JOELI: Journal of Educational and Learning Innovation
Vol. 2, No. 1, July 2025. pp. 46 – 56
ISSN: 3063-3966 *(online)*

Implementation of Guided Inquiry Learning Assisted by PhET Simulation to Improve Students' Science Process Skills

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Article Info

Artikel History
Received : 8 January 2026
Reviewed : 25 January 2026
Accepted : 27 January 2026

Keywords:
Guided inquiry learning
PhET Simulation
science process skills

ABSTRACT

This study aims to improve students' process skills through the implementation of guided inquiry learning assisted by PhET Simulation at SMP Lab school UNESA 1. This study is a quantitative study with a pre-experimental design using a one group pretest-posttest design. Data analysis uses N-Gain calculations to measure the improvement of students' process skills. The results of the study indicate that the implementation of guided inquiry learning assisted by PhET Simulation is able to improve students' science process skills with an average N-Gain of 0.48 in the medium category. A total of 22 students experienced an increase in the medium category, 8 students in the low category, and 2 students in the high category. This study shows that the combination of guided inquiry learning models with PhET Simulation is effective in improving students' science process skills on temperature and heat materials.

Please cite this article APA style as:
Umatullaila Istiqfarin, & Subekti, H. (2026). Implementation of Guided Inquiry Learning Assisted by PhET Simulation to Improve Students' Science Process Skills. *JOELI: Journal of Educational and Learning Innovation*., 2(1), pp. 46-56.

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1. Introduction

Science education in the 21st century requires students not only to master theoretical concepts but also to have adequate science process skills to face the challenges of the times (Sakdiah et al., 2022). Science process skills are essential abilities necessary to acquire, develop, and apply scientific concepts, principles, laws, and theories, which are mental, physical, and social abilities (Putri et al., 2022). Science process skills include various aspects such as formulating problems, formulating hypotheses, identifying variables, interpreting data, and drawing conclusions, as emphasized in Permendikbud No. 22 of 2016 that these competencies must be developed by students in science learning (Hidayati & Budiyanto, 2021).

However, the reality on the ground shows a significant gap between global demands and the achievements of students in Indonesia. This is based on the results of the TIMSS (Trends in International Mathematics and Science Study) assessment of junior high school students' achievement in the field of natural sciences. TIMSS data since 1999 shows that Indonesia's achievements have not improved significantly over time. In 2015, Indonesia ranked 45th out of a total of 48 participating countries with a final score of 397 poin (Sutrisna et al., 2023). This achievement shows that the average number of correct answers by Indonesian students in science lessons was only 32, far below the international average of 50. Indonesia's low ranking in TIMSS indicates that the science abilities of Indonesian students are still below international standards. Further analysis of the TIMSS questions shows that 96% of the questions tested science process skills, which include the ability to understand complex information, analyze theories, connect facts, solve problems, and conduct scientific investigations. The TIMSS study results show that Indonesian students are only able to achieve a low level in these aspects, which proves that Indonesian students' science process skills are low (Darmayanti et al., 2019).

Research Results by Rahma & Wahyuni (2025) research explain that these low science process skills are caused by several factors. First, learning is still focused on cognitive aspects with a dominant lecture method, so that students lack active scientific inquiry processes. Second, teachers lack understanding of KPS. Many science teachers do not fully understand the concept and implementation of KPS. This results in limitations in the implementation of practical activities, which should be the main means of training students' science process skills. Third, the science textbooks used still contain few aspects of inquiry and contain more knowledge aspects, so they are not optimal in facilitating the development of students' science process skills.

Based on these problems, a learning model is needed that can increase the active involvement of students in the science learning process. The guided inquiry learning model is one of the appropriate approaches for training science process skills. The results of Latukau's (2022) research confirm that guided inquiry learning can provide concrete experiences for students, especially when students conduct inquiries in conducting experiments with the help of LKS. In this approach, students can be actively involved in learning, develop a positive attitude towards science, and at the same time develop various scientific process skills. Andarie's (2023) research results also show that the effective application of the guided inquiry model can improve students' abilities in carrying out scientific processes.

