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Diagnosing and Remediating Students' Misconceptions on Vibrations and Waves: Evidence from Certainty of Response Index Three-Tier Diagnostic Tests and Guided Inquiry Instruction

Amanda Monica Surviva Sinaga, Muhamad Taufiq*
Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Semarang, 50229, Indonesian

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* *Corresponding author:*
E-mail: muhamadtaufiq@mail.unnes.ac.id

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A B S T R A C T

Misconceptions in science learning remain a challenge because they hinder students from developing accurate conceptual understanding. Vibration and wave concepts are prone to misconceptions due to their nature and interconnected quantities. This study aimed to identify students' misconception profiles, analyze factors contributing to misconceptions, and examine changes in understanding following Guided Inquiry-based remediation. A study using a One-Group Pretest–Posttest Design was conducted with 145 Grade VIII students at SMP Negeri 9 Semarang, Indonesia. Data were collected using a Three-Tier Diagnostic Test integrated with the Certainty of Response Index (CRI), a questionnaire, and interviews. Data were analyzed by comparing students' conceptual understanding before and after remediation. Results showed that 32.28% of responses indicated correct conceptual understanding, while 18.76% reflected misconceptions, 32.87% indicated lack of conceptual understanding, and 16.09% represented partial understanding. The misconception rates occurred in amplitude (43.4%), frequency and period (33.8%), and wave concepts (29.7%). After Guided Inquiry remediation, correct conceptual understanding increased from 33.67% to 62.46%. Findings suggest that Guided Inquiry can support change and serve as a remediation strategy for addressing misconceptions in learning.

1. Introduction

Science education plays a fundamental role in developing students' scientific literacy by enabling them to understand natural phenomena through observation, investigation, and evidence-based reasoning. At the junior secondary level, science learning integrates concepts from physics, chemistry, biology, and earth sciences into a unified curriculum. Among these disciplines, physics is frequently perceived as one of the most challenging because many of its concepts are abstract and require students to connect mathematical representations with observable phenomena. Consequently, successful science learning depends not only on memorizing scientific facts but also on constructing accurate conceptual understanding that can be applied in various contexts (Agustin et al., 2017; Dewi & Ibrahim, 2019; Entino et al., 2021). Students who possess sound conceptual understanding are more capable of explaining natural phenomena, solving scientific problems, and transferring their knowledge to new learning situations.

One of the major challenges in science education is the persistence of misconceptions. Misconceptions refer to students' conceptions that differ from scientifically accepted explanations and are often held with strong confidence despite contradicting scientific evidence (Hasan et al., 1999; Suparno, 2013). Unlike a simple lack of conceptual understanding, misconceptions represent incorrect conceptual structures that interfere with subsequent learning because students tend to interpret new information based on their existing beliefs (Sadhu et al., 2017). According to conceptual change theory, students enter classrooms with prior conceptions developed from everyday experiences. When these prior conceptions are inconsistent with understand concept and are not explicitly reconstructed during instruction, misconceptions may persist and become increasingly resistant to change (Posner et al., 1982; Vosniadou & Skopeliti, 2017). Consequently, misconceptions have become one of the central concerns in science education research because they directly influence conceptual understanding and academic achievement.

Misconceptions are particularly prevalent in vibration and wave topics because these concepts involve abstract reasoning, mathematical relationships, and dynamic processes that cannot always be directly observed. Students frequently experience difficulties in distinguishing amplitude from displacement, interpreting the inverse relationship between frequency and period, understanding wavelength, and explaining wave propagation as energy transfer rather than movement of matter (Caleon & Subramaniam, 2010; Christiani et al., 2021; Liza et al., 2016). These misconceptions often arise because students rely on intuitive interpretations derived from everyday observations instead of scientific explanations. Similar findings have been reported across different educational contexts, indicating that vibration and wave concepts remain among the most difficult topics in junior secondary physics education.

Various factors contribute to the development of misconceptions. Previous studies have shown that misconceptions may originate from students' prior knowledge, cognitive ability, learning motivation, classroom instruction, textbooks, language interpretation, and daily experiences (Dewi & Ibrahim, 2019; Harso et al., 2021; Yuliati, 2017). Since misconceptions result from complex cognitive processes rather than simple memory failure, identifying their causes is essential for designing appropriate instructional interventions. Therefore, effective misconception diagnosis should not only determine whether students answer correctly but also reveal the reasoning and confidence underlying their responses.

Several diagnostic instruments have been developed to identify misconceptions in science learning. Among them, The Three-Tier Diagnostic Test remains one of the most widely adopted diagnostic instruments because it simultaneously measures students' answers, scientific reasoning, and confidence levels, thereby enabling more accurate identification of misconceptions than conventional achievement tests (Auliya et al., 2025; Makhrus & Hidayatullah, 2021; Peşman & Eryılmaz, 2010). When integrated with the Certainty of Response Index (CRI), this instrument enables researchers to distinguish students who truly understand concepts from those experiencing misconceptions, guessing, or lacking conceptual understanding (Hasan et al., 1999; Mellyzar et al., 2022). Compared with conventional multiple-choice tests, the Three-Tier Diagnostic Test provides more comprehensive information regarding students' conceptual conditions and has therefore been increasingly applied in science education research.

Nevertheless, identifying misconceptions alone is insufficient to improve conceptual understanding. Students who hold misconceptions require learning experiences that challenge their existing conceptions and facilitate conceptual reconstruction toward scientifically accepted explanations. Inquiry-based learning provides opportunities for students to construct scientific explanations through observation, investigation, evidence evaluation, and reflective reasoning. Recent evidence indicates that inquiry-oriented instruction promotes deeper conceptual understanding and supports conceptual change when combined with diagnostic assessment and feedback (Larasati et al., 2025; Vo & Simmie, 2025). Through these inquiry processes, students compare their prior conceptions with empirical evidence, creating cognitive conflict that encourages reconstruction of scientific understanding. Recent systematic reviews indicate that research on misconception diagnosis has predominantly emphasized the development and validation of tiered diagnostic instruments, whereas considerably fewer studies have integrated diagnostic assessment with structured instructional remediation and conceptual change interventions (Auliya et al., 2025; Shiddiqi et al., 2024).

