Implementation of Guided Inquiry Assisted by Phet Interactive Simulation to Improve Science Process Skills of Junior High School Students

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Article Info	ABSTRACT
	The purpose of this study was to improve the science process skills of seventh-grade junior high school students through the application of a guided inquiry learning model assisted by PhET Interactive Simulations about force and motion. This study used a quantitative approach with a one-group pretest and posttest pre-experimental design. The research subjects were 25 seventh-grade students in class VII-C at SMP Negeri 51 Surabaya in the 2024/2025 academic year. Data were collected through multiple-choice tests covering five SPS indicators, then analysed using Normalized Gain (N-Gain) analysis and descriptive statistics. The results of the study indicate that all KPS indicators experienced a significant increase. In the posttest stage, the indicators of interpreting data, determining variables, analysing data, and proposing hypotheses achieved an average score of 296.0, while the indicator of drawing conclusions achieved the highest score of 304.0. Based on individual N-Gain analysis, 48% of students were in the high improvement category, 28% in the moderate category, and 24% in the low category.

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1. Introduction

Regulation of the Minister of Primary and Secondary Education of the Republic of Indonesia Number 19 (2025) states that the implementation of science education in junior high school classes in the Merdeka Curriculum encourages students to develop basic skills in reading, arithmetic, science, and technology. Science education aims to improve science process skills (SPS) through activities such as

observation, data collection, analysis, critical thinking, and communication of results to improve problem-solving skills (Sihite Sakti M, 2024). Improving the quality of digital education, including the use of technology such as AI in scientific experiments and research, is very important to support the development of KPS (Regulation of the Minister of Primary and Secondary Education of the Republic of Indonesia Number 19, 2025). In the context of science education, the use of digital technology is highly relevant to emphasize the characteristics of science as knowledge that develops through systematic methods. Science consists of knowledge and methods for applying that knowledge.

However, learning conditions at one public junior high school in Surabaya show that educational practices are still dominated by conventional teacher-centered methods, with students playing a passive role as recipients of information (Azzahra et al., 2024). The main problem identified is the low level of students' mastery of science process skills. Students are not yet accustomed to carrying out basic scientific activities, such as designing and conducting experiments, making systematic observations, analysing data, and drawing conclusions based on empirical evidence (Ilhamdi et al., 2020). This condition is exacerbated by limited laboratory facilities, minimal access to digital learning resources, and unstable internet connectivity (Bakar et al., 2020) PhET Interactive Simulations, which are web-based science simulations developed by the University of Colorado Boulder, offer an alternative solution to overcome these problems. These simulations allow students to conduct virtual experiments by directly manipulating variables (Moore et al., 2014) The advantages of PhET include the ability to conduct repeated experiments without resource limitations, experiment safety, time efficiency, and the ability to visualize abstract concepts in a more concrete way (Dy et al., 2024; Perkins et al., 2012). Several studies show that the use of PhET simulations can improve students' understanding of science concepts (Astuti & Febriana, 2025; Koilmo et al., 2025)

However, research specifically examining the integration of guided inquiry models with PhET Interactive Simulations in improving students' science process skills is still very limited, especially in the context of science learning in Indonesian junior high schools with limited facilities. Previous studies have generally focused on only one approach or one specific aspect (Fauzi et al., 2024) and have not comprehensively examined the potential synergy between the two approaches. Therefore, this study aims to improve junior high school students' KPS in science learning through the application of a guided inquiry model assisted by PhET Interactive Simulations. It is hoped that this study can make a significant contribution to improving the quality of science learning in the digital age, particularly in developing scientific thinking skills as preparation for facing the challenges of the 21st century.

2. Method

This study used a one-group pre-test and post-test design with a quantitative approach and pre-experimental method. This design was chosen because the purpose of the study was to determine the effectiveness of the PhET Interactive Simulation model in process-based science learning in improving the efficiency of the learning process of students in one study group. In this design, one group of

students was given a pre-test to measure their initial abilities, then given treatment, and finally given a post-test to measure their final abilities after treatment. The effectiveness of the study was analyzed by comparing the pre-test and post-test results to determine whether there was a significant increase in KPS. The subjects of this study were seventh-grade students at SMP 51 Negeri Surabaya in the first semester of the 2024/2025 academic year. The selection of seventh-grade students in class VII C as research subjects was conducted using a sampling technique based on the following criteria: (1) availability of science infrastructure to collaborate in the research project; (2) educational resources that facilitate the research project; and (3) computer and laptop capabilities suitable for accessing PhET simulations.