However, the implementation of guided inquiry learning in the field often faces obstacles, especially related to limited laboratory equipment and limited learning time. Learning in the laboratory aims to help students understand abstract scientific concepts by making them more real and concrete (Anbiya et al., 2023). This is where the role of learning technology becomes very important. Physics Education and Technology (PhET) Interactive Simulations developed by the University of Colorado Boulder offer an innovative solution to overcome these limitations. PhET Simulation is a virtual laboratory that provides a variety of research-based interactive simulations that allow students to explore physics phenomena visually (Saputra, 2025). Verdian's (2021) research reveals that PhET Simulation media is highly effective when combined with the guided inquiry learning model. The combination of the guided inquiry learning model and PhET Simulation media creates a strong synergy where the guided inquiry model provides a systematic and structured learning framework, while PhET Simulation provides effective and interactive media that can increase students' interest and curiosity. This integration facilitates learners to not only understand concepts theoretically, but also develop science process skills through authentic virtual hands-on experiences (Chotimah et al., 2023).

Based on the description above, this study aims to implement guided inquiry learning assisted by PhET Simulation as an effort to improve students' science process skills. It is hoped that this study can contribute to the development of more creative and efficient learning practices that can address the challenges of science education in the information age. By combining the guided inquiry learning model with interactive simulation technology, it is hoped that students can develop optimal science process skills, so that they are not only able to understand physics concepts in depth.

2. Method

This quantitative study employed a pre-experimental design with a one-group pretest-posttest design. This experiment involved a group being given a treatment using the guided inquiry learning model using PhET Simulation media. The sample consisted of 32 students from class VII A at SMP Labschool UNESA 1. Purposive sampling was used, considering that this class has science process skills that need improvement. The research pattern is stated in table 1.

Table 1. One Group Pretest-Posttest Research Design Scheme

Pretest	***Treatment***	***Posttest***
O_1	X	O_2

(Sugiyono, 2022)

The data collection method used was a test consisting of ten multiple-choice questions, which were completed independently, without students being allowed to open books or engage in discussion, and with a 10-minute time limit. The pretest and posttest data were then analyzed to identify improvements in critical thinking skills after participating in the guided inquiry learning using PhET Simulation media. The questions were structured based on the skill indicators used in this study: problem formulation, hypothesis formulation, variable identification, data interpretation, and conclusion drawing. The mapping of KPS indicators with the question numbers used in this study can be seen in Table 2.

Table 2. Mapping of KPS indicators with question numbers

KPS Indicator	**Question Number**
Formulating Problems	1 and 2
Formulating Hypotheses	3 and 5
Identifying Variables	4 and 8
Interpreting	6 and 7
Concluding	9 and 10

Examples of questions for each indicator used in this study are presented in Table 3.

