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Effectiveness of Phet Simulation in Improving Students' Science Process Skills on Static Electricity Concept Material

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Abstract

This study aims to determine the effectiveness of using PhET simulations in improving students' science process skills on the concept of static electricity. The research was conducted at MTs At-Taqwa Beru with the research subjects being 20 eighth-grade students from class VIII-A. The research method used was a pre-experimental design with a one-group pre-test and post-test approach. Data collection instruments included a written test to measure students' science process skills and an observation sheet to support data on students' performance during the learning process. The results showed a significant improvement in students' science process skills after learning with the PhET simulation. The average observation score increased from 58.8 (categorized as fair) to 83.2 (categorized as good). In addition, the N-Gain analysis resulted in an average score of 0.481, which falls into the medium category according to Hake's (1998) classification. Therefore, the use of PhET simulations is proven to be effective in enhancing students' science process skills and is recommended as an alternative instructional medium for teaching abstract physics concepts such as static electricity.

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INTRODUCTION

In today's information and technology era, the need for individuals who have a strong understanding of scientific processes is increasingly pressing. (Chakilam, 2025; Gursoy et al., 2025; Qi et al., 2024). The scientific process is the main foundation in scientific learning which emphasizes the development of understanding, reasoning, and practical skills in dealing with natural phenomena. (Affandy et al., 2024; AlAli & Al-Barakat, 2024) This process helps students not only understand the world around them in more depth, but also trains them to think critically, solve problems, and make evidence-based decisions (Cagle et al., 2025; Cheung et al., 2025). Thus, students are expected to be able to become active producers of knowledge through scientific stages such as observation, problem formulation, experiments, data analysis, and reporting results (Chen, 2025; Sukackė et al., 2022).

However, in practice, science process-based learning often faces various challenges (Aderele et al., 2025; Kite & Park, 2024). Some of the main obstacles faced are time constraints, minimal resources, and low teacher ability in integrating the science process approach into teaching and learning activities (Li et al., 2025; Zuniari et al., 2025). In addition, the limited availability of interesting and interactive learning aids also hinders student involvement in the science learning process(Febrina & Setiawan, 2024; Zuniari et al., 2025). Based on the results of interviews with students at MTs At-Taqwa Beru, it is known that limited learning resources cause difficulties in understanding abstract concepts, such as static electricity. In fact, the concept of static electricity is a very important basic material in learning physics because it is the foundation for understanding the concept of dynamic electricity and its application in everyday life (Cahyani et al., 2025; Febrianti et al., 2025).

Several studies have shown that the use of interactive simulations such as PhET can improve learning outcomes and student engagement in science learning (Banda & Nzabahimana, 2021a; Bogar et al., 2023; Buar & Obiedo, 2025; Diab et al., 2024; Fauziah & Rusilowati, 2025). PhET provides a virtual learning environment that allows students to conduct experiments, observe phenomena, and understand scientific concepts directly without having to use a physical laborator (Banda & Nzabahimana, 2021b; Mashami et al., 2023) y. However, most studies focus more on improving conceptual understanding, not many have examined the effectiveness of these media in improving science process skills specifically (Hu, 2024; Zulyusri et al., 2023). In addition, there is still little research conducted in the context of schools with limited facilities, such as those at MTs At-Taqwa Beru.

Although many researchers have conducted research on the use of PhET simulations in science learning, this study is novel in its focus on evaluating the effectiveness of PhET simulations in improving students' science process skills, not just conceptual understanding. Furthermore, this study was conducted at a madrasah-based junior high school (SMP) with limited laboratory facilities and resources. Therefore, the results of this study are expected to provide new contributions in developing technology-based learning strategies that are more adaptive to real-world conditions.

The urgency of this research is based on the importance of science process skills as a provision for students in facing the challenges of the 21st century, which requires the ability to think critically, creatively, and data-based Meanwhile, the limited facilities and infrastructure in schools encourage the need for learning innovations through the use of technology, such as interactive simulations (Chang & Liu, 2025; Muh Habibulloh et al., 2024). Therefore, the use of PhET simulation media is seen as one of the strategic alternatives to bridge the gap between theory and practice in science learning at school.

This study aims to explore the extent to which the use of PhET simulation can improve the science process skills of VIII grade students of MTs At-Taqwa Beru. The focus of the research includes basic science process skills such as the ability to observe, formulate hypotheses, conduct virtual experiments, analyze data, and draw conclusions in understanding the concept of static electricity.