The research procedure was carried out by administering questions before the learning began as pretest data in the form of 10 multiple-choice questions that measured five indicators of science process skills. In this study, five main indicators were used to measure science process skills, which reflect students' scientific thinking stages in inquiry-based science learning. These include the ability to determine variables (independent, dependent, and control), formulate logical and testable hypotheses, systematically collect data through PhET simulations, analyze and interpret data in tabular or graphical form, and draw conclusions consistent with the data and initial hypotheses. The science learning objectives in the Independent Curriculum, which emphasize improving scientific literacy and scientific reasoning, motivated the selection of these five indicators. The purpose of this pre-learning test was to assess the students' initial abilities before they received the learning. This was followed by the learning process as shown in Table 1 below:

Table 1. Syntax of PhET Simulation-Assisted Guided Inquiry in Research

Activity	Description
Problem Orientation	Through PhET simulations, teachers present phenomena or problems related to science material. Students observe and discover problems that can be implied.
Formulating the Problem	Students are guided to formulate research questions based on the phenomena observed in the simulation.
Formulating Hypotheses	Based on their prior knowledge and observation results, students propose a preliminary hypothesis.
Collecting Data	Using PhET Interactive Simulations, students conduct virtual experiments by manipulating identified variables, tracking changes, and keeping records of their observations.
Interpreting Data	Students process the collected data by creating tables or graphs and finding patterns or relationships between variables.
Drawing Conclusions	Students analyze the data and compare it with the initial hypothesis.

After conducting investigative activities in class, students were given a posttest. This test was conducted after the treatment using the same questions as in the previous test, with the aim of determining the improvement in students' science process skills after participating in the learning process. The data obtained from the pretest and posttest results were then analyzed quantitatively using various relevant statistical analysis techniques to answer the research questions. The initial analysis was conducted using descriptive statistics, such as mean values and percentages, to provide an overview of students' Science Process Skills (SPS) at each stage of learning.

The paired sample t-test was used to test the hypothesis of a significant difference between the scores before and after treatment. This test was chosen to determine whether there was a significant difference between the average pretest and posttest scores of students after participating in guided inquiry-based learning assisted by PhET Interactive Simulations. In addition to analyzing the difference in means, this study also applied Normalized Gain (N-Gain) analysis to quantify the increase in Science Process Skills (SPS) experienced by students, both individually and after the learning process. The N-Gain calculation is important for determining the effectiveness of applying the guided inquiry learning model assisted by PhET Interactive Simulations in learning activities. The results of the index increase analysis were then categorized according to strict effectiveness interpretation criteria, as shown in Table 2 below:

Table 2. Normalized N-gain Criteria

| N-gain value	Interpretation
N-Gain > 0,70	Height
0,30≤ N-Gain ≤ 0,70	Currently
N -Gain < 0,30	Low

(Hake, 1998)

3. Results and Discussion
Results

In this study, the implementation of Guided Inquiry-based learning using PhET Interactive Simulations was carried out in accordance with predetermined criteria The learning process began with a problem-oriented phase, in which the teacher presented the PhET simulation to the entire class using a projector, as shown in the image below.

Figure 1. Students observe the PhET Forces and Motion: Basics simulation demonstrated via projector during the orientation and exploration phase of guided inquiry-based learning.

The simulation used in this study is Forces and Motion: Basics with a tug-of-war mode, as shown in Figure 1. This simulation is designed interactively with features that support the development of students' Science Process Skills (SPS). The main features used include: (1) setting the number of forces by adding or reducing the number of people on each side, which helps students identify and determine independent variables; (2) displaying force values in Newtons (N), which allows students to develop skills in measuring and collecting quantitative data; and (3) class motion speed indicators, which help students observe and interpret the relationship between force and motion.
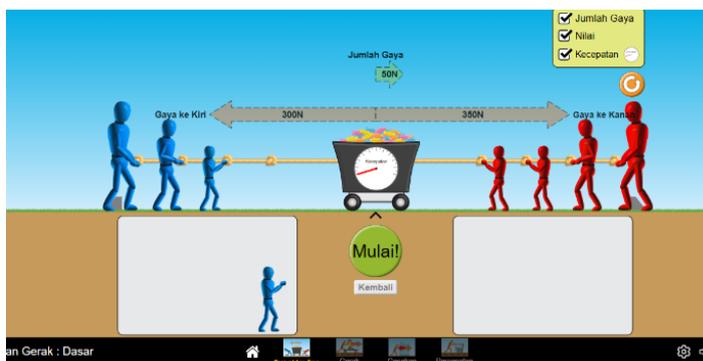
Figure 2. PhET Forces and Motion simulation display: Basics mode tug-of-war with features for setting the number of forces, force values, and speeds that support KPS development.

