Journal of Progressive Science Education e-ISSN: 3163-7175
Volume 2, Number 2, 2026 pp. 67-79
Open Access: https://journal.kopialinea.com/index.php/JPSE

The Effect of Guided Inquiry Model Assisted by PhET Simulation on Students' Conceptual Understanding

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A R T I C L E I N F O

Article History
Submitted : June 30, 2026
Final Revised : July 26, 2026
Accepted : July 27, 2026
Published : July 31, 2026

Keywords:
Guided Inquiry, PhET Simulation, Conceptual Understanding, Science Education

A B S T R ACT
Conceptual understanding is an essential competency in science learning because it enables students to interpret scientific phenomena and apply scientific knowledge in everyday life. However, students' conceptual understanding of vibration and wave concepts at SMP Negeri 24 Padang remained below the expected learning achievement criteria. This study aimed to investigate the effect of the Guided Inquiry learning model assisted by PhET Simulation on students' conceptual understanding of vibration and wave topics. The study employed a quasi-experimental method using a non-equivalent control group design involving two eighth-grade classes selected through purposive sampling. Data were collected through a conceptual understanding test, classroom observation sheets, and student response questionnaires. The findings revealed that students who learned through Guided Inquiry assisted by PhET Simulation demonstrated better conceptual understanding than those who experienced conventional instruction. The integration of inquiry activities and interactive simulations facilitated students in exploring scientific phenomena, constructing concepts, and applying their understanding more effectively. These findings suggest that Guided Inquiry assisted by PhET Simulation can be used as an alternative approach to support meaningful and technology-integrated science learning, particularly for abstract science concepts such as vibrations and waves.

1. INTRODUCTION

The educational paradigm has changed as a result of the rapid advancement of technology and science in the 21st century. The previous paradigm focused on knowledge transfer, and now it focuses on improving students' abilities (Mor, 2025). Conceptual understanding is a crucial skill in science learning. This skill will help students interpret scientific phenomena, connect various concepts, and apply their knowledge to solve everyday problems (Mi et al., 2020). The integration of technology in learning is also a requirement of 21st century education because it is able to support the creation of a learning process that is relevant, interesting, and interactive with the needs of students in the digital era (Zou et al., 2025). Furthermore, adequate technology readiness and digital literacy have been proven to significantly enhance student learning engagement and prepare the foundations for future educational ecosystems (Firdaus & Nurohman, 2025).

In Indonesia, efforts to realize learning oriented towards competency development are realized through the implementation of the Independent Curriculum (Sartini & Mulyono, 2022). This curriculum provides teachers with the flexibility to design student-centered learning through the application of innovative learning models, the use of technology, and the

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provision of learning experiences that are appropriate to student characteristics (Supartama et al., 2023). Therefore, the aim of science learning, apart from increasing mastery of the material, is to increase the ability to understand concepts comprehensively so that students are able to relate the knowledge they acquire to various phenomena in their surrounding environment (Julaeha, 2021).

Good conceptual understanding is demonstrated by students' ability to not only remember information, but also explain, interpret, connect concepts, and apply the concepts learned to various different situations and problems (Vosniadou, 2019). On the other hand, low conceptual understanding can cause students to experience misconceptions, which can have an impact on low ability to solve scientific problems (Murniayudi et al., 2018). In addition, the level of student concept mastery has a large influence on learning outcomes, so that increased conceptual understanding will be followed by increased learning outcomes (Sihombing, 2021).

Based on observations and interviews at SMP Negeri 24 Padang, the learning process still tends to use the lecture method with the teacher as the center of learning. Furthermore, the use of digital-based learning media has not been maximized to support the learning process, while practical activities are still limited due to limited laboratory equipment and materials. This situation aligns with broader findings indicating that while educators recognize the value of Inquiry-Based Learning (IBL), its practical implementation is often hindered by limited resources, technological constraints, and institutional barriers (Winarto et al., 2026).

Consequently, This condition causes students to tend to memorize concepts without gaining learning experiences that allow them to construct understanding independently. As a result, a number of students are still unable to meet the Learning Objective Achievement Criteria (KKTP) established for science subjects. This condition indicates a difference between the objectives of the Independent Curriculum to enable active, contextual, and technology-based learning in schools compared to a more teacher-centered learning method. Based on these conditions, it is necessary to implement a learning model that can encourage student participation in the learning process and is supported by learning media that can visualize abstract science concepts for easier understanding.