METHOD

This type of research is quantitative research, the research design that will be used in this study is Quasi Experiment with One-Group Pretest-Posttest Design. The following is a table research method design.

Table 1.1 Research method design

subject	***Pre-test***	**treatment**	***Post-test***
experimental class	O_1	X	O_2

The sample in this study was class VIII-A consisting of 20 students as an experimental class.

External variables relate to aspects of the external environment that can affect the provision of treatment to research samples, so that the results to be observed are disturbed or different. Some variables that can affect external variables so that they must be controlled are:

1) Treatment selection interaction: Interaction of successive treatment selection. This is controlled by giving one treatment to one group.
2) Selection treatment: Selection treatment occurs when the researcher's influence is unintentional on the subject during the treatment process.
3) Experimenter effect: Experimenter effect occurs when the researcher's influence is unintentional on the subject during the data collection process.
4) Reactive arrangement: Reactive arrangement is related to the attitudes and behavior of students when they become research subjects, so that it can affect the attitudes, motivation, activities and responses of students.

In this study, the data collection techniques used were using test and non-test techniques. The test technique used written tests and non-tests in the form of observation sheets. The following are the data collection techniques used by researchers:

1) Test technique: The written test in this study aims to determine the improvement of students' science process skills by conducting a pre-test and post-test. Science process skills are measured through questions designed to represent skill indicators such as observation, classification, data interpretation, prediction, and conclusion. Science process skills can be measured through written instruments that contain contextual problems and require the application of scientific thinking processes explicitly (HARLEN, 1999). Thus, the written test used in this study not only assesses aspects of knowledge, but also students' abilities to apply scientific processes systematically. The post-test was conducted to observe the improvement of students' science process skills after the learning media was applied using a learning model at school and using a phet simulation application.The preliminary test functions as an initial reference to determine the initial condition of students before being given treatment, and is not used to determine corrective steps.
2) Non-test techniques: namely testing using observation sheets. Observation sheets are used to observe and record student activities and interactions during the learning process, in order to obtain data on student behavior, responses, and development directly.

The test question sheet used is in the form of essay test choices with a total of 14 questions. The test question sheet covers various cognitive aspects, such as remembering (C1), understanding (C2), applying (C3), analyzing (C4), to evaluating (C5). Each question is made to measure science process skills, such as the ability to observe, interpret data, formulate hypothesis, and evaluate the results of the experiment. The process of compiling questions considering varying levels of difficulty to suit the abilities of grade XI students. Before being used in the study, the questions were validated by experts to ensure their validity, reliability, and suitability to the research objectives. Table 1.2 shows test question instrument indicator.

table 1.2 Test Question Instrument indicator

Sub-aspect	**Cognitive Level**	**Indicator**	**Number of Instruments**	**Number of Instruments**
observation	C1 C2	1) Students are able to identify the basic properties of electric charge. 2) Students are able to observe the phenomena of static electricity in everyday objects.	2	1, 2
classification	C2 C4 C4	1) Students are able to group objects into conductors and insulators. 2) Students are able to differentiate the charge of objects based on the results of their interactions. 3) Students are able to differentiate the properties of the charge of objects in a simple electrical circuit.	3	3,4,5
communication	C2 C3 C5	1) Students are able to explain the effect of the Coulomb force on the distance between charges. 2) Students are able to describe the direction of the electric force acting between two charges. 3) Students are able to convey information from experimental results	3	6,7,8

		about packet interactions.		
prediction	C3 C3 C5	1) Students are able to predict the interaction between two objects that fall together. 2) Students are able to predict the magnitude of the electric force based on the number of charges. 3) Students are able to describe the effect of changes in distance between charges on the force.	3	9,10,11
inference	C5 C5 C5 C5	1) Students are able to draw conclusions from the results of experiments on electrical force. 2) Students are able to conclude the effect of material objects on charge interactions. 3) Students are able to conclude the electrical properties of objects after rubbing. 4) Students are able to draw conclusions about the properties of muatan dalam percobaan mistar dogosokan ke rambut	4	12,13,14,15

The second instrument in this research is an observation sheet used to directly observe student activities when using the PhET simulation, with 14 questions and statements referring to science process skills. Sub-aspects in the Basic Science Process Skills Observation Instrument include observation, clarification, communication, forecasting, and conclusion. These sub-aspects are compiled based on sources from several experts. The following is a table of the Observation Sheet Instrument Grid based on Basic Science Process Skills.