Despite extensive research on misconceptions and inquiry-based learning, several important research gaps remain. First, most previous studies on vibration and wave concepts have focused primarily on diagnosing misconceptions without integrating diagnosis with structured remedial instruction (Christiani et al., 2021; Liza et al., 2016). Second, studies investigating Guided Inquiry specifically as a misconception remediation strategy at the junior secondary level remain relatively limited. Existing remediation studies have predominantly employed Conceptual Change Texts, Predict–Observe–Explain strategies, or Problem-Based Learning, while relatively few have examined Guided Inquiry as a systematic remediation approach for misconception reduction (Batdı et al., 2024; Kusuma & Wayan, 2025). Third, only a limited number of studies have integrated Three-Tier Diagnostic Tests based on the Certainty of Response Index with Guided Inquiry within a single instructional framework that encompasses misconception identification, analysis of contributing factors, and evaluation of conceptual change.

This study offers several novel contributions to science education research. Unlike previous studies, this research integrates misconception diagnosis, analysis of misconception causes, and Guided Inquiry-based remediation into a single continuous instructional framework. The remediation activities were explicitly designed according to the misconception profile identified through the Three-Tier Diagnostic Test with CRI, allowing instructional interventions to directly address students' specific conceptual difficulties rather than providing general remedial instruction. Furthermore, this study contributes empirical evidence regarding conceptual changes experienced by junior secondary school students after participating in Guided Inquiry remediation on vibrations and waves, thereby extending previous studies that primarily emphasized misconception identification. Accordingly, this study aimed to (1) identify students' misconception profiles regarding vibrations and waves using the Three-Tier Diagnostic Test with the Certainty of Response Index (CRI), (2) analyze the factors contributing to students' misconceptions, and (3) investigate changes in students' conceptual understanding following Guided Inquiry-based remedial instruction.

2. Methodology

Research Design

This study employed a quantitative approach using a Pre-Experimental One-Group Pretest–Posttest Design. The design was selected because the primary objective of the study was not to compare different instructional models but to examine conceptual changes experienced by students after receiving misconception remediation through the Guided Inquiry learning model. The One-Group Pretest–Posttest Design enables researchers to identify changes in students' conceptual understanding by comparing their conceptual profiles before and after remedial instruction. The design is appropriate for misconception remediation research because the intervention is implemented after misconceptions have first been diagnosed, allowing the effectiveness of the remedial instruction to be evaluated within the same group of students (Creswell & Creswell, 2017).

The research design is illustrated as follows:

$$O_1 \rightarrow X \rightarrow O_2.$$

where:
O_1 = Pretest using the Three-Tier Diagnostic Test with CRI
X = Guided Inquiry remedial instruction
O_2 = Posttest using the same diagnostic instrument

Unlike quasi-experimental designs that require equivalent comparison groups, this study emphasized individual conceptual change following diagnosis-based remediation. Therefore, the One-Group Pretest–Posttest Design was considered the most appropriate approach because every participant received remedial instruction based on the misconceptions identified during the diagnostic stage. The study was conducted at SMP Negeri 9 Semarang, Indonesia, during the second semester of the 2025/2026 academic year. The participants consisted of 145 eighth-grade students aged 13–14 years who participated in the misconception identification stage. The participants were distributed across six classes (VIII A, VIII C, VIII D, VIII E, VIII F, and VIII G).

Class VIII B was not included because the class was unavailable during the data collection period. Following the diagnostic assessment, Class VIII F was purposively selected as the remedial class because it demonstrated one of the highest proportions of misconceptions across the measured concepts. Consequently, this class was considered the most appropriate group for implementing Guided Inquiry-based remediation. SMP Negeri 9 Semarang is a public junior secondary school implementing the Indonesian national curriculum. Science instruction is conducted through integrated science learning in which physics concepts are taught together with biology and chemistry. Prior interviews with science teachers indicated that students frequently experienced conceptual difficulties in learning vibrations and waves, particularly in understanding amplitude, frequency, period, wavelength, and wave propagation.

Purposive sampling was employed to determine the class receiving remedial instruction. The selection criteria were based on the results of the initial diagnostic assessment using the Three-Tier Diagnostic Test with CRI. The class selected for remediation fulfilled the following criteria: (1) demonstrated one of the highest percentages of misconceptions; (2) showed relatively low conceptual understanding; (3) represented the overall misconception profile identified in the participating population; (4) received recommendations from the science teacher based on students' learning difficulties. Accordingly, Class VIII F was selected because it satisfied these criteria and therefore provided an appropriate setting for evaluating Guided Inquiry-based misconception remediation.

Research Instruments

This study employed a researcher-developed Three-Tier Diagnostic Test integrated with the Certainty of Response Index (CRI) to identify students' misconceptions regarding vibrations and waves. The instrument consisted of 15 diagnostic items, each comprising three components: (1) a multiple-choice answer, (2) the scientific reasoning underlying the selected answer, and (3) the students' confidence level measured using the CRI scale ranging from 0 (pure guess) to 5 (certain). The integration of these three tiers enabled the differentiation between understand concept, misconception, lack of conceptual understanding, and guessing responses (Hasan et al., 1999; Peşman & Eryılmaz, 2010).

The Three-Tier Diagnostic Test was developed based on the Grade VIII science curriculum on vibrations and waves. The development process included determining conceptual indicators, constructing distractors representing common misconceptions identified in previous studies, preparing reasoning options, and incorporating the Certainty of Response Index (CRI) scale. The distractors were intentionally designed to represent specific misconceptions commonly experienced by students rather than functioning merely as incorrect alternatives. An example of a Three-Tier Diagnostic Test item used to assess students' understanding of the relationship between frequency and period is presented in Figure 1. The figure illustrates the three-tier structure used in the diagnostic assessment, including the conceptual answer, the reasoning underlying the selected answer, and the confidence level provided by students.