Table 3. Example questions for each indicator

KPS Indicators	Example questions used
Formulating the Problem	in a physics laboratory experiment, Andi heated five types of metal (aluminum, iron, copper, brass, and tin) with equal masses using an electric heater. Andi noted that although all the metals were heated for the same time with the same energy, the final temperatures of each metal were different. Aluminum reached the highest temperature, while copper reached the lowest. Furthermore, Andi also observed that when the metals were cooled again, their temperature drops also differed. Based on this complex phenomenon, the most appropriate scientific problem formulation for further investigation is... A. Why do metals with different colors produce different temperature changes? B. How do the intrinsic characteristics of a type of metal (such as specific heat) affect its temperature response when receiving or releasing the same amount of heat energy? C. Does the mass of the metal affect the thermal conductivity of the material? D. Why do different heat sources produce different temperature increases in the metals?
Formulating a Hypothesis	In an experiment, a researcher observes heat transfer between two identical metal blocks attached with varying initial temperatures. In the first experiment, with a temperature difference of 20°C, thermal equilibrium was reached in 15 minutes. In the second experiment, with a temperature difference of 40°C, equilibrium was reached in 10 minutes. In the third experiment, with a temperature difference of 60°C, equilibrium was reached in 7 minutes. The researchers also noted that the final equilibrium temperature was always midway between the initial temperatures of the two blocks. Based on these observations and the concept of heat transfer, the most appropriate hypothesis to explain the relationship between temperature difference and the rate of heat transfer is... A. If the initial temperature difference between two objects is greater, the rate of heat transfer will increase, resulting in thermal equilibrium being reached more quickly. B. If the initial temperature difference is smaller, thermal equilibrium will be reached more quickly because less energy needs to be transferred. C. Heat will not transfer efficiently if the temperature difference is too large due to high thermal resistance. D. The time it takes to reach thermal equilibrium is not affected by the initial temperature difference, but only by the surface area of contact between the two objects.
Identify Variables	Consider the following experiment! student conducted a water heating experiment. Water with an initial temperature of 30°C was heated using an electric stove at constant power. After 3 minutes, the water temperature rose to 45°C. The experiment continued for 6 minutes. Question: Based on the experiment above, the independent variable, dependent variable, and control variable, respectively, are... A. Water temperature, heating time, stove power B. Heating time, water temperature, stove power C. Stove power, water temperature, heating time

<table>
<tr><th>KPS Indicators</th><th>Example questions used</th></tr>
<tr><td></td><td>D. Water temperature, stove power, heating time</td></tr>
<tr><td>Interpretation</td><td>A student conducted an experiment using four different materials and recorded the following heat transfer times:
<table>
<tr><th>Materials</th><th>Transfers tiem</th></tr>
<tr><td>Alumunium</td><td>8</td></tr>
<tr><td>Iron</td><td>12</td></tr>
<tr><td>Wood</td><td>45</td></tr>
<tr><td>Plastic</td><td>50</td></tr>
</table>
Based on these results, the material with the best heat conduction ability is...
A. Plastic because it has the longest heat transfer time
B. Wood because its temperature does not change quickly
C. Aluminum because it has the fastest heat transfer time
D. Iron because it has the lowest thermal conductivity</td></tr>
<tr><td>Conclusion</td><td>Based on various heat conduction experiments conducted with metals and non-metals, it can be concluded that...
A. All materials have the same ability to conduct heat
B. Heat transfer always occurs from objects with low temperatures to those with high temperatures
C. The type of material affects the rate of heat transfer due to differences in the structure of its constituent particles
D. Heat transfers regardless of the temperature difference of the objects</td></tr>
</table>

The data analysis techniques used in this study were paired t-tests due to the normally distributed data and the N-Gain test. N-Gain was used to analyze the improvement in students' science process skills after being given treatment by comparing the pretest and posttest scores that had been tested. The calculation of the normalized gain score (N-Gain) is described in the following formula:

$$\text{N-Gain}=\frac{(((\text{Final score}-\text{Initial score})))}{(\text{Maximum score}-\text{Initial score}))}$$

Table 4. N-Gain Score Criteria

Gain Value	Criteria
$g \geq 0{,}7$	High
$0{,}7 > g \geq 0{,}3$	Medium
$g < 0{,}3$	Low

(Hake, 1998)

3. Results and Discussion

Results

The measurement of students' science process skills was assessed through pretest and posttest instruments in the form of 10 multiple-choice questions covering science process skill indicators in the temperature and heat subchapter. After that, students received material through a guided inquiry learning model with the help of PhET Simulation media, which aimed to hone students' science process skills.

The results of the study showed that the researchers obtained better science process skills during the pretest and posttest. With a significance value of the Paired Sample T Test <0.05, H0 was rejected and H1 was accepted, meaning there was a significant difference between the pretest and posttest after the application of the

PhET Simulation-assisted guided inquiry model on science process skills. The results of the T Test can be seen in Figure 1.