Sub-aspect	Indicator	Number	Instrument Items
observation	1) Identifying objects 2) Using all appropriate senses	2	1, 2
classification	3) Identifying the advantages, disadvantages,	2	3,4

	and examples of objects correctly 4) Sorting objects carefully		
communication	4) Discussing a problem 5) Making an experimental report 6) Transmitting information to others correctly	3	5,6,7
prediction	7) Present simple predictions 8) Apply the prediction process in appropriate situations 9) Suggest tests to check the predictions	3	8,9,10
inference	10) Connecting observed objects and events 11) Using all appropriate information in making inferences 12) Separating non-essential information appropriately 13) Interpreting obtained experimental data	4	11,12,13,14

Table 1.3. Grid of Basic Process Skills Observation Sheet Instrument Sains.
Source: Galuh Chusnullia Wiranti, (2011: 104) and author's modifications

Prerequisite testing is the initial step in statistical data analysis that aims to ensure that the data meets the basic assumptions before conducting a hypothesis test. Prerequisite testing consists of two types, namely normality testing and homogeneity testing. The normality test is used to determine whether the data is normally distributed, which is an important requirement in parametric statistical tests. Meanwhile, the homogeneity test is used to test whether the data variance from two or more groups is homogeneous or the same. Both of these tests are important to ensure the validity and accuracy of the results of the statistical analysis carried out.

Hypothesis testing, including the t-test, is a statistical method used to test whether there is a significant difference between two sets of data. This test is usually applied in research to compare the means of two samples, either paired (paired t-test) or unpaired (independent t-test).

RESULTS AND DISCUSSION

This research was carried out starting from the stage of submitting a proposal to the madrasah to the stage of drawing conclusion. The research sample, namely class VIII-A consisting of 20 students, was selected to ensure the data obtained were more focused and in-depth in describing the effectiveness of the use of PhET Simulation in learning static electricity concepts. Although the number of respondents of 20 people is relatively small and statistically may not be ideal for broad generalizations, this number is still acceptable in educational research with a quasi-experimental approach, especially under limited conditions, such as limited number of classes, facilities, and resources in madrasahs. In addition, the research design that prioritizes depth of analysis and control of treatments allows the use of small samples to provide meaningful and relevant findings.

The research instrument used test questions and observation sheets designed to see the level of students' understanding of concepts and science process skills. The test questions of science process skills, such as observing, classifying, interpreting data, and designing experiments. The test was conducted in two stages, namely pre-test and post-test, to measure changes in students' science process skills before and after the implementation of PhET Simulation. Meanwhile, the observation sheet was used to assess students' activities during the learning process.

A. Research result

1. Test Question Data Analysis

Analysis of test result data is conducted to interpret the data obtained systematically so that it can answer the research objectives. This analysis process includes several stages to ensure the validity and reliability of the data before hypothesis testing is carried out. The stages of data analysis in this study include:

2. Descriptive analysis

a. Experimental class pre-test results

Descriptive analysis of the pre-test results was conducted to determine the initial abilities of students before using PhET Simulation. This analysis includes the average, median, mode, standard deviation, and minimum and maximum values. These results are used as a basis for comparing the increase in understanding after treatment. Measurement of these data can be seen in the following table 1.3:

Table 1.4. Pre-test of experimental class

Experimental class	**Pre-test**
Maximum value	79
Minimum value	55
Mean	69,65
Median	69,65
Mode	74

Table 1.4. Pre-test experimental class above the results of the descriptive analysis of the pre-test scores of the experimental class show that the maximum score obtained by students is 79, while the minimum score is 55. The average pre-test score is 68.15, with a median of 69.50, which indicates that most students get scores around that number. The mode or value that appears most often is 60, this result describes the level of initial understanding of students before being given treatment in the study. To be clearer, the following is a picture.

To provide a more focused interpretation of the scores obtained by students, the following assessment criteria are used:

Table 1.5. Score Assessment Criteria

Score range	**Assessment categories**
86-100	Very good
76-85	Good
66-77	Adequate
≤ 65	poor

of the frequency distribution of students' initial science process skills scores before using PhET Simulation in the experimental class.