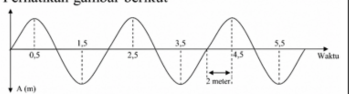
12.	Konsep dasar perhitungan gelombang	Menghitung frekuensi gelombang	Siswa belum memahami hubungan terbalik antara frekuensi dan periode	*Tier 1* Perhatikan gambar berikut  Besar frekuensi pada gelombang diatas adalah… a. 6 Hz b. 3 Hz c. 1 Hz d. 0,5 Hz *Tier 2* Pilihlah alasan yang tepat untuk mendasari jawaban kamu diatas! a. Frekuensi gelombang bernilai sama dengan periode gelombang (SALAH) **b. Frekuensi gelombang berbanding terbalik dengan periode gelombang. (BENAR)** *Tier 3* Apakah kamu yakin atas jawaban dan alasan diatas? 0 | Menebak	C3	**D. 0,5 Hz** Dari gambar: -puncak berturut-turut terjadi pada 0,5 s, 2,5 s, dan 4,5 s -maka periode: $T = 2$ s Frekuensi: $f = \frac{1}{T} = \frac{1}{2} = 0{,}5$ Hz Semakin banyak jumlah gelombang, maka frekuensi yang dihasilkan semakin besar Siswa mengalami **miskonsepsi false positive** apabila menjawab: Tier 1 Benar Tier 2 Alasan salah Tier 3 CRI ≥ 3

Figure 1. Example of a Three-Tier Diagnostic Test Item Used to Identify Students' Misconceptions about the Relationship between Frequency and Period.

The first tier measures students' conceptual answers, the second tier assesses the scientific reasoning underlying the selected answers, and the third tier measures students' confidence using the Certainty of Response Index (CRI). The integration of these three components enables the differentiation among scientific conceptions, misconceptions, lack of conceptual understanding, and partial understanding. To ensure that the diagnostic instrument adequately represented the concepts assessed in this study, the conceptual indicators and item distribution used to construct the Three-Tier Diagnostic Test are presented in Table 1. Blueprint of The Three-Tier Diagnostic Test.

Table 1. Blueprint of The Three-Tier Diagnostic Test

Concept	Indicator	Item
Vibration	Distinguishing vibration from motion	1–2
Amplitude	Identifying maximum displacement	3
Frequency	Calculating and interpreting frequency	4–5
Period	Relationship between frequency and period	6
Wave	Characteristics of transverse and longitudinal waves	7–8
Wavelength	Identifying wavelength correctly	9–10
Wave speed	Relationship among λ, f, and v	11–13
Energy transfer	Wave propagation concept	14–15

The misconceptions assessed in each item were developed based on previous misconception studies on vibrations and waves (Christiani et al., 2021; Liza et al., 2016), the Indonesian junior high school science curriculum, and interviews with science teachers. Consequently, each distractor was intentionally designed to represent a specific misconception commonly experienced by students rather than functioning merely as an incorrect alternative. Students' responses were subsequently interpreted by considering the correctness of their answers, the accuracy of their reasoning, and their level of confidence based on the CRI. The classification scheme used to interpret students' responses is presented in Table 2. Criteria for CRI Interpretation.

Table 2. Criteria for CRI Interpretation

Answer	Reason	CRI	Category
Correct	Correct	High	Understand concept
Wrong	Wrong	High	Misconception
Wrong	Wrong	Low	Lack of Conceptual understanding
Correct	Wrong	High	Error / Partial understanding

Content validity was evaluated by five experts, consisting of four university lecturers in science education and one experienced junior high school science teacher. The validation assessed four dimensions: content relevance, item construction, language clarity, and conformity with the Three-Tier Diagnostic Test format. The results of the content validity assessment for each dimension are presented in Table 3. Content Validity Results.

Table 3. Content Validity Results

Aspect	Number of Indicators	Aiken's V	Interpretation
Content	7	0.94	Very valid
Construction	4	0.90	Very valid
Language	3	0.89	Very valid
Three-Tier CRI format	5	0.92	Very valid
Average	**19**	**0.91**	**Very valid**

The content validity index was calculated using Aiken's V, resulting in coefficients ranging from 0.67 to 1.00, with an average value of 0.91, indicating that the instrument possessed very high content validity. After expert revision, empirical validation was conducted through a pilot test involving students with characteristics similar to the research participants. The reliability analysis using Cronbach's Alpha yielded a coefficient of 0.700, indicating acceptable internal consistency for misconception diagnosis. Students' responses were subsequently classified into four conceptual categories by combining answer correctness, reasoning accuracy, and CRI values, namely understand concept, misconception, lack of knowledge, and error/partial understanding, following the interpretation proposed by Hasan et al. (1999) and further adapted in misconception diagnostic studies.

Research Procedure

The research procedure consisted of four sequential stages: (1) misconception diagnosis, (2) analysis of factors contributing to misconceptions, (3) Guided Inquiry-based remedial instruction, and (4) post-remediation evaluation. These stages were designed as a continuous process in which the results of the initial diagnostic assessment were used as the basis for identifying students' learning difficulties and designing the subsequent remedial instruction. The overall research procedure, including the sequence from misconception identification to the evaluation of conceptual change following remediation, is illustrated in Figure 2.