The guided inquiry learning model is an alternative that can be used in the learning process to improve students' understanding of the material. Using this learning model, students are facilitated to actively acquire knowledge through the process of investigation, data collection and analysis, and formulation of conclusions, while still receiving direction and guidance from the teacher according to their needs and development (Garrison et al., 2018). This learning process enables students to not only receive information passively, but to build their own understanding of the concepts being studied, thus creating a more meaningful learning experience (Sulistiyono, 2020). Compared to teacher-centered learning, guided inquiry encourages students' active involvement in developing scientific thinking skills, solving problems, and understanding the relationships between concepts more deeply (Zafira et al., 2025).

The success of guided inquiry is also influenced by the use of learning media that can facilitate the exploration and investigation process. In science learning, many concepts are still abstract and therefore difficult to observe directly (Riku, 2021). The use of interactive digital platforms has proven effective in overcoming these limitations by providing cognitive stimuli for complex materials, which in turn significantly increases student engagement and motivation (Djara et al., 2026) To address this issue, one medium that can be used is PhET simulation. This interactive simulation provides students with the opportunity to conduct virtual experiments, change certain variables, directly observe changes that occur during the learning process, and visualize abstract concepts more concretely (Kumar, 2024). In addition, the use of PhET simulation can be an alternative for implementing practical work when schools have limited laboratory equipment and materials so that students can still gain learning experiences through scientific investigation activities (Diab et al., 2024). Through the stages of orientation, exploration, concept formation, application, and closing, students build concepts gradually so that understanding of the concept develops better.

According to previous research, guided inquiry learning models and the use of technology-based media can improve the quality of science learning. Research conducted by Zulfa & Astra (2025) studies have shown that guided inquiry learning improves students' understanding of concepts by enabling them to actively participate in the scientific inquiry process. Students not only receive information from the teacher during the learning process, but also construct concepts through inquiry activities that include observing, collecting and analyzing data, and drawing conclusions based on the findings. This finding is supported by Djola et al. (2021) which states that more significant learning experiences are obtained through the guided inquiry learning model because students gain knowledge through the discovery process so that students' understanding of the concepts being studied increases and the concepts are more easily retained in long-term memory.

In addition to learning models, the use of interactive learning media has also been proven to provide a positive contribution to improving students' understanding of concepts. Lamanepa et al. (2020) explained that through interactive simulations, PhET simulations can help students visualize abstract science concepts. This allows the material being studied to be visualized more concretely, and the learning process becomes more engaging and easier for students to understand. In line with this, Wardani & Rosdiana (2022) stated that using PhET simulations as a medium allows students to conduct experiments independently at home, thereby deepening and strengthening their understanding of the concepts they are learning. Through these simulations, students can still conduct investigations, manipulate variables, observe phenomena, and gain learning experiences that resemble real-life practical activities (Dasmo et al., 2020). By using a guided inquiry learning model supported by PhET simulation, students are more motivated to complete assignments. This is because the media and models used are able to capture students' attention, making them more interested in conducting experiments and completing assignments.

This study shares similarities with Zafira et al. (2025) study, which examined the application of a guided inquiry learning model assisted by PhET simulation. However, previous studies predominantly treat conceptual understanding as a single, uniform outcome and often overlook the cognitive challenges students face when learning highly abstract mechanical phenomena. A significant theoretical gap remains in understanding how the integration of virtual simulations and guided inquiry functions as a cognitive scaffold to address specific dimensions of conceptual understanding, particularly the transition from visual interpretation to verbal explanation in early secondary education. Therefore, the novelty of this research goes beyond merely applying a different subject matter (vibrations and waves). It lies in evaluating the functional integration of the Guided Inquiry model and PhET simulation to mitigate cognitive load and map its differential impact on varying levels of conceptual understanding competencies. By doing so, this study provides deeper empirical insights into how interactive technology facilitates generative sense-making in junior high school science learning.

2. METHODOLOGY

This study employed a quantitative approach to examine the effect of the Guided Inquiry learning model assisted by PhET simulation on students' conceptual understanding. This approach was used because it can produce objective measurements of changes in student abilities through statistical analysis, making it suitable for answering the research objectives.