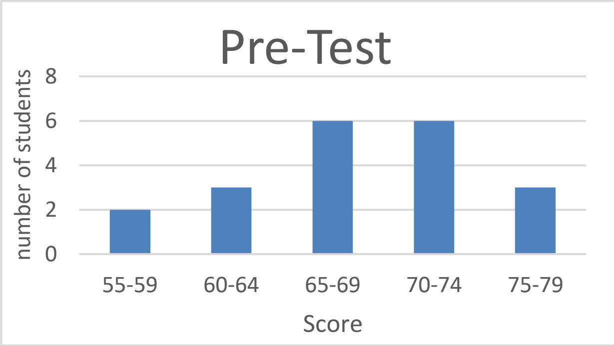

Figure 1.1 Frequency distribution grap

Figure 1. shows that the majority of students obtained scores in the range of 70-74 with 7 students, while the groups with the lowest scores (55-59) and the highest (75-79) were each filled by only 3 students. The distribution of these scores indicates that students' understanding of the material tends to be at an intermediate level, while a small portion still has difficulty or has a better understanding. These results can be the basis for evaluation for educators to improve the effectiveness of learning, especially for students with low scores.

b. Post-test results of the experimental class

The post-test was conducted after the implementation of PhET Simulation to measure the increase in students' understanding. Descriptive analysis includes the mean, median, mode, standard deviation, and minimum and maximum values. These results were compared with the pre-test to assess the effectiveness of using PhET Simulation.

Table 1.6. Post-test of experimental class

Experimental class	**Post-test**
Maximum value	89
Minimum value	80
Mean	84,9
Median	85
Mode	83

From Table 1.6 Post-test of the experimental class, the results of the descriptive analysis of the post-test scores of the experimental class show that the maximum score obtained by students is 89, while the minimum score is 80. The average post-test score is 84.9, with a median of 85, which indicates that most students get scores around that number. The mode or the most frequently appearing score is 83. These results indicate an increase in students' understanding after being given treatment in the study.

The following is a picture of the frequency distribution of students' science process skills scores after being given a simulation test in the experimental class.

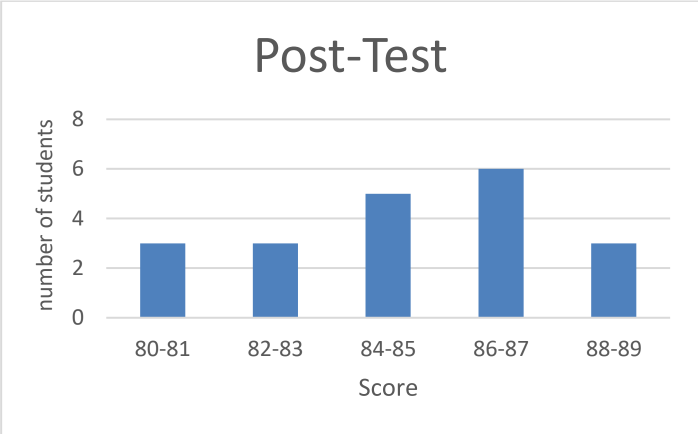

Figure 2. Frequency distribution

Figure 1.2. Frequency distribution shows that the majority of students are in the 82-83 range with 6 students, while the other ranges have smaller numbers. The 80-81 and 86-87 ranges are each filled by 3 students, while the 84-85 and 88-89 ranges have 4 students. This pattern shows that most students have a fairly good understanding, with little difference between the lower and higher score groups.

3. Normality test

Before testing N-Gain, a normality test is first performed on the pretest and posttest data. If the data is not normally distributed, the Mann-Whitney test is used, which is a non-parametric statistical test that functions to compare two independent groups. This test is an alternative to the t-test if the normality assumption is not met.

Normality test was conducted on pre-test and post-test data for the experimental class and control class. In this study, the normality test used the Kolmogorov-Smirnov or Shapiro-Wilk method. This test aims to determine whether the data is normally distributed or not. Data is considered normally distributed if the significance value (sig) > 0.05. After testing using the SPSS statistical application, the results were obtained.

Table 1.7. Normality Test

Calculation results	**sig**	**conclusions**
Pre-test	0,364	data is normally distributed
Post-test	0.200	data is normally distributed

Test results Table 1.7. The results of the normality test of the pre-test and post-test data show that both data are normally distributed. This is indicated by the significance value (sig) obtained, which is 0.364 for the pre-test and 0.200 for the post-test. The second value is for the post-test. Both values are greater than the significance limit of 0.05, so it can be concluded that the pre-test and post-test data meet the normality assumption.

4. Homogeneity test

In educational research, this test ensures that the groups being compared have balanced characteristics before the treatment is given, so that changes in results can be interpreted more as the effect of the treatment, rather than due to differences in initial variance between groups. The following table presents Homogeneity test.