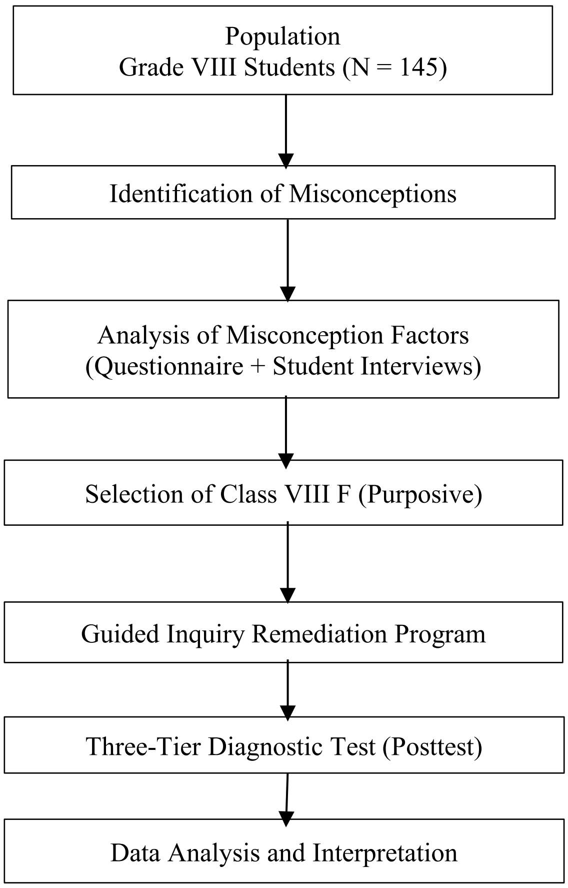


Figure 2. Research Procedure of Misconception Identification and Guided Inquiry

The first stage focused on misconception diagnosis. Students' conceptual understanding of vibrations and waves was identified using the Three-Tier Diagnostic Test integrated with the Certainty of Response Index (CRI). Students' responses were classified into four categories, namely understand concept, misconception, lack of conceptual understanding, and error/partial understanding. The diagnostic results were subsequently analyzed to determine the concepts with the highest misconception rates and to identify students requiring remedial instruction. The results of this diagnostic stage also served as the basis for determining the conceptual difficulties that needed to be addressed through the Guided Inquiry-based remediation.

Following the diagnostic assessment, the second stage focused on identifying factors contributing to students' misconceptions. Students completed a misconception-factor questionnaire to obtain quantitative information regarding factors that potentially influenced the development of misconceptions. Semi-structured interviews were subsequently conducted with selected students representing different conceptual categories to obtain a deeper understanding of the cognitive processes underlying their misconceptions. Information obtained from the questionnaire and interviews was triangulated to identify the dominant factors contributing to students' misconceptions and to provide a more comprehensive understanding of the conditions associated with students' conceptual difficulties.

The third stage involved the implementation of Guided Inquiry-based remedial instruction. Based on the misconception profile obtained during the diagnostic stage, the remedial activities were designed to create cognitive conflict by confronting students' initial conceptions with scientific evidence obtained through observation, experimentation, discussion, and reflection. Unlike conventional remedial instruction, the Guided Inquiry activities were specifically organized according to the misconception profile identified in the diagnostic assessment. Consequently, each learning activity directly targeted the concepts most frequently misunderstood by students and encouraged them to reconstruct their conceptual understanding based on empirical evidence.

The fourth stage focused on evaluating changes in students' conceptual understanding following the remedial instruction. Students completed the same Three-Tier Diagnostic Test after participating in the Guided Inquiry-based remediation, and the posttest results were compared with the pretest results to evaluate changes in their conceptual understanding. To provide a clearer description of how the Guided Inquiry process was implemented to address students' misconceptions, the alignment between the Guided Inquiry phases, teacher activities, student activities, targeted misconceptions, and expected conceptual changes is presented in Table 4.

Table 4. Guided Inquiry Activities for Misconception Remediation

Guided Inquiry Phase	Teacher Activities	Student Activities	Targeted Misconceptions	Expected Conceptual Change
Orientation	Presents contextual phenomena related to vibrations and waves and asks conceptual questions	Observe phenomena and express initial ideas	Reveal students' initial misconceptions	Students become aware of their prior conceptions
Problem Formulation	Guides students to formulate investigable questions	Formulate questions and predict outcomes	Amplitude, wave propagation, frequency–period relationship	Students recognize inconsistencies in their own explanations
Hypothesis Formulation	Encourages students to predict	Develop hypotheses collaboratively	Intuitive explanations	Initial conceptions become explicit

Guided Inquiry Phase	Teacher Activities	Student Activities	Targeted Misconceptions	Expected Conceptual Change
	based on prior knowledge		inconsistent with understand concept	
Investigation / Experimentation	Facilitates experiments using simple apparatus and worksheets	Conduct experiments, collect and analyze data	Amplitude, wavelength, wave speed, energy transfer	Students obtain empirical evidence that challenges misconceptions
Data Analysis	Guides interpretation of experimental results	Compare predictions with observations	Incorrect scientific reasoning	Students reconstruct conceptual understanding based on evidence
Conclusion	Guides formulation of scientific explanations	Present conclusions supported by evidence	Remaining misconceptions	Students formulate scientifically accepted concepts
Reflection	Provides feedback and facilitates conceptual discussion	Reflect on conceptual changes	Persistent misconceptions	Strengthening long-term conceptual understanding

Data Analysis

The results obtained through the use of Three-Tier Diagnostic Test were analyzed by the interpretation scheme of Three-Tier Diagnostic Test and CRI. Responses of the participants were grouped into four groups: understand concept, misconceptions, lack of conceptual understanding, and partial knowledge. Participants were considered to have scientific knowledge when their responses involved correct answers, correct justification, and high confidence ratings. When students provided incorrect answers and/or incorrect justifications and had high confidence ratings, it was classified as misconceptions. Low confidence ratings of students were considered as lack of conceptual knowledge, while other responses were considered as partial understanding. The percentage of students in each category was calculated using the following formula:

$$P = \frac{f}{N} x100\%$$

The quantitative data were analyzed descriptively to determine the percentage of students in each conceptual category. The percentage of students in each category was calculated to describe the overall profile of students' conceptual understanding and to identify concepts associated with high levels of misconception or lack of conceptual understanding. In addition to the descriptive analysis, changes in students' conceptual understanding following Guided Inquiry-based remediation were evaluated by comparing the results obtained before and after the intervention. The improvement in students' conceptual understanding was further analyzed using the normalized gain (N-Gain) proposed by Hake (1998), which was calculated by comparing students' pretest and posttest scores:

$$N\text{-}Gain = \frac{Posttest - Pretest}{100 - Pretest}$$

The N-Gain score was interpreted using three categories: high, moderate, and low. The criteria used to interpret the normalized gain scores are presented in Table 5.