The checklist feature in the simulation allows students to independently select and manipulate variables according to their research focus, while the "Start" and "Back" symbols encourage the completion of challenging tasks. Through this simulation, students can test hypotheses about the relationship between force and motion by analysing changes in the speed and direction of objects. This helps students become more proficient in interpreting data, identifying variables, analysing data, and evaluating hypotheses. The analysis presented focuses on changes in student abilities in each KPS indicator measured through multiple-choice questions on the pretest and posttest. Based on the research data, a summary of the percentage of achievement for each KPS indicator on the pretest and posttest is presented in Table 3.

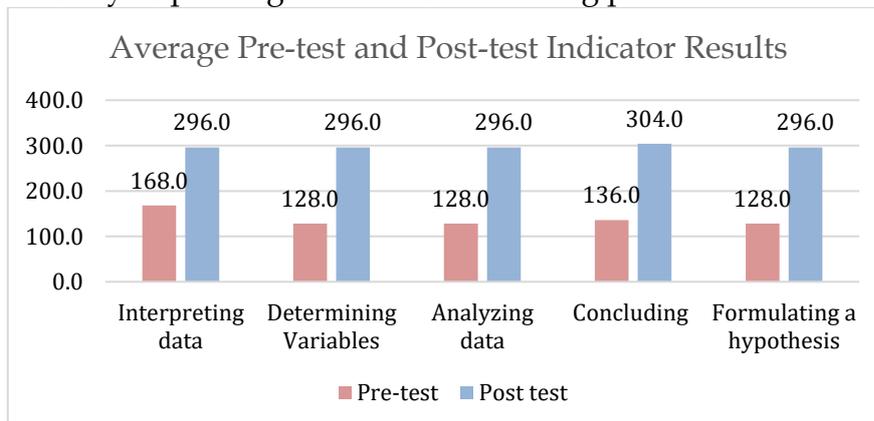**Table 3. KPS Indicator Achievement Results on Pretest and Posttest Questions**

KPS Indicator	Pre-test	Post test
Interpreting data	168,0	296,0
Determining Variables	128,0	296,0
Analyzing data	128,0	296,0
Concluding	136,0	304,0
Formulating a hypothesis	128,0	296,0

Pretest and posttest results showed that all KPS indicators had improved. However, several indicators, such as determining variables, generating hypotheses, and analyzing data, were still considered low in the pretest. All indicators improved after the implementation of PhET guided questions, with the indicator drawing conclusions showing the highest achievement. This indicates that students acquired more comprehensive science process skills through learning.

Based on Table 2, there were several science process indicators that were examined before and after testing. In the pre-test stage, the indicators with the lowest achievement percentage were determining variables, analyzing data, and formulating hypotheses, which was 128.0%, indicating that before learning, students still faced difficulties in formulating temporary assumptions based on problem formulations. Conversely, the highest pre-test percentage was found in the data interpretation indicator at 168.0%, although this achievement was still relatively low.

Meanwhile, in the post-test stage, all indicators showed significant Improvement. These indicators were based on the highest achievement percentage of 304.0%, which showed that students were able to draw conclusions based on data

analysis and observation results. Conversely, indicators for interpreting data, identifying variables, and analyzing data in general reached a percentage of 296.0%, indicating that students' abilities in various aspects of the science process were in the good category. This improvement shows that the learning was effective in comprehensively improving the students' learning process.