2.1 Research Design

This study applied the Quasi Experiment method with a Non-Equivalent Control Group design. In this design, the research subjects were divided into two groups without randomization, namely the experimental class received learning using a guided inquiry model with the help of PhET simulation, while the control class received conventional learning. The selection of conventional learning as a treatment in the control class was based on the learning conditions commonly applied at SMP Negeri 24 Padang before the study was conducted. Thus, this study was designed to compare the effectiveness of the Guided Inquiry model assisted by PhET Simulation with learning practices commonly used in schools. Therefore, the purpose of the study was not to isolate the effect of each component (Guided Inquiry or PhET Simulation), but rather to evaluate the effect of the integration of both on students' conceptual understanding in the context of real learning in the classroom. A pretest before treatment and a posttest after learning were conducted on both groups to determine whether there were changes in conceptual understanding.

The research was conducted through three stages: preparation, implementation, and completion. The preparation phase included the development of teaching modules, Student Worksheets (LKPD), conceptual understanding test questions, learning implementation observation sheets, and student response questionnaires. All instruments were then validated and tested before being used in the research.

In the implementation phase, before the treatment was administered, a pretest was conducted to evaluate the initial abilities of the experimental and control classes. Next, the experimental class was taught through a guided inquiry model supported by PhET simulation, while the control class was taught conventionally. During the learning process, observers observed the implementation of each stage of the learning syntax by the teacher and students.

The completion stage involved administering a posttest to both groups to measure conceptual understanding after the treatment. At the end of the lesson, students in the experimental class were also asked to complete a response questionnaire to evaluate the implementation of the learning model.

2.2 Research Population and Sample

All eighth-grade students of SMP Negeri 24 Padang participated in this study. Using purposive sampling, two groups were selected for the study, with one group known as the experimental group and the other known as the control group. Data were collected through tests and non-tests. These considerations included the similarity of the teaching teachers, the similarity of the materials provided, and the relatively balanced average mid-term exam scores. The test technique measured students' conceptual understanding with a multiple-choice instrument created based on conceptual understanding indicators. The non-test technique was carried out through observations of the implementation of learning and the distribution of questionnaires to obtain data on students' responses to learning. The observation sheet instrument was used to evaluate the implementation of the learning model syntax during learning activities, while the questionnaire was used to collect data on how students interacted with the learning process.

2.3 Data Collection and Analysis

The collected data were analyzed using SPSS version 26. The initial stage of the analysis included a normality test using Shapiro–Wilk and a homogeneity test using Levene. To eliminate potential bias arising from the non-homogeneous variance of the pretest data (Sig. 0.001), the primary hypothesis testing in this study was directly applied to the N-Gain scores of both classes, rather than comparing the raw posttest scores. The N-Gain score was specifically selected because it mathematically normalizes individual gains, thereby neutralizing baseline differences in students' initial capacities. To evaluate the significance of the difference in conceptual understanding improvement between the experimental and control groups, a Mann–Whitney test was performed on the N-Gain data using SPSS version 26 at a significance level of 0.05. Furthermore, improvements in conceptual understanding were analyzed using the N-Gain test. Data from observations of learning implementation and student questionnaire responses were analyzed descriptively by calculating the percentage value of each indicator.

The concept understanding test instrument is compiled based on concept understanding indicators that refer to the understanding category (C2) in the revised Bloom's Taxonomy, which includes the ability to interpret, provide examples, classify, conclude, compare, explain, and summarize (Anderson & Krathwohl, 2001). Before being used in the research, the instrument was tested for validity and reliability. The instrument validity test aimed to determine the suitability of each question item before it was used in the research data collection process. The validity test results showed that 29 of the 35 multiple-choice questions were valid and suitable for use as a research instrument. Meanwhile, the other six questions were declared invalid and were eliminated from the research instrument.

To determine the level of instrument consistency, instrument reliability was analyzed using the Spearman-Brown formula. The test results showed a reliability coefficient of 0.86, which is in the very high category, indicating that the instrument has an excellent level of consistency. Therefore, this instrument is suitable for measuring students' conceptual understanding in this study.