Table 5. The N-Gain interpretation

Score	Category
>0.70	High
0.30–0.70	Moderate
<0.30	Low

To determine whether the improvement in students' conceptual understanding was statistically significant, pretest and posttest scores were analyzed using a paired-sample t-test after the normality assumptions had been examined. If the data were not normally distributed, the Wilcoxon signed-rank test was employed as a non-parametric alternative. Questionnaire data were analyzed using mean scores for each indicator to identify the factors contributing to students' misconceptions. In addition, interview data were analyzed qualitatively through data reduction, coding, categorization, and interpretation to support and provide a deeper explanation of the quantitative findings.

3. Results and Discussion

Students' Misconception Profile on Vibrations and Waves

Students' misconceptions were identified using the Three-Tier Diagnostic Test integrated with the Certainty of Response Index (CRI). The diagnostic test was administered to 145 Grade VIII students at SMP Negeri 9 Semarang, and students' responses were classified into four conceptual categories: understand concept, misconception, lack of conceptual understanding, and error/partial understanding. This classification enabled the identification of students who possessed scientifically acceptable conceptual understanding as well as those who experienced misconceptions or other forms of incomplete conceptual understanding. The overall conceptual profile of students before the implementation of Guided Inquiry-based remediation is presented in Figure 3.

Figure 3 shows that only 32.28% of students demonstrated scientifically acceptable conceptual understanding. In contrast, the remaining 67.72% of responses were distributed among the categories of misconception (18.76%), lack of conceptual understanding (32.87%), and error/partial understanding (16.09%). These findings indicate that most students entered the learning process without an adequate scientific understanding of vibration and wave concepts.

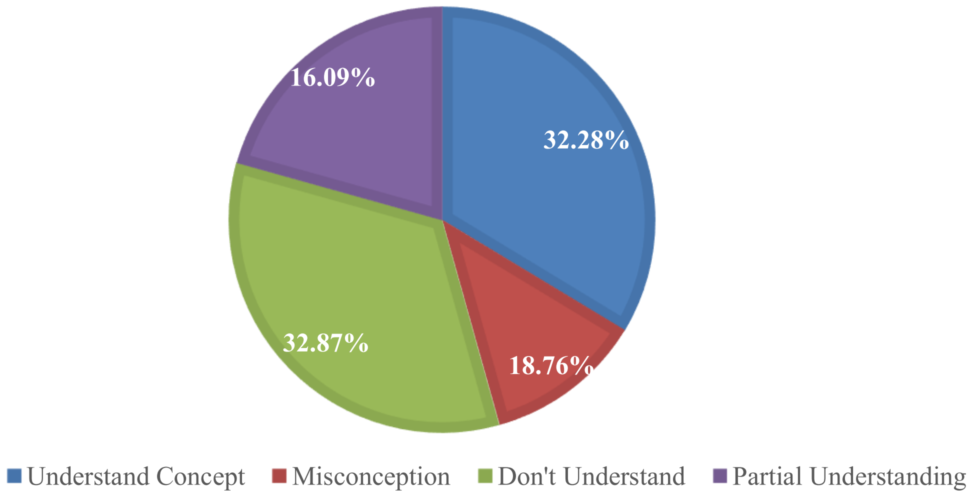


Figure 3. Overall Conceptual Profile of Students Before Remediation

To provide a more detailed presentation of the distribution of students' conceptual understanding across the four categories, the percentage of responses in each category is presented in Table 6.

Table 6. Distribution of Students' Conceptual Understanding

Category	Percentage (%)
Understand Concept	32.28
Misconception	18.76
Lack of Conceptual Understanding	32.87
Error/ Partial Understanding	16.09
Total	100

The results revealed that only 32.28% of students demonstrated scientifically acceptable conceptual understanding, whereas 67.72% were classified as experiencing misconceptions, lack of conceptual understanding, or error/partial understanding. These findings indicate that conceptual difficulties remain a significant challenge in junior secondary science education, particularly in abstract physics topics such as vibrations and waves. Unlike ordinary achievement tests, the Three-Tier Diagnostic Test combined with the Certainty of Response Index (CRI) enabled the identification of students who confidently held scientifically incorrect conceptions. This distinction is important because students with misconceptions require different instructional interventions from those who simply lack conceptual knowledge (Hasan et al., 1999; Peşman & Eryılmaz, 2010).

The findings also indicate that several concepts were particularly susceptible to misconceptions. The highest misconception rate was found in the concept of amplitude, where many students interpreted amplitude as the total distance travelled during vibration rather than the maximum displacement from the equilibrium position. Similar misconceptions have been reported in previous studies on vibration and wave concepts, suggesting that amplitude is consistently among the most difficult concepts for junior secondary students because it requires abstract spatial reasoning (Christiani et al., 2021; Liza et al., 2016). These findings support Constructivist Learning Theory, which proposes that learners actively construct knowledge based on prior experiences rather than passively receiving information (Driver et al., 1994; Piaget, 1974). When students interpret oscillatory motion using everyday observations instead of scientific explanations, they may develop alternative conceptions that become increasingly resistant to change.