Average Pre-test and Post-test Indicator Results

Indicator	Pre-test	Post test
Interpreting data	168.0	296.0
Determining Variables	128.0	296.0
Analyzing data	128.0	296.0
Concluding	136.0	304.0
Formulating a hypothesis	128.0	296.0

**Figure 3.** Comparison of Pretest-Posttest Results for Each Indicator

In addition to analyzing each indicator, N-Gain analysis was conducted for each student individually to examine the distribution of KPS growth in class VII-C. The individual N-Gain results for each student are shown in Table 4 below:

Table 4. Results of Individual Student KPS N-Gain Calculations

Name	Pretest	Posttest	N gain Score	Kategori
M1	40	90	5,00	Height
M2	20	80	0,75	Height
M3	30	90	0,86	Height
M4	20	90	0,88	Height
M5	40	70	0,50	Currently
M6	50	80	0,60	Currently
M7	40	90	0,83	Height
M8	60	90	0,75	Height
M9	40	80	0,67	Currently
M10	30	90	0,86	Height
M11	50	80	0,60	Currently
M12	20	30	0,13	Low
M13	20	80	0,75	Height
M14	10	30	0,22	Low
M15	20	90	0,88	Height
M16	30	100	1,00	Height
M17	50	60	0,20	Low
M18	40	40	0,00	Low
M19	50	70	0,40	Currently
M20	30	90	0,86	Height
M21	40	70	0,50	Currently
M22	10	30	0,22	Low

Name	Pretest	Posttest	N gain Score	Kategori
M23	40	80	0,67	Currently
M24	20	80	0,75	Height
M25	60	80	0,50	Currently

Based on Table 4, the N-Gain analysis results show variations in KPS for each student. Of the 25 students analyzed, approximately 6 students were in the low category, 7 students in the medium category, and 12 students in the high category. To provide a more visual illustration, the following pie chart depicts the distribution of the N-Gain categories.
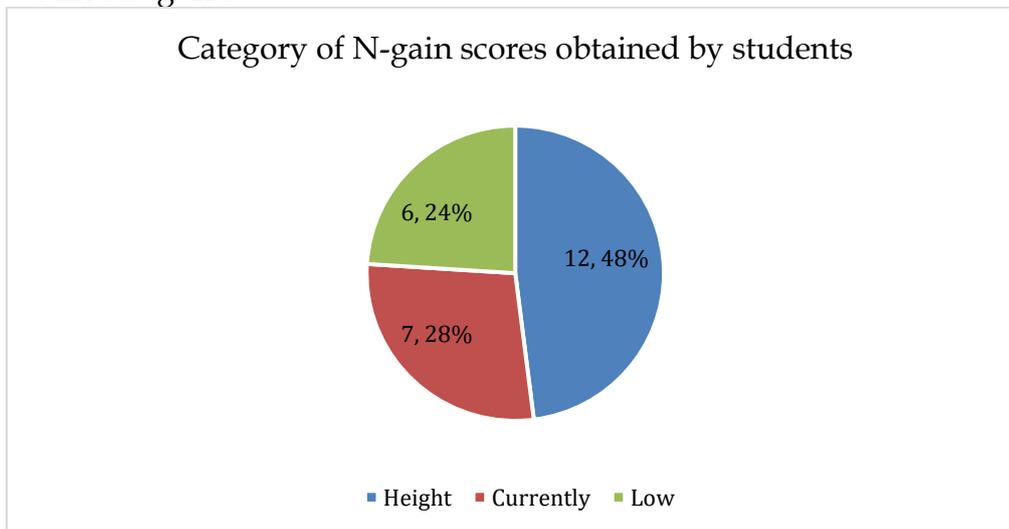
Figure 4. Student KPS Score Categories Based on N-Gain Analysis

Based on Figure 4, the graphical representation of the distribution of students' KPS categories shows that 12 students (48%) are in the high category, 7 students (28%) in the medium category, and 6 students (24%) in the low category. Overall, about 76% of students are in the medium to high categories, indicating that simulation-based learning using PhET is effective in improving students' KPS. Students in the high category showed active participation, good simulation skills, and adequate computer literacy, with some even achieving an N-Gain score of ≥ 1.00. Students in the moderate category experienced moderate growth, while students in the low category showed limited growth due to difficulties in understanding and using simulations. Despite these variations in results, the N-Gain analysis generally shows that the inquiry-based learning applied had a positive impact on students' KPS, with the need for additional intervention for students in the low category.