3. RESULTS AND DISCUSSION

There are two sample classes, class VIII F used as the experimental group and class VIII G used as the control group, used in this investigation. The number of students in both groups is the same, 32 students each. The experimental class is taught using the Guided Inquiry model with the help of PhET simulation, while the control class is taught using conventional methods. The implementation of the syntax of the Guided Inquiry learning model during learning activities can be seen through the observation sheet given to the observer. Observations of the implementation of learning were carried out by one observer who is a science teacher at SMP Negeri 24 Padang. Before the study was conducted, the observer was given an explanation of the research objectives, the syntax of the learning model, and how to fill out the observation sheet to minimize differences in perception during the observation process. The results of the implementation assessment of learning activities are presented in the following table.

Table 1. Percentage of Learning Implementation

Activity	Guided Inquiry Model Syntax	Teacher Implementation (%)	Student Implementation (%)
Preliminary Activities		100%	100%
	Orientation	100%	88%
	Exploration	94%	83%
Core activities	*Concept Formation*	100%	92%
	Application	100%	92%
	Closure	94%	89%
Closing Activities		99%	93%
Average Implementation		98%	91%

Based on the data in the table, the average percentage of implementation of the Guided Inquiry learning model in the experimental class by teachers was 98% and students 91%. The high implementation percentage indicates that all Guided Inquiry syntax can be implemented according to the learning plan. High implementation is an important prerequisite for the model's effectiveness because each learning stage plays a role in facilitating students' knowledge construction. The observed 100% perfect implementation rate across several stages of teacher implementation syntax (such as preliminary activities, orientation, concept formation, and application) can be rigorously justified by certain methodological controls.

First, this study used a highly structured teaching module and student worksheets integrated with PhET simulations, which provided a rigorous procedural framework. This design strictly defined each instructional step for teachers, minimizing potential for bias in the field. Second, the observation sheet used a Likert scale that focused entirely on concrete, observable behaviors rather than subjective rating scales that are highly inferential. Prior to data collection, intensive briefings were conducted with observers to align perceptions regarding the operational definitions of each syntactic stage, thus significantly reducing interpretation ambiguity.

In the preliminary activities, the implementation of teachers and students reached 100%. This stage includes activities to open the lesson, pray together, and check student attendance. The percentage reaching 100% indicates that the preliminary activities were implemented according to the lesson plan. Preliminary activities play a role in preparing students' physical and mental readiness before participating in learning so that students are better prepared to participate in learning activities and receive the material to be studied.

The orientation phase achieved a 100% success rate for teachers and 88% for students. At this stage, teachers guided students to understand the learning objectives, prerequisite material, and answer the provocative questions in the worksheet. The orientation phase aimed to build learning motivation and activate students' prior knowledge. The percentage of students who did not reach 100% indicates that some students still showed a low level of activeness in responding to questions posed during the learning process. According to Hanson (2005), the orientation stage aims to build learning motivation, activate students' prior knowledge, and help students understand the learning objectives to be achieved.

The exploration stage achieved a 94% success rate for teachers and 83% for students. This stage is the core of the guided inquiry activity, where students conduct experiments using PhET simulations, collect data, and discuss observations. This aligns with research Haidar et al. (2020), which states that the exploration stage gives students the opportunity to carry out investigations, collect data, and discover relationships between concepts through direct learning experiences. The suboptimal percentage indicates that some students still need assistance in operating the simulation and analyzing data from the experiment. However, the exploration phase allows students to directly engage in scientific inquiry and gain valuable learning experiences.

The use of PhET Simulation in this study was not conducted through free exploration, but rather integrated in a structured manner into the Student Worksheet (LKPD). During the exploration phase, students were given operational instructions for using the simulation, the required experimental steps, the variables to be observed, a data collection table, and guiding questions to guide the investigation. Through this design, students not only interacted with the simulation randomly but also conducted investigations based on the established learning objectives.

The concept formation stage achieved 100% success among teachers and 92% success among students. At this stage, students connected the results of their exploration with the concepts learned through discussions and solving questions in the worksheet. The results showed that most students successfully formed conceptual understanding based on their learning experiences. This finding aligns with constructivism, which emphasizes that students must actively participate in interactions with their learning environment to shape their understanding and knowledge (Masgumelar & Mustafa, 2021). The percentage of student implementation has not reached 100% because some students still show difficulty in interpreting experimental results and connecting them with the concepts being studied, so they require further guidance from the teacher and their group friends.