Furthermore, misconceptions concerning the relationship between frequency and period demonstrate that students may memorize equations without fully understanding their physical meaning. This finding is consistent with previous studies reporting that mathematical relationships in physics often become sources of misconceptions when students emphasize symbolic manipulation over conceptual reasoning (Docktor & Mestre, 2014). The misconception regarding wave propagation also deserves particular attention because many students believed that waves transport matter rather than energy. According to Vosniadou's Framework Theory, students naturally construct explanatory models based on everyday experiences. Since moving waves are commonly observed together with moving objects, students may incorrectly infer that the medium itself travels with the wave. Without explicit conceptual reconstruction, these intuitive explanations may remain stable despite formal classroom instruction (Vosniadou, 2022).

Miconceptions Across Individual Concepts

The analysis of misconceptions across individual concepts revealed considerable variation in the percentage of students experiencing misconceptions. The highest misconception rate was identified in the concept of amplitude (43.40%), indicating that this concept represented one of the most challenging topics for students. Many students interpreted amplitude as the total distance travelled by an oscillating object rather than the maximum displacement from the equilibrium position. This misconception reflects students' tendency to rely on everyday visual experiences rather than scientific definitions when interpreting oscillatory motion. The second highest misconception rate was found in the relationship between frequency and period (33.80%), where many students believed that both quantities increased simultaneously. This finding indicates that students had not fully understood the inverse relationship between frequency and period and may have focused on memorizing mathematical relationships without adequately understanding their conceptual meaning by $f = \frac{1}{T}$.

The misconception rates across each conceptual indicator assessed in this study are summarized in Table 7. The results demonstrate considerable variation among the concepts, with the highest misconception rate found in amplitude (43.40%), followed by the relationship between frequency and period (33.80%) and wave propagation (29.70%). In contrast, wave speed showed the lowest misconception rate (15.90%). Overall, this pattern suggests that concepts involving abstract reasoning and mathematical relationships tend to generate higher levels of misconception than concepts that are more directly observable in everyday situations.

Table 7. Misconception Percentage for Each Concept

Concept	Misconception (%)
Amplitude	43.40
Frequency and Period	33.80
Wave Propagation	29.70
Vibration	22.10
Longitudinal and Transverse Waves	20.00
Wavelength	18.50
Wave Speed	15.90

Misconceptions concerning wave propagation (29.70%) revealed that students commonly believed that waves transport matter rather than energy. This finding demonstrates that abstract concepts requiring students to visualize processes that cannot be directly observed remain particularly difficult for junior secondary students. Overall, the findings indicate that concepts involving abstract reasoning, mathematical relationships, and dynamic processes may be more susceptible to misconceptions than concepts that can be more easily connected to observable experiences. These results reinforce the importance of identifying specific conceptual difficulties before implementing remedial instruction, as different misconceptions require instructional activities that directly address the underlying reasoning held by students.

Factors Contributing to Misconceptions

The analysis of questionnaire data identified six major factors contributing to students' misconceptions regarding vibrations and waves. These factors included concentration and attention, thinking ability, prior knowledge, language and communication, learning motivation, and study habits. Among the investigated factors, concentration and attention obtained the highest mean score (3.19), indicating that this factor contributed most strongly to the development of students' misconceptions. In contrast, study habits obtained the lowest mean score (2.09), suggesting a relatively smaller contribution compared with the other factors. The mean scores and categories for all factors contributing to students' misconceptions are presented in Table 8.

Table 8. Mean Scores of Misconception Factors

Factor	Mean	Category
Concentration and attention	3.19	High
Thinking ability	2.88	High
Prior knowledge	2.82	High
Language and communication	2.82	High
Learning motivation	2.74	High
Study habits	2.09	Low

The results indicate that concentration and attention emerged as the dominant factors contributing to students' misconceptions. Interview results further revealed that many students experienced difficulties in maintaining attention when teachers explained the relationships among frequency, wavelength, period, and wave speed. Students also reported relying heavily on memorizing equations rather than understanding their physical meanings, which may contribute to persistent misconceptions regarding abstract physics concepts. After identifying students' misconception profiles and the factors contributing to them, remedial instruction was implemented using the Guided Inquiry learning model in Class VIII F. This class was selected based on the initial diagnostic results because it demonstrated a relatively high level of misconception, and the effectiveness of the remediation was subsequently evaluated by comparing the pretest and posttest results using the Three-Tier Diagnostic Test integrated with CRI.

Overall, the questionnaire results demonstrated that concentration and attention constituted the strongest contributing factor, followed by thinking ability, prior knowledge, language and communication, and learning motivation. These findings suggest that misconceptions cannot simply be attributed to insufficient instructional time or limited exposure to scientific content. Instead, the formation of misconceptions represents a complex process involving interactions among prior knowledge, cognitive processing, language, and classroom learning experiences. This finding is consistent with Conceptual Change Theory, which proposes that students are more likely to replace existing conceptions when they experience dissatisfaction with their previous conceptions and perceive new conceptions as intelligible, plausible, and fruitful (Posner et al., 1982). The present findings suggest that students may not always experience sufficient cognitive dissatisfaction when instruction emphasizes formula memorization rather than conceptual reasoning, allowing scientifically inaccurate conceptions to remain internally consistent from the students' perspectives.

Interview data further indicated that students frequently relied on memorizing formulas without fully understanding the relationships among physical quantities. This tendency may prevent students from integrating frequency, period, wavelength, and wave speed into coherent conceptual frameworks. Language and communication also emerged as important contributing factors because scientific terms such as “frequency,” “period,” and “amplitude” may have meanings that differ from students' everyday interpretations. Previous studies have similarly reported that linguistic ambiguity can contribute to misconceptions in science education when students assign everyday meanings to scientific terminology (Treagust & Duit, 2008). Collectively, these findings reinforce the view that misconceptions originate from multiple interacting cognitive and instructional factors rather than from a single cause (OECD, 2023; Tang et al., 2024).

Changes in Students' Conceptual Understanding after Guided Inquiry Remediation

Changes in students' conceptual understanding following Guided Inquiry-based remediation were examined by comparing the results of the pretest and posttest.