Discussion

The results of this study indicate that the application of the guided inquiry learning paradigm is effective in improving the science process skills of seventh-grade junior high school students. In addition to the use of technology, the synergy between guided inquiry models and PhET simulations plays a crucial role in enhancing KPS. While PhET provides students with an exploratory environment that allows them to manipulate variables and understand cause-and-effect relationships, guided inquiry provides a structured framework for thinking. This

aligns with constructivism theory and demonstrates how learning shifts from receptive to participatory, with students acting as active knowledge builders and teachers as facilitators.

This is consistent with science education that emphasizes the development of knowledge through experiments and research (Zompero et al., 2024). The following analysis highlights important aspects of the research presented in the results section. Significant improvements in KPS across all indicators show that PhET Interactive Simulations provide a learning experience that supports the development of students' intellectual abilities. Force and motion simulation: the basic use of a tug-of-war model used in this study allows students to engage in interactive exploration of the concepts of force and motion. Features available in the simulation, such as the number of forces, force values in one Newton, and speed indicators, allow students to manipulate variables in a relaxed manner and see the results in real time (Octavia & Susiyawati, 2025).

PhET's simulation capabilities to view abstract concepts as concrete representations greatly assist students in understanding the cause-and-effect relationships of physical phenomena. According to (Hanikah et al., 2025), virtual simulations can bridge the gap between theoretical knowledge and practical application, especially for concepts that are difficult to apply in everyday life. In the context of this study, students can observe in detail how the amount of force affects the speed and direction of an object, which previously may have only been understood abstractly through verbal explanations or statistical illustrations. PhET's high accessibility and ability to be used frequently without batteries is an effective solution for schools with inadequate laboratory facilities (Widiyatmoko et al., 2023). In this study, the laboratory infrastructure at SMP Negeri 51 Surabaya is still a major obstacle in implementing experiment-based learning. Students can engage in various virtual learning activities necessary to understand concepts, test alternative hypotheses, and investigate various scenarios without worrying about affecting the functionality of tools or practical materials.

Analysis of the six KPS indicators used in this study shows an upward trend that needs to be further investigated. In the pretest phase, the indicators of determining variables, analyzing data, and applying hypotheses showed the lowest achievement (128.0), indicating a need for improvement in students' performance in process skills that require higher-order thinking. This is consistent with the findings (Ariyansyah & Nurfathurrahmah, 2022), which state that junior high school students generally still have difficulty identifying and analyzing variables in the context of scientific experiments. Students' initial ability to formulate hypotheses can be explained by their minimal experience in inquiry-based learning. Conventional education, which still dominates in schools, tends to teach knowledge in a way that does not involve students in the process of knowledge creation (Dewi et al., 2025) As a result, students are not accustomed to making tentative hypotheses based on their observations or prior knowledge.

Conversely, the indicator interpreting data showed the highest score on the pretest (168.0), although it was still relatively low. This indicates that students have the basic ability to read and understand data but are not yet able to analyze it and use it to produce scientific work. Data interpretation skills are important skills that form the basis for other scientific processes. At the posttest stage, each indicator

showed a significant improvement. The indicators reached the highest percentage (304.0), indicating that students were able to analyze experimental data and draw conclusions based on empirical evidence. This shows that guided inquiry-based teaching using PhET simulations successfully teaches students to think critically and logically when connecting facts with the concepts taught (Martatis, 2023). The indicators of interpreting data, identifying variables, analyzing data, and proposing hypotheses achieved the same percentage (296.0) on the posttest, which shows a clear improvement. This balanced pattern of improvement shows that the learning model applied provides opportunities for students to develop various aspects of KPS holistically. This is in line with the principle of inquiry learning, which emphasizes active student participation in all stages of the learning process, from problem solving to goal setting (Marva & Fauziah, 2025).

Individual N-Gain analysis revealed significant variation in students' KPS. Of the 25 students studied, 48% were in the high category, 28% in the medium category, and 24% in the low category. (Resti et al., 2024), this distribution highlights the diversity of students' characteristics and abilities in responding to technology-based learning. Students in the high category (N-Gain > 0.70) showed consistent characteristics, namely active participation in learning, proficient operation of simulations, and good digital literacy. Some students even achieved N-Gain ≥ 1.00, indicating improvement above their initial abilities. This is in line with research (Ariyansyah & Nurfathurrahmah, 2022), which shows that students' digital literacy is positively correlated with learning success through virtual simulations. Students in the moderate category (0.30 ≤ N-Gain ≤ 0.70) show moderate growth. This group needs more time to adapt to a technology-based learning environment or has a learning style that is not fully compatible with the visual-interactive learning methods offered by PhET simulations. According to (Widiyatmoko et al., 2023), students' learning styles can affect the effectiveness of digital learning media, so teachers need to offer a variety of teaching strategies. Students in the low category (N-Gain < 0.30) experienced limited improvement, with some even showing an N-Gain of 0.00. Further analysis revealed that students in this group had difficulty understanding instructions, using simulations, and participating in inquiry-based learning activities. This indicates the need for further intervention, such as individual counseling, simulation training, or the development of more structured (Maulani Soraya & Muhammad, 2023)