The application stage achieved a 100% success rate for teachers and 92% for students. At this stage, students have the opportunity to apply the concepts they have learned by solving practice questions in the Student Worksheet (LKPD). The application stage serves to strengthen conceptual understanding through application to various situations. The percentage of students who did not reach 100% indicates that some students are still not very active in participating in group discussions and tend to rely on other group members. This activity is also in line with the opinion Nurhasanah et al. (2022) which states that learning will be more meaningful if new information can be connected to the knowledge that students already have.

The closing stage achieved a 94% teacher and 89% student participation rate. Activities included presentations of discussion results, group feedback, and reflection on learning. This stage served to strengthen students' understanding of the concepts learned and encouraged them to reflect on the learning process. The percentages that fell short of 100% were due to time constraints, which meant that not all groups had an equal opportunity to provide feedback during the class discussion.

In the closing activity, teacher implementation reached 99% and students 93%. The teacher provided opportunities for students to ask questions, provide information about the next lesson, and conclude the lesson. The closing activity played a role in strengthening students' understanding of the material learned and preparing them for the next lesson (Ni'imah & Widodo, 2022). The percentage that has not reached 100% shows that not all students took advantage of the opportunity to ask questions, and in some meetings the teacher did not have time to explain the material for the next meeting in detail due to time constraints.

An analysis of students' conceptual understanding across all indicators was conducted to determine whether there were significant differences in conceptual understanding between the experimental and control classes. Table 2 shows an analysis of students' conceptual understanding across all indicators.

Table 2. Analysis of Students' Conceptual Understanding of All Indicators

	Pretest		*Posttest*	
	Control	Experiment	Control	Experiment
Mean	53,43	52,81	66,71	81,56
Min	40	30	45	50
Max	75	80	95	100
Normality Test				
α	0,05			
Sig.	0,010	0,030	0,521	0,008
Conclusion	Abnormal	Abnormal	Normal	Abnormal
Homogeneity Test				
α	0,05			
Sig.	0,001		0,301	
Conclusion	Not homogeneous		Homogeneous	
Hypothesis Testing				
α	0,05			
Sig.	0,740		0,000	
Conclusion	There is no difference		There is a difference	

According to the table, the average pretest score for the control class was 53.43 and the experimental class was 52.81. These results indicate that the initial conditions of both classes were at a comparable level before the implementation of the different learning treatments. After the implementation of the different learning treatments, the average posttest score for the control class increased to 66.71, while the experimental class's score increased to 81.56. The increased scores obtained in both classes indicate that students understood the concept better. However, the experimental class showed a greater improvement than the control class.

The results of the Shapiro–Wilk normality test show that the control class pretest data has a significance value of 0.010, the experimental class pretest 0.030, and the experimental class posttest 0.008, which is lower than 0.05, indicating that the data does not have a normal distribution. In contrast, the control class posttest data has a significance value of 0.521, which is higher than 0.05, indicating a normal distribution.

Based on the results of the homogeneity test, the significance value of the pretest data was 0.001. Because this value is less than 0.05, the variance of the pretest data between the control and experimental classes is declared inhomogeneous. Meanwhile, the results of the homogeneity test on the posttest data showed a significance value of 0.301. This value is greater than 0.05, so the variance of the posttest data for both classes can be declared homogeneous. The results of the homogeneity test indicate that the variance of the pretest scores between the two groups is not homogeneous. However, the results of the Mann–Whitney test on the pretest data indicate that there is no significant difference in initial ability between the experimental and control classes. Thus, although the distribution of scores in the two groups is different, the level of students' initial ability can still be considered statistically relatively equal. Therefore, the next analysis focused on the differences in achievement after the treatment was given.

The results of the hypothesis test showed that the initial conditions of both groups were equivalent, with a pretest significance value of 0.740 (> 0.05), indicating that there was no significant difference in initial abilities between students in the experimental class and the control class. Thus, it can be concluded that students' conceptual understanding was influenced by the application of the guided inquiry learning model with the help of PhET simulation. The results of this study are in line with Fadholi et al. (2025) who stated that guided inquiry learning provides opportunities for students to acquire and develop conceptual understanding through the process of investigation, data collection, and drawing conclusions. Because the data did not fully meet the assumption of normality, hypothesis testing was conducted using the Mann–Whitney test. This test was applied to pretest and posttest data to compare students' conceptual understanding between the experimental class and the control class after the treatment was given. In addition, N-Gain analysis was used as supporting data to describe the level of improvement in conceptual understanding that occurred in each group.