The comparison focused on the proportion of students classified into the four conceptual categories: understand concept, misconception, lack of conceptual understanding, and error/partial understanding. The overall comparison of students' conceptual understanding before and after the implementation of Guided Inquiry-based remediation is illustrated in Figure 4.

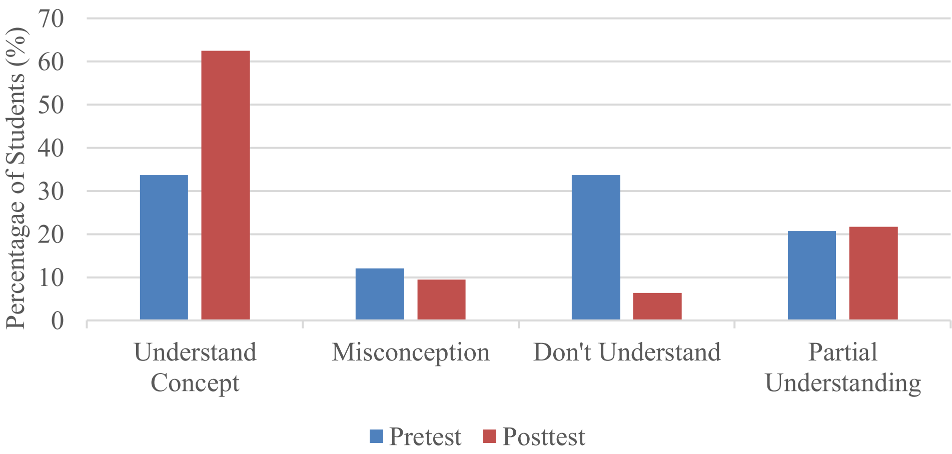


Figure 4. Comparison of Students' Conceptual Understanding Before and After Remediation

As shown in Figure 4, the proportion of students categorized as understanding the concept increased markedly from 33.67% in the pretest to 62.46% in the posttest. At the same time, the percentage of students classified as having a lack of conceptual understanding decreased substantially from 33.67% to 6.32%, while the percentage of students experiencing misconceptions also declined from 12.00% to 9.47%. These results indicate that the Guided Inquiry-based remediation was associated with meaningful improvements in students' conceptual understanding. To provide a more detailed comparison of changes in each conceptual category, the pretest and posttest percentages and the magnitude of change are presented in Table 9.

Table 9. Changes in Students' Conceptual Understanding Before and After Remediation

Category	Pretest (%)	Posttest (%)	Change
Understand concept	33.67	62.46	+28.79
Misconception	12.00	9.47	-2.53
Lack of Conceptual Understanding	33.67	6.32	-27.35
Error/ Partial Understanding	20.67	21.75	+1.08

One of the most important findings of this study is the substantial improvement in students' conceptual understanding following Guided Inquiry-based remediation. The percentage of students categorized as understanding the concept increased from 33.67% to 62.46%, whereas the proportion of students classified as having a lack of conceptual understanding declined dramatically. The moderate N-Gain score of 0.43 indicates meaningful conceptual improvement despite the complexity of vibration and wave concepts. These findings support the principles of Inquiry-Based Learning, which emphasize that meaningful learning can occur when students actively investigate scientific phenomena rather than merely receive explanations from teachers.

In addition to examining the overall conceptual categories, the effectiveness of the remediation was evaluated by comparing misconception rates across the three major conceptual indicators targeted during the Guided Inquiry activities. The changes in misconception percentages before and after remediation for amplitude, the relationship between frequency and period, and wave propagation are presented in Table 10.

Table 10. Percentage of misconceptions before and after remediation for each concept

Concept	Pre	Post
Amplitude	43.4	18.5
Frequency & Period	33.8	15.6
Wave	29.7	12.9

The results indicate that all targeted concepts experienced reductions in misconception levels. The largest decrease occurred in the amplitude concept, followed by the frequency–period relationship and wave propagation. Throughout Guided Inquiry instruction, students observed physical phenomena, formulated hypotheses, conducted experiments, analyzed evidence, and constructed explanations based on empirical observations. Such learning experiences encouraged students to compare their initial conceptions with scientific evidence, thereby facilitating conceptual reconstruction. From the perspective of Conceptual Change Theory, Guided Inquiry successfully created cognitive conflict. Students whose predictions differed from experimental observations became dissatisfied with their previous explanations, motivating them to construct alternative understand concept. This mechanism explains why Guided Inquiry produced much greater reductions in lack of conceptual understanding than conventional remedial teaching approaches. Recent international studies similarly conclude that Guided Inquiry significantly improves conceptual understanding because inquiry activities promote evidence-based reasoning, metacognitive reflection, and active conceptual reconstruction (Furtak et al., 2012; Lazonder & Harmsen, 2016; OECD, 2023).

N-Gain Analysis

To quantitatively evaluate the improvement in students' conceptual understanding following Guided Inquiry-based remediation, a normalized gain (N-Gain) analysis was conducted by comparing the average pretest and posttest scores. The results provide additional evidence regarding the magnitude of students' conceptual improvement beyond the changes observed in the distribution of conceptual categories and misconception rates. The average pretest score increased from 33.67 to 62.46 in the posttest, resulting in an N-Gain value of 0.43. According to the N-Gain interpretation criteria proposed by Hake (1998), this value falls within the moderate category, indicating a meaningful improvement in students' conceptual understanding following the implementation of Guided Inquiry-based remediation. A summary of the N-Gain analysis is presented in Table 11.

Table 11. N-Gain Results

Variable	Score
Mean Pretest	33.67
Mean Posttest	62.46
N-Gain	**0.43**
Interpretation	Moderate

The moderate N-Gain result indicates that the Guided Inquiry-based remediation contributed to a meaningful improvement in students' conceptual understanding, although the improvement was not sufficient to eliminate all conceptual difficulties. This finding is consistent with the results presented in the previous subsection, which showed a substantial increase in the proportion of students categorized as understanding the concept and a considerable decrease in the proportion of students lacking conceptual understanding. At the same time, the persistence of some misconceptions and error/partial understanding suggests that conceptual change is a gradual process and that some students may require additional learning experiences to fully reconstruct their initial conceptions. Therefore, the N-Gain result should be interpreted together with the diagnostic findings rather than as the sole indicator of the effectiveness of the remediation.