Independent Samples Test

		Levene's Test for Equality of Variances				
		F	Sig.	t	df	Sig. (2-tailed)
pretest	Equal variances assumed	.728	.397	-7.478	62	.000
	Equal variances not assumed			-7.478	60.405	.000

Figure 1. T-test results
Source: Personal Documentation

In this study, N-Gain analysis was conducted to determine the improvement in students' science process skills after applying the guided inquiry model with PhET Simulation media on the topic of temperature and heat. N-Gain scores were calculated for each student, resulting in an average N-Gain of 0.48, which is categorized as moderate. The overall N-Gain scores can be seen in Figure 2.

Descriptives

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
NGain	32	.25	.86	.4878	.15761
Valid N (listwise)	32				

Figure 2. Overall N-gain results
Source: *Personal documentation*

Of the 32 students, 22 received a moderate score, 8 received a low score, and 2 received a high score. The following table shows the number of students' scores improved by each category using the normalized gain calculation, as shown in Table 5.

Table 5. Number of Students in Each N-Gain Category

KPS Value Improvement Category	Number of Students
Low	8
Medium	22
High	2

An N-Gain analysis was also conducted to determine the improvement in each indicator of students' science process skills. The N-Gain scores for each indicator of science process skills are outlined in Table 3.

Table 6. N-Gain Results for Each KPS Indicator KPS Indicator

KPS Indicator	N-Gain	Category
Formulating Problems	0,44	Medium
Formulating Hypotheses	0,63	Medium
Identifying Variables	0,10	Low
Interpreting Data	0,56	Medium
Concluding	0,48	Medium

In Table 6, the N-Gain results for the five science process skill indicators show that the problem formulation indicator scored 0.44, which is in the moderate category. The hypothesis formulation indicator scored 0.63, also in the moderate category. The third indicator, identifying variables, only scored 0.10, falling into the low category. Then, data interpretation scored 0.56 in the moderate category, and finally, conclusion scored 0.48, also within the moderate category.

Discussion

The results of the study showed that the implementation of guided inquiry learning assisted by PhET Simulation was able to improve students' science process skills with an average N-Gain of 0.48 in the moderate category. Of the 32 students, 22 students (68.7%) experienced an increase in the moderate category, 8 students (25%) experienced an increase in the low category, and 2 students (6.2%) experienced an increase in the high category. The results of the T-test showed 0.000 <0.05 further strengthening the N-Gain results. The T-test produced a value of 0.000 smaller than 0.05, which means there was a significant difference between the pretest and posttest after the implementation of the guided inquiry learning model assisted by PhET simulation. This increase in science process skills shows that the combination of the guided inquiry learning model with PhET Simulation has a significant positive impact on students' abilities in conducting scientific investigations. The results of Wardani & Rosdiana's (2022) research also showed that students' science process skills increased after implementing learning using PhET media with a guided inquiry method with a high category.

The success of guided inquiry learning in improving science process skills can be explained through systematic and structured learning stages. The guided inquiry model provides opportunities for students to be actively involved in the learning process through investigation activities guided by teachers. Panggabean (2022) in his research explains that the application of the guided inquiry learning model is effective in improving the high-order thinking skills of junior high school students by creating a learning environment that encourages students to actively explore, analyze, and evaluate information. The results of Ramlawati's (2025) research also confirmed that the application of the science inquiry learning model was significantly able to improve students' science process skills, because students were actively involved in scientific investigation activities that trained their ability to observe, process data, formulate hypotheses, and draw conclusions. Through the stages mentioned above, students do not only receive information passively but actively construct their own knowledge.