Table 1.8 Homogeneity test

Calculation results	X_{count}	X_{table}	conclusion
Pre-test and post test	16,43	30,14	Data is distributed homogeneously

Table 1.8 The homogeneity test above shows the results of the homogeneity test based on the comparison between the X_count and X_table values. The X_count value is 16.43 <X_table of 30.14, which indicates that the pre-test and post-test data are homogeneously distributed. The homogeneity of this data means that the variance between the pre-test and post-test groups is relatively the same, so that the statistical test used can be considered valid for further analysis.

5. Paired sample T test

paired sample T test was conducted to see whether there were differences in the pre-test and post-test results of students from the experimental and control classes. The results of the pre-test and post-test hypothesis test calculations using SPSS can be seen in the following table.

Table 1.9 Paired sample t test

	mean	N	Std.deviation	Std.eror mean
Pre-test	68.15	20	7.727	1.728
Post-test	85.35	20	3.200	.716

Table 1.9 Paired Sample above shows a comparison of pre-test and post-test results on 20 students (N = 20) in the experimental class. The average pre-test score was 68.15 with a standard deviation of 7.727, while the average post-test score increased to 85.35 with a smaller standard deviation of 3.200, indicating that students' science process skills were more stable after the treatment was given. The smaller standard error mean value in the post-test (0.716) compared to the pre-test (1.728) indicates that the distribution of post-test scores is more consistent. Overall, the increase in the average score from pre-test to post-test indicates a positive effect of the treatment given in learning.

6. N-Gain test

This study used the N-Gain test because the main objective of the study was to determine the extent of improvement in students' science process skills after learning using the PhET simulation. Using the N-Gain test, improvement categories (low, medium, high) can be determined, indicating the extent of the intervention's impact on student learning outcomes. The following table shows the results of the N-Gain test:

Table 1.10 N-Gain test

Calculation results	g	N-Gain
Pre-test and post-test	0,481	currently

Table 1.10 presents the analysis results of the average N-Gain Score (⟨g⟩) of Grade VIII-A students after learning using the PhET simulation on the topic of static electricity. Based on the calculation, the average N-Gain value obtained was 0.481. Referring to Hake’s (1998) classification, this value falls into the medium category ($0.30 < \langle g \rangle \leq 0.70$), which means that learning with the PhET simulation effectively improved students’ science process skills at a moderate level.

This category indicates that although the improvement in science process skills did not reach a high level, the instructional intervention using the PhET simulation still provided a noticeable positive impact. These findings support the idea that interactive media such as PhET can serve as an effective alternative learning strategy, particularly for abstract physics concepts like static electricity.

7. Observation sheet results

This observation was conducted to analyze students' science process skills in understanding the concept of statistical electricity through the use of PhET simulation. Data were obtained from observation sheets filled out by teachers during the learning process in the experimental class. The results of the observation showed a significant difference in students' science process skills before and after learning using PhET simulation. Before the intervention, students tended to be passive and less involved in learning activities. However, after the use of PhET simulation, their science process skills increased significantly, as seen from the increase in the number of "YES" answers on the indicator

a) Observation

In the pre-test stage, students still had difficulty in identifying objects and statistical electricity phenomena. They tended to rely on memorization rather than making direct observations of the given phenomena. However, after learning with PhET simulation, students were better able to recognize the basic properties of electric charge and use direct observation to explain statistical electricity phenomena that occurred in the simulation.

b) Classification

Before using PhET simulation, students had difficulty in distinguishing conductors and insulators and understanding the interactions between charges based on their properties. After the post-test, their abilities improved, as seen from their ability to group objects based on their electrical properties and understand the basic principles of interactions between electric charges.

c) Communication

Initially, students were less active in discussing and expressing their opinions regarding the Coulomb force and interactions between charges. After using the PhET simulation, they were more active in discussing with peers, better able to compile experimental reports systematically, and better able to convey experimental results to teachers.

d) Forecasting

Before learning with PhET simulation, students had difficulty in making predictions about changes in electric force when one of the charges was doubled. After the intervention, they showed improvements in their prediction skills and designed experimental steps to prove the predictions more precisely.

e) Conclusion

In the pre-test stage, many students had difficulty in drawing conclusions from the results of the experiment and connecting them to Coulomb's law. After the post-test, they were better able to sort out essential information from the experiment, draw logical conclusions based on experimental evidence, and understand the concept of statistical electricity more deeply.