Table 3. N-Gain Test Analysis

Kelas	N-Gain	Kategori
Eksperimen	0,63	Sedang
Kontrol	0,28	Rendah

Table 3 shows that the N-Gain value of the experimental class was 0.63, which is included in the medium category, and the N-Gain value of the control class was 0.28, which is included in the low category. These results indicate that students' conceptual understanding in the experimental class was better than in the control class. Thus, the implementation of the Guided Inquiry learning model with the help of PhET simulations is more effective in improving students' understanding of the material. Based on the Mann–Whitney test results on the N-Gain scores between the two groups, a significance value (Asymp. Sig. 2-tailed) of 0.000 was obtained, which is lower than $\alpha = 0.05$. This finding provides statistically valid evidence that there is a significant difference in the improvement of conceptual understanding between students taught using the PhET Simulation-assisted Guided Inquiry model and those under conventional instruction. Testing the hypothesis directly on the N-Gain index successfully circumvents the methodological limitations posed by the non-homogeneous baseline data. These results strengthen the findings of the hypothesis test, which shows the influence of the learning model on students' conceptual understanding.

Active student engagement throughout the learning process supports improved conceptual understanding in the experimental class. During the orientation phase, students are instructed to relate their prior knowledge to the material to be studied. Furthermore, during the exploration phase, students conduct investigations using PhET simulations, observe the phenomena that occur, and collect and analyze experimental data. This process facilitates hands-on learning experiences for students, enabling them to more easily grasp the concepts they are learning.

Furthermore, the use of PhET simulations helps students visualize the abstract concepts of vibrations and waves. Through interactive simulations, students can observe the relationships between various variables more clearly than through verbal explanations or textbooks alone. This allows students to grasp concepts more deeply because they are not merely passive recipients of information but also engage in exploration and investigation.

Students' conceptual understanding was analyzed not only as a whole, but also based on each conceptual understanding indicator. This analysis was conducted to identify indicators that improved after the learning process. The comparison of pretest and posttest scores for each conceptual understanding indicator can be seen in the following table.

Table 4. Comparison of Students' Conceptual Understanding by Indicator

Concept Understanding Indicators	Control Class		Experimental Class	
	Pretest %	*Posttest %*	*Pretest %*	*Posttest %*
Interpreting	60%	69%	81%	87%
Exemplifying	58%	80%	26%	81%
Classifying	56%	66%	31%	92%
Inferring	22%	34%	56%	80%
Comparing	59%	69%	66%	83%
Explaining	61%	88%	45%	69%
Summarizing	47%	57%	53%	73%

The analysis results presented in Table 4 show that after the learning process, there was an increase in conceptual understanding across all observed indicators in both research groups. However, the improvement achieved in the experimental group was higher than in the control group. These findings indicate that the implementation of the guided inquiry model combined with PhET simulation played a role in improving students' conceptual mastery across the various aspects focused on the measurements.

The indicator with the highest percentage in the experimental class after learning was classification, with a percentage of 92%. The high achievement in this indicator indicates that students are able to group concepts based on certain characteristics after participating in the learning process. This achievement is supported by the exploration and concept formation stages in the Guided Inquiry model, where students make observations, analyze experimental results, and connect the obtained data with the concepts being learned. Through these learning activities, students have the opportunity to build a more structured understanding of the relationships between concepts. This more systematic understanding supports students' increased ability to group or classify the concepts they learn.

The interpreting indicator also achieved a high percentage, at 87%. These results indicate that most students are able to interpret the information and data obtained during the learning process. The use of PhET simulations allows students to directly observe changes in variables through interactive simulations, helping them understand the meaning of each observed phenomenon. This supports the development of a deeper conceptual understanding.

Meanwhile, the indicator with the lowest percentage in the experimental class was explaining, with a percentage of 69%. Although this showed an increase compared to the pretest score, these results indicate that students' ability to rephrase concepts using their own words still needs improvement. The relatively lower percentage in the explaining indicator (69%) and the subjective response regarding conceptual understanding (78%) can be critically examined through the lens of Cognitive Load Theory and the Generative Sense-Making Framework. According to Fiorella (2023), human cognitive processing operates through distinct generative modes, such as visualizing and explaining. While the interactive nature of PhET Simulation effectively supports the visualizing mode to construct initial mental models of abstract wave phenomena, transitioning to the explaining mode demands a significantly higher level of generative cognitive processing.

