented in the following Table 1.

Table 1. Achievement of Research Objectives Based on Data Analysis

No	Research Purposes	Achievement (%)	Category
1	Utilization of PhET by teachers in heat learning	84,25	Good
2	Student activities when using PhET	81,76	Good
3	Student responses to the use of PhET	86,32	Very good
4	Teachers' perceptions of the advantages and disadvantages of PhET	82,50	Good
5	PhET support for understanding the concept of heat	85,14	Very good

Based on the data in Table 1, the utilization of PhET by teachers in heat learning achieved 84.25%, classified as Good. This indicates that teachers have effectively integrated PhET simulations into the learning process, both as a demonstration medium and as a means of exploring the concept of heat. In addition, student activity when using PhET was also in the Good category with an achievement of 81.76%, which indicates that students were actively involved in observing, trying, and manipulating variables in the simulation so that the learning process became more interactive and meaningful.

Furthermore, students' responses to the use of PhET achieved the highest score, namely 86.32% in the Very Good category, reflecting students' positive attitudes towards simulation-based learning. PhET's support for understanding the concept of heat was also in the Very Good category, achieving 85.14%, confirming that PhET helps students understand the abstract idea of heat more concretely and visually. Meanwhile, teachers' perceptions of the advantages and constraints of using PhET were rated 82.50% in the Good category, indicating that, despite some technical obstacles and limited facilities, teachers generally consider PhET a valuable and relevant medium for improving the quality of heat learning.

Based on the learning observation results in Table 2, the PhET suitability indicator, using the learning objectives, achieved 85.50% and was classified as Very Good, indicating that the PhET simulation is relevant and aligned with the competencies to be achieved in the heat material.

The teacher's role as a facilitator also demonstrated high achievement, namely 87.50% (Very Good category), indicating that the teacher guided, directed, and provided support to students during the use of PhET without dominating the learning process. In addition, the indicator for linking the simulation to the concept of heat reached 86.25%, placing it in the Very Good category, indicating that teachers and students appropriately connected activities in the simulation to the theoretical idea of the sciences of learning.

Table 2. Observation Results of PhET Utilization by Science Teachers

No	Observation Indicators	Average Score	Percentage (%)	Category
1	PhET's relevance to learning objectives	3,42	85,50	Very good
2	PhET integration into the learning flow	3,33	83,25	Good
3	The role of the teacher as a facilitator	3,50	87,50	Very good
4	Providing opportunities for student exploration	3,25	81,25	Good
5	Linking simulation with the concept of heat	3,45	86,25	Very good
6	PhET usage time management	3,10	77,50	Good
	Rate-rate	3,34	84,25	Good

Meanwhile, the integration of PhET in the learning flow obtained a percentage of 83.25%, and the provision of opportunities for student exploration was 81.25%, both of which are in the Good category, which indicates that PhET has been used systematically and provides space for students to explore, although it can still be optimized. The time management indicator for PhET use obtained the lowest percentage, namely 77.50% in the Good category, indicating the need for more effective time management to ensure balanced progress across all learning stages. Overall, the average observation percentage of 84.25% in the Good category indicates that the implementation of PhET-based learning on the heat material has been effective and supports the achievement of learning objectives.

Table 3. Results of Observations of Student Activities Using PhET

No	Student Activity Indicators	Percentage (%)	Category
1	Operate the simulation independently	82,35	High
2	Exploring the heat variable	79,41	Currently
3	Discuss with friends	83,82	High
4	Ask a question	76,47	Currently
5	Concluding the simulation	80,88	High
6	Recording observation results	87,65	High
	Rate-rate	81,76	High

Based on observations of student activities during PhET use, most students demonstrated high engagement in learning in Table 3. Indicators such as operating simulations independently (82.35%), discussing with friends (83.82%), drawing conclusions from simulations (80.88%), and recording observation results (87.65%) were in the High category, which indicates that students were active in carrying out learning activities, able to work independently and collaboratively, and systematically record and analyze experimental results.

However, several indicators fall within the Medium category: exploring the heat variable (79.41%) and asking questions (76.47%). These findings indicate that although students are already engaged, some still need encouragement to be more active in exploring variables or asking questions to deepen their understanding. Overall, the average percentage of student activity was

81.76%, indicating that the use of PhET increases student engagement and participation in learning heat material.