The results of this study, which used a PhET-based learning approach with guided inquiry methods, have important implications for science education in the digital age. The findings of this study show that physical laboratory facilities are no longer a barrier to implementing experiment-based learning(Gede et al., 2022). As an effective alternative, virtual simulations can offer advantages over real-world experiments, such as the ability to manipulate variables that are difficult to analyze in a real environment. Furthermore, the integration of technology in science education must be aligned with appropriate teaching models. Technology does not automatically improve the quality of education if it is not supported by the right pedagogical strategies. In the context of this study, PhET Interactive Simulations are effective because they are integrated with a guided inquiry model, which provides structure and guidance in the learning process (Mufidah & Putranta, 2024; Sunan & Surabaya, 2023).

Although the results of the study show positive effectiveness, there are several limitations that need to be acknowledged. First, the single-group pretest–posttest design used did not have a control group, making it impossible to isolate the influence of other factors that could potentially affect students' KPS. Therefore, further research could use a more robust experimental design with a control group to validate these findings (Muazaroh, 2024). In addition, this study only focused on one topic, namely force and motion, and one type of PhET simulation. The effectiveness of this teaching technique on other science topics or with different simulations needs to be further investigated to ensure the generalization of the research results(Ben Ouahi et al., 2022; Reny Indah Whayuni & Laily Rosdiana, 2023) Based on these findings, several recommendations for further research include: (1) using an experimental design with a control group; (2) investigating the effectiveness of this model on various science topics; (3) using more varied assessment instruments; (4) investigating the factors that influence student performance individually in a more comprehensive manner; and (5) using longitudinal research to measure student KPS retention in the long term (Yusuf et al., 2024) To better generalize the findings, further research should involve more diverse subjects and school contexts after considering the study's findings and limitations. To gain a deeper understanding of the learning process, a mixed approach combining quantitative and qualitative data is recommended. Furthermore, additional research cycles or stages should be considered to assess the continuous improvement and long-term impact of KPS. It is hoped that these recommendations will enhance the contribution of research to the development of technology-based science learning.

4. Conclusions

This study shows that the use of guided inquiry learning models with the help of PhET Interactive Simulations is effective in improving the Science Process Skills (SPS) of seventh grade junior high school students in the subject of science, force and motion. There was a significant increase in all measured SPK indicators, with one indicator reaching the highest value of 304.0. This increase was followed by indicators of interpreting data, identifying variables, analyzing data, and concluding hypotheses, which averaged 296.0 in the posttest phase. Based on individual N-Gain analysis, 76% of students were in the moderate to high category, with 48% in the high category (N-Gain > 0.70), 28% in the moderate category (0.30 ≤ N-Gain ≤ 0.70), and 24% in the low category (N-Gain < 0.30). This variation in achievement highlights differences in student characteristics, particularly in digital literacy and adaptability to technology-based learning.

PhET Force and Motion Simulation: Fundamentals effectively facilitates the development of KPS through interactive features that allow students to manipulate variables, observe phenomena directly, and conduct repeated experiments (Mahzum et al., 2024; Nurulfajri et al., 2024) The applied learning model provides a systematic learning structure, guiding students from the problem orientation stage to drawing conclusions. The practical implications of this study indicate that PhET Interactive Simulations can be an alternative solution for schools with limited laboratory facilities in implementing experiment-based science learning (Muliyadi I, 2025). The application of this learning model in the curriculum can help students

achieve the objectives of the Merdeka Curriculum, comprehensively improve their KPS, and prepare them to face the challenges of the 21st century (Lutfiani et al., 2023). However, its implementation requires adequate technological infrastructure support, strengthening digital literacy for teachers and students, and applying differentiated learning strategies to accommodate student diversity (Sudirman & Qaddafi, 2023).

5. Acknowledgment

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