The guided inquiry learning model is supported by several learning theories, including constructivism and cognitive multimedia learning. Constructivism emphasizes that students play a crucial role in the learning process. The principle of scaffolding is assistance or support provided by teachers, peers, or adults to help students achieve higher levels of understanding or skills. The guided inquiry learning model aligns with the scaffolding principle, where students are actively involved in the process of discovering knowledge through observation and exploration (Ngertini, 2014). In the guided inquiry learning process using PhET simulations, students conduct their own experiments, while the teacher acts only as a facilitator. This allows guided inquiry learning to develop science process skills. Cognitive Theory of Multimedia Learning (CTML) from Mayer's (2009) explains that learning is more effective when information is presented through a combination of words and visual images because humans have dual processing channels for verbal and visual information. PhET simulation as an interactive multimedia learning media fulfills CTML principles such as the multimedia principle (combination of text and visual animation), the interactivity principle (students can manipulate variables directly), and the modality principle (visual representation of abstract phenomena), which are proven to reduce students' cognitive load and allow them to focus on the scientific inquiry process.

The role of PhET Simulation as a virtual learning medium is very important in supporting every stage of guided inquiry learning. PhET simulations provide an interactive learning environment where students can conduct virtual experiments by changing various variables and observing the results directly without the limitations of physical laboratory equipment. Buhera's (2025) research shows that integrating technology, particularly PhET simulations, into science learning using learning models can be an effective strategy. The implementation of guided inquiry using PhET Simulation media showed an increase in N Gain scores in the pretest and posttest results. This indicates that after students were given treatment using the PhET-assisted guided inquiry model, their science process skills improved.

The results of this study show different variations in improvement in each indicator of science process skills. The hypothesis formulation indicator showed the highest increase with an N-Gain of 0.63 (moderate category). This indicates that the use of PhET Simulation is very effective in helping participants formulate hypotheses. In guided inquiry syntax, it is very effective because PhET simulation provides clear and interactive visualization of phenomena (Yunita & Martini, 2025). In the indicators of formulating problems, interpreting data, and concluding, the N-Gain results were in the moderate category, which indicates that the orientation stage (formulating problems), the data analysis stage (interpreting data), and the conclusion drawing stage (concluding) in guided inquiry syntax are quite effective in training these skills through teacher scaffolding and visualization features in PhET that facilitate understanding of patterns and relationshipsh (Hidayah et al., 2023). The results of this study also show a low increase in the variable identification indicator with an N-Gain value of 0.10, which is in the low category. Low variable identification skills can be caused by students not yet understanding the meaning of response, control, and manipulation variables. In practice, students can recognize variables from a statement or illustration and relate the two variables. However, they struggle to distinguish between statements as manipulation, response, or control variables. Students often misplace them, for example, considering the response variable to be manipulation or control (Fahmi & Sari, 2024).

Overall, students in grade VII-A experienced an increase in their science process skills. This indicates that the application of the guided inquiry learning model with Medina PhET Simulation on temperature and heat material has a positive impact on improving students' science process skills. However, this study only used a limited sample size and the duration of the study was only two meetings. Future studies are recommended to use a quasi-experimental research design and include a larger sample with a longer study duration.

4. Conclusions

This study shows that the implementation of guided inquiry learning assisted by PhET Simulation can significantly better the science process skills of seventh grade junior high school students on the topic of temperature and heat. An average increase in N-Gain of 0.48 in the moderate category indicates that the combination of the guided inquiry learning model with interactive simulation technology can have a positive impact on students' ability to carry out scientific investigation processes. Of the five indicators of scientific process skills measured, the indicator of formulating hypotheses showed the highest increase, while the indicator of identifying variables still requires special attention in learning. The application of this method in the curriculum can help overcome the limitations of physical laboratory equipment and provide a more interactive and effective learning experience. The integration of the guided inquiry model with PhET Simulation has been proven generate a learning domain that encourages students to actively explore, analyze, and construct their own knowledge. This method not only improves conceptual understanding but also develops essential science process skills to face the challenges of science education in the digital age.

5. Acknowledgment

The author would like to express his gratitude to SMP Labschool UNESA 1, all students of class VII A, and the teachers who have allowed the researcher to conduct the research. The author also greatly appreciates the guidance, suggestions, and valuable input from Mr. Hasan Subekti, S.Pd., M.Pd., as the supervisor who has provided invaluable guidance, direction, and input during the research process and the preparation of this article. In addition, the author thanks his family and friends for their meaningful support and motivation.

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