Conceptual Indicators that Were Most Difficult to Remediate

Although overall conceptual understanding improved, several misconceptions persisted after remediation. The most resistant misconception remained the concept of amplitude, followed by the frequency–period relationship. Students who continued to exhibit misconceptions generally retained high confidence in their incorrect explanations, suggesting that these misconceptions were deeply rooted in their prior knowledge. In contrast, misconceptions regarding wave propagation showed greater improvement following experimental observations and PhET simulations. This finding suggests that concepts directly supported by visual demonstrations are more amenable to conceptual change than concepts requiring abstract mathematical reasoning. These results imply that Guided Inquiry is particularly effective for promoting conceptual understanding through empirical investigation; however, additional instructional support, such as multiple representations, conceptual scaffolding, and repeated diagnostic feedback, may be necessary to eliminate persistent misconceptions involving abstract quantitative relationships.

Why Some Misconceptions Persisted

Despite significant improvement, misconceptions were not completely eliminated. The concepts of amplitude and the frequency-period relationship remained the most resistant. According to Posner et al. (1982), conceptual change is rarely instantaneous because learners tend to preserve existing cognitive structures unless alternative explanations appear substantially more convincing.

Students with persistent misconceptions generally exhibited high confidence in incorrect explanations, indicating that their misconceptions had become cognitively stable. This observation is consistent with contemporary neuroscience research suggesting that misconceptions often represent coherent mental models rather than isolated factual errors (Amin, 2025). Consequently, a single cycle of Guided Inquiry may not be sufficient to completely replace deeply rooted misconceptions. Repeated inquiry experiences, diagnostic feedback, conceptual discussions, and multiple scientific representations may therefore be necessary for long-term conceptual reconstruction.

Limitations of the Study

Several limitations should be acknowledged in this study. First, this study employed a pre-experimental One-Group Pretest–Posttest Design without a comparison group. Consequently, improvements in students' conceptual understanding cannot be attributed solely to the Guided Inquiry intervention with complete certainty. Future studies are recommended to employ quasi-experimental or true experimental designs involving control groups. Second, the remediation was implemented in only one eighth-grade class from a single junior high school. Therefore, caution should be exercised when generalizing the findings to different educational contexts. Third, the effectiveness of remediation was evaluated immediately after the intervention. Long-term retention of conceptual change was not investigated. Future research should include delayed posttests to determine whether conceptual changes remain stable over time. Finally, this study focused exclusively on vibration and wave concepts. Further studies should investigate whether similar remediation strategies are equally effective for other abstract science topics.

Practical Implications

The findings of this study provide several important implications for science education, particularly in improving students' conceptual understanding of vibration and wave concepts. First, for science teachers, the integration of the Three-Tier Diagnostic Test with the Certainty of Response Index (CRI) offers a practical diagnostic tool for distinguishing students who truly possess misconceptions from those who simply lack conceptual understanding or answer by guessing. Consequently, teachers can design remedial instruction that specifically targets students' conceptual difficulties instead of providing generalized review activities.

Second, this study contributes to the development of misconception diagnostic instruments by demonstrating that combining answer accuracy, scientific reasoning, and confidence level provides a more comprehensive representation of students' conceptual profiles than conventional multiple-choice tests. The blueprint and validation procedures presented in this study may serve as references for developing similar diagnostic instruments on other science topics characterized by abstract concepts. Third, the results demonstrate that Guided Inquiry can be effectively implemented as a structured remedial strategy following misconception diagnosis. The inquiry activities were intentionally organized according to the misconception profile identified during the diagnostic stage, allowing students to confront their initial conceptions through observation, experimentation, discussion, and evidence-based reasoning. This diagnosis-driven instructional framework supports the principles of conceptual change by creating cognitive conflict and encouraging students to reconstruct scientifically acceptable explanations.

Finally, this integrated framework may serve as a practical model for future science instruction in junior secondary schools. Rather than treating diagnosis and remediation as separate activities, teachers are encouraged to implement continuous cycles consisting of misconception identification, analysis of contributing factors, inquiry-based remediation, and post-remediation evaluation. Such an approach has the potential to improve conceptual understanding more effectively while reducing the persistence of misconceptions in science learning.

4. Conclusion

This study demonstrates that misconceptions remain a significant challenge in learning vibration and wave concepts among junior secondary students. The diagnostic assessment revealed that students experienced difficulties particularly with amplitude, the relationship between frequency and period, and wave propagation. These difficulties were associated with several interacting learning factors, with attention and concentration emerging as the most prominent factor, followed by cognitive ability, prior knowledge, language and communication, learning motivation, and study habits. These findings highlight the importance of considering both conceptual and learner-related factors when designing science instruction.

The Guided Inquiry-based remediation showed evidence of improvement in students' conceptual understanding and a reduction in misconceptions and lack of conceptual understanding. The inquiry process enabled students to actively examine their initial conceptions through observation, experimentation, discussion, evidence interpretation, and scientific reasoning, thereby supporting conceptual reconstruction. However, the persistence of some misconceptions and partial understanding indicates that conceptual change may require sustained instructional support rather than a single remediation intervention. Overall, integrating CRI-based Three-Tier Diagnostic Assessment with Guided Inquiry provides a promising framework for diagnosing misconceptions and supporting conceptual change in junior secondary science learning. The approach offers practical implications for teachers by linking diagnostic information with targeted remedial instruction. Future studies should examine this framework using larger samples, control groups, and longer intervention periods to provide stronger evidence of its effectiveness across different science topics.

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