This increase is reflected in the increase in the average score for each of the following science process skills indicators:

Table 1.11 Average Observation Scores of Students' Science Process Skills

No	Science process skill indicator	Pre-observation score	Post-observation score	Pre category	Post category
1	observation	58.0	84.0	fair	good
2	classification	56.0	82.0	fair	good
3	communication	60.0	83.0	fair	good
4	prediction	59.5	81,5	fair	good
5	conclusion	60,5	85,0	fair	good
6	Total averege	58,8	83,2	fair	good

The observation results showed that after learning using PhET simulation, students' science process skills increased significantly compared to before the intervention. The use of PhET simulation has proven effective in helping students understand the concept of statistical electricity more concretely and interactively. Therefore, this method can continue to be developed in science learning to improve science process skills for abstract physics concepts.

B. **Discussion**

Based on the results of the test analysis, there was a significant difference between the pre-test and post-test in terms of students' understanding of the concept of static electricity. In the pre-test, the most frequently answered question was number 1, which measures the observation sub-aspect with a cognitive level of C1 in Bloom's taxonomy. This shows that before the treatment, students already had an initial understanding of observation skills. However, in the pre-test, many students had difficulty with question number 12 which measures the inference indicator with a cognitive level of C5. This error shows that students are still weak in drawing conclusions from the given phenomena.

After the implementation of PhET Simulation in learning, the post-test results showed a significant increase in understanding. The most correctly answered questions extended to numbers 1, 5, and 15, indicating that students not only understood the basic concepts but were also able to apply them better. On the other hand, the question that was still answered incorrectly was number 14, indicating that some students still had difficulty in certain aspects of the material being taught. This difference shows that the use of interactive simulations such as PhET helps improve students' understanding in fundamental aspects, although there are still challenges in higher-level cognitive aspects.

The results of observations during learning support these findings, showing an increase in students' science process skills after learning using PhET Simulation. In the early stages, students tended to be passive and only relied on teacher instructions. However, after using interactive simulations, they were more active in observing, classifying, interpreting data, and designing simple experiments. who found that the use of interactive simulations in physics learning significantly improved students' science process skills (Sari & Pradita, 2021). Also shows that the use of PhET Simulation in the concept of static electricity can improve conceptual understanding and critical thinking skills of students (Napirah, Sahara, & M, 2023). In addition, the results of this study also show that the use of PhET simulation allows students to be more involved in the learning process. This interactive simulation provides an opportunity for students to explore the concept of static electricity independently, thereby improving their problem-solving skills. In a study conducted byalso shows that the use of PhET Simulation in the concept of static electricity can improve conceptual understanding and critical thinking skills of students. In addition, the results of this study also show that the use of PhET simulation allows students to be more involved in the learning process. This interactive simulation provides an opportunity for students to explore the concept of static electricity independently, thereby improving their problem-solving skills. In a study conducted by (Melati & Fayola, 2023), It was found that interactive media based on simulation can increase students' learning motivation and strengthen their understanding of abstract concepts in physics.

Thus, the application of PhET Simulation in static electricity learning has proven effective in improving students' understanding, especially in the aspects of science process skills and understanding of basic concepts. These results strengthen the importance of using interactive technology-based learning media in improving the quality of physics learning, especially in helping students understand abstract concepts such as static electricity. Therefore, educators are advised to integrate interactive simulations into learning strategies to improve the effectiveness and quality of students' science process skills.

CONCLUSION

Based on the results of the research conducted, it can be concluded that the use of PhET simulations is effective in improving the science process skills of Grade VIII-A students on the topic of static electricity. This effectiveness is supported by two main sets of data, namely observation results and the N-Gain test. The observation results show an increase in the average score of science process skills from 58.8 in the pre-observation (categorized as fair) to 83.2 in the post-observation (categorized as good). This improvement covers five main indicators of science process skills: observing, classifying, communicating, predicting, and concluding. In addition, the average N-Gain Score (⟨g⟩) was calculated at 0.481, which falls into the medium category according to Hake's (1998) classification. This also indicates that the use of PhET simulations has a significantly positive effect on improving student learning outcomes. Therefore, PhET simulations can be considered an effective alternative learning medium, particularly for teaching abstract physics concepts such as static electricity

CONFLICTS OF INTEREST

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

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Endang Sulastri is the primary author responsible for the research implementation, data processing, analysis, and writing of the article. Zakaria Alfarizi and Epi Rusdin served as supervisors, providing methodological guidance, corrections to the academic content, and evaluation of the overall quality of the manuscript.

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