Table 4. Student Responses to the Use of PhET Simulations

No	Statement	Agree (%)	Disagree (%)
1	PhET makes learning about heat more interesting	88,24	11,76
2	PhET is easy to use	85,29	14,71
3	PhET visualization helps understand heat	91,18	8,82
4	PhET helps differentiate between heat and temperature.	82,35	17,65
5	I am more active when learning using PhET	84,12	15,88
6	I want PhET to be used on other materials.	86,76	13,24
	Rate-rate	86,32	13,68

Based on PhET use data in Table 4, most students responded positively. Indicators such as PhET make heat learning more interesting (88.24%), PhET visualization helps students understand heat (91.18%), and PhET helps differentiate heat and temperature (82.35%), indicating that students perceive real benefits from using this simulation in facilitating understanding of abstract concepts. In addition, most students (84.12%) reported becoming more active when learning with PhET and wanted this simulation applied to other materials (86.76%), indicating strong enthusiasm for simulation-based learning.

Overall, the average percentage of student responses was 86.32%, with only 13.68% disagreeing, indicating that the majority of students accepted and appreciated the use of PhET as a learning medium. This confirms that PhET not only increases student engagement but also supports a deeper understanding of the concept of heat through its visual and interactive approach.

Table 5. Summary of Science Teacher Interview Results

Aspect	Analysis Results
Reasons to use PhET	Interactive and easily accessible media
Main advantages	Visualization of the abstract concept of heat
Impact on students	Increase activity and enthusiasm.
Technical constraints	Limitations of student devices
Pedagogical constraints	Learning time management
Learning suitability	In line with active learning

Based on the analysis of teachers' perceptions of PhET use, teachers stated that the primary reason for using PhET is its accessibility and interactivity, which make it easier to provide a more engaging and dynamic learning experience. PhET's main advantage lies in the visualization of the abstract concept of heat, which helps students understand material that is difficult to grasp through theoretical explanations alone.

The impact of PhET use on students was evident in their increased activeness and enthusiasm during learning, as students were more encouraged to experiment, discuss, and directly observe phenomena. Challenges faced by teachers included limited access to student devices as a technical barrier and difficulties with time management as a pedagogical barrier. Nevertheless, teachers assessed that PhET use remained aligned with active learning, supported student interaction, and strengthened the achievement of heat learning objectives.

Based on the analysis of PhET's support for understanding heat, this simulation makes a significant contribution to students' mastery of the concept. The indicator of the difference between heat and temperature received the highest score of 3.52 (88.00%), placing it in the Very

Good category, indicating that PhET is effective in helping students distinguish between these two often-confusing concepts. In addition, the energy changes received a score of 86.75% in the Very Good category, confirming PhET's ability to visualize energy transformations concretely.

Table 6. Analysis of PhET Simulation Support for Understanding the Concept of Heat

The Concept of Heat	Support Score	Percentage (%)	Category
The difference between heat and temperatur	3,52	88,00	Very good
Heat transfer	3,38	84,50	Good
Effect of mass and temperature	3,29	82,25	Good
Energy changes	3,45	86,75	Very good
Rate-rate	3,41	85,14	Very good

Meanwhile, the heat transfer indicators (84.50%) and the influence of mass and temperature (82.25%) were in the Good category, indicating that PhET supported understanding of the concept. However, there remained room for further exploration. Overall, the average PhET support for the heat concept was 85.14%, placing in the Very Good category, indicating that this simulation effectively strengthened students' understanding of the heat concept as a whole.

DISCUSSION

The analysis results indicate that the use of the Colorado PhET simulation in science learning on heat at SMP Negeri 12 Jakarta falls within the good-to-very good category. Instructional media function as tools to facilitate learning by delivering information, enhancing understanding, and increasing student engagement(Solihin, et al., 2025); (Solihin et al., 2025). Media can be categorized into manual forms, such as physical models and printed materials (Solihin, et al., 2025), robotic media that provide interactive and automated learning experiences, and digital media that utilize technology-based platforms and simulations like virtual lab and phET(Syafkitamsana et al., 2025). Each type of media supports the learning process in different ways depending on the context, resources, and learning objectives. The average PhET utilization among teachers is 84.25%, indicating that this simulation is used optimally in the learning process. This finding confirms that PhET not only functions as a supporting medium but is also integrated into the learning flow to visualize the concept of heat. From the perspective of the teacher's role, the observation data indicate a high score on the indicator of teachers as facilitators, with a percentage of 87.50% (Asriningsih et al., 2021). This shows a shift in teachers' roles from primary sources of information to learning companions who provide space for student exploration (Iskandar et al., 2021). This condition aligns with the principles of constructivist learning, in which students build understanding through direct experience and interaction with learning media (Augustine et al., 2025).