To explain a concept, students must reorganize their mental schemata, integrate new information with existing knowledge structures, and translate these ideas into structured verbal or written language. This sequence imposes a high intrinsic cognitive load on the working memory. Consequently, although students successfully grasped the concepts visually, their working memory capacity experienced temporary saturation when required to articulate formal scientific explanations. This explains why the explaining competency necessitates a longer cognitive adaptation period and yielded the lowest performance among all indicators.

Overall, the improvements seen in all indicators of conceptual understanding indicate that the implementation of the guided inquiry model assisted by PhET simulation contributed to the development of students' conceptual understanding. This finding is in line with the results of research Zafira et al. (2025) which states that the guided inquiry model is able to improve conceptual understanding because it encourages students to construct their own knowledge through active involvement in learning activities.

The response of eighth-grade students at SMP Negeri 24 Padang after implementing the guided inquiry model with the help of PhET simulation was positive. This is indicated by the presence of 12 positive and negative statements. The data can be seen in the following table.

Table 5. Percentage of Student Responses

Indicator	Percentage
Students' attitudes towards guided inquiry steps	79%
Student interest in using PhET simulation	86%
Conceptual understanding	78%
Student activity	80%
Average	81%

Based on the student response questionnaire data, an average percentage of 81% was obtained, which is categorized as positive. This indicates that the implementation of the Guided Inquiry learning model assisted by PhET simulation received positive acceptance and responses from students in learning the vibration and wave material. The positive student responses indicate that the learning model and media used were able to increase student engagement in learning and facilitate their understanding of the concepts being studied.

The indicator with the highest percentage was student interest in using PhET simulations, at 86%. These results demonstrate that the use of interactive simulations can increase student engagement in science learning. Through PhET simulations, students can conduct virtual experiments, observe vibration and wave phenomena, and manipulate various variables available in the simulation. This makes the learning process more interactive and makes it easier for students to understand abstract concepts more concretely. This is in line with the opinion Lamanepa et al. (2020) which states that PhET simulation is able to help students understand abstract science concepts through interactive and easy to understand visualizations.

The student activity indicator achieved a percentage of 80%. This result indicates that the majority of students were actively involved throughout the learning process, both in group discussions, conducting investigations using PhET simulations, and when presenting discussion results. The high level of student participation demonstrates that the guided inquiry model facilitates student-centered learning, enabling students to play an active role in building understanding and knowledge. Research result Zafira et al. (2025), also supports that the use of guided inquiry learning models combined with interactive simulation media can increase student engagement and help students understand concepts better.

The student attitude indicator toward the guided inquiry steps was 79%. These results indicate that students were able to optimally accept and follow each stage of the learning process. The stages of orientation, exploration, concept formation, application, and closure helped students gradually understand the material through a process of investigation and concept discovery.

Meanwhile, the conceptual understanding indicator achieved a percentage of 78%, the lowest among other indicators. These results indicate that most students felt the learning process helped them better understand the concepts of vibrations and waves. However, some students still needed more time to grasp certain concepts due to differences in academic ability and learning speed.

4. CONCLUSION

This study shows that the implementation of the Guided Inquiry model assisted by PhET Simulation provides a positive contribution to improving students' conceptual understanding of vibrations and waves at SMP Negeri 24 Padang. The integration of investigation activities through guided inquiry syntax with interactive visualizations provided by PhET Simulation helps students build conceptual understanding more meaningfully compared to conventional learning. These findings indicate that the use of technology combined with guided inquiry-based learning can be an alternative science learning strategy that supports students' active involvement in the knowledge construction process.

This study has limitations because it only involved two classes in one school, thus limiting the generalizability of the results. Furthermore, the study was conducted over a relatively short period of time, and the field observations were conducted by a single observer. This operational constraint introduces a vulnerability to observer bias, given the absence of an inter-rater reliability assessment. Therefore, further research is recommended involving a larger sample size across multiple schools, utilizing at least two independent observers alongside video-recorded data logging to significantly enhance the objectivity, reliability, and transparency of classroom implementation, and examining the application of the PhET Simulation-assisted Guided Inquiry model to other learning materials and variables.

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