However, time management for PhET use achieved a relatively low percentage (77.50%) compared with other indicators. This finding indicates that although PhET is pedagogically effective, teachers still face challenges in managing the duration of simulation exploration to align with the allocated learning time (Revvina et al., 2023). This suggests that media effectiveness is determined not only by media quality but also by teachers' pedagogical skills in managing technology-based learning (Mashami et al., 2023). Analysis of student activities showed an average engagement of 81.76%, which is considered high. The highest percentages were observed for recording observations (87.65%) and discussing with peers (83.82%). This finding indicates that the use of PhET can encourage collaborative and reflective learning, rather than merely passive individual learning. However, the indicator for asking questions achieved a lower percentage (76.47%). This indicates that not all students actively expressed their curiosity through questions, despite their engagement in simulation exploration. This condition suggests the need for additional pedagogical strategies, such as provocative questions or structured discussions, to maximize PhET's potential in stimulating critical thinking (Solihin et al., 2025).

Regarding student responses, the questionnaire data showed an average of 86.32% in the agree category, indicating strong acceptance of PhET use. The highest percentage appeared in the statement that PhET visualization helps understand the concept of heat (91.18%). This finding strengthens the argument that interactive visualization is highly effective at bridging abstract concepts, particularly in materials that are difficult to observe directly. In addition, student responses regarding the ease of use of PhET were 85.29%, indicating that this simulation is relatively easy for junior high school students to operate. Ease of access and use are essential to the successful implementation of technology-based media, as high technical complexity can hinder the learning process (Sunandar et al., 2022). Student responses indicating a desire to use PhET with other materials also accounted for a high percentage (86.76%). This suggests that the PhET learning experience leaves a positive impression and increases students' motivation to learn. This motivation is an essential factor in science learning because it directly influences engagement and the sustainability of the learning process (Dheeraj Kumar, 2024).

Interviews with science teachers reinforced these quantitative findings. Teachers assessed that PhET had a key advantage in visualizing the abstract concept of heat, which is difficult to explain using conventional methods(Chotimah et al., 2023). Teachers also observed that students became more active and enthusiastic during the lesson, particularly when they were allowed to explore variables in the simulation. However, teachers also reported technical challenges, particularly the limited equipment available to students (Augustine et al., 2025). This constraint affected PhET's use, which was often demonstrative for teachers rather than exploratory for each student. These findings indicate that the availability of facilities and infrastructure strongly influences the success of technology integration in learning. Analysis of PhET's support for understanding the concept of heat showed an average of 85.14%, with the highest support for the distinction between heat and temperature (88.00%). This is important, given that misconceptions about the distinction between heat and temperature are a significant problem in heat education (Ouahi et al., 2022). The visualization of energy flow in PhET helps students understand that heat is energy in transfer, not simply a measure of heat (Pramanda, Fandi, n.d.). PhET's support for the concept of heat transfer and the influence of mass and temperature was also rated as good. This demonstrates that PhET simulations enable students to conduct virtual experiments by manipulating variables and directly observe cause-and-effect relationships. This process contributes to the development of deeper conceptual understanding (Al-Nakhle, 2022).

Although the research shows positive outcomes, the use of PhET is not yet optimal. Several indicators remain in the moderate-to-good category rather than the excellent category, indicating room for improvement (Manalu et al., 2025). Optimizing the use of PhET requires more thorough learning planning, including the development of simulation-based worksheets and structured discussion strategies. Overall, the results of this study indicate that PhET Colorado is a practical and relevant learning medium for heat science learning in junior high schools.(Mashami et al., 2023). However, this effectiveness is highly dependent on how the medium is used in real-world learning contexts. Without proper pedagogical integration, PhET's full potential will not be achieved (Harum et al., 2020). The implications of this research are the need to improve teachers' competence in designing digital simulation-based learning and to secure institutional support for the provision of technological resources. With such support, PhET will not only serve as an alternative medium but also function as a primary instrument for active, meaningful, and conceptually oriented science learning.

CONCLUSION

This study concludes that the PhET Colorado simulation can be effectively utilized as a learning medium in teaching heat concepts in junior high school science. The findings show that teachers were able to integrate PhET well into the learning process, as indicated by good to very good implementation scores. The use of PhET encouraged active student engagement, including exploring variables, discussing, drawing conclusions, and recording observations. Student responses were predominantly positive, demonstrating that PhET made learning more interesting, interactive, and easier to understand, especially for abstract concepts such as the difference between heat and temperature. Furthermore, the simulation significantly supported students' conceptual understanding by providing clear visualizations of heat transfer, energy changes, and the influence of mass and temperature. Although challenges were identified, particularly related to limited devices and time management, these constraints did not outweigh the benefits of using PhET. Overall, PhET serves as a practical and effective instructional tool that enhances engagement, supports active learning, and facilitates deeper understanding of abstract scientific concepts. Therefore, careful instructional planning, adequate facilities, and structured guidance are recommended to optimize the integration of PhET simulations in science classrooms.

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