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Detecting misconceptions in basic physics using a three-tier diagnostic test: Evaluation and learning implications

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Abstract: One of the major obstacles in physics learning that hampers students' conceptual understanding is the occurrence of misconceptions. This issue is particularly evident in the Basic Physics course, where critical concepts are often misunderstood, affecting students' success in subsequent stages of learning. This study aims to detect and analyze students' misconceptions in Basic Physics using a Three-Tier Diagnostic Test as the evaluative instrument. A quantitative-descriptive method was employed, involving 82 students selected through purposive sampling. The research instrument consisted of three-tiered questions designed to probe students' conceptual understanding. Data were analyzed using the Certainty of Response Index (CRI) to measure students' confidence levels in their answers. The diagnostic test results showed that only 8.75% of students demonstrated correct conceptual understanding, while 55.58% exhibited misconceptions, 2.25% understood the concepts but lacked confidence, and 33.82% showed poor conceptual understanding. These findings confirm that misconceptions are highly prevalent among students in the Basic Physics course, reflecting significant gaps in their foundational understanding. Addressing these issues requires adopting more interactive and conceptually focused teaching strategies to enhance students' mastery of fundamental physics concepts.

Keywords: misconceptions, Basic Physics, Three-Tier Diagnostic Test, evaluation, learning implications

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Introduction

Physics is one of the basic disciplines that is essential in the development of technology and science. A correct and strong understanding of the underlying physics concepts behind physical phenomena is crucial for students (Pratiwi et al., 2024). This is because they will become educators in the future and some of them will continue to higher education (Irvani et al., 2024). If prospective teacher students have a strong conceptual understanding, they will be able to explain the material systematically, connect theory with real phenomena, and develop effective learning strategies to help students understand physics concepts better. Conversely, if prospective teachers have a weak understanding, they risk spreading misunderstandings to students, which can ultimately hinder the learning process at the school level.

However, in the process of learning physics, many students have difficulty understanding fundamental concepts, which often leads to misconceptions. Misconceptions are understandings that are incorrect or not aligned with accepted scientific concepts (Vosniadou, 2020). Misconceptions can also hinder the learning process and understanding of advanced concepts (Sari Mulya, 2022). Misconceptions will have an impact on low student learning outcomes if they are not followed up properly. (Sari & Mufit, 2023). In addition, uncorrected misconceptions can have an impact on students' low ability to apply physics concepts in problem-solving (Irianti, 2021).

In the long term, misconceptions can hinder the development of students' critical and analytical thinking skills, because there is a strong relationship between critical thinking skills and misconceptions. If students have high critical thinking skills, they can check the truth of a physics concept so that they avoid misconceptions (Yolviansyah et al., 2022). Physics is not only about understanding formulas and doing calculations, but also about the ability to develop conceptual understanding, make accurate predictions, and evaluate and interpret experimental data. If misconceptions are left unchecked, students will have difficulty developing these skills, which ultimately impacts their readiness to face academic and professional challenges in the future.

Misconceptions in physics can be caused by various factors, ranging from preconceptions in the form of daily experiences when interacting with the surrounding environment that is not under scientific principles (Irianti, 2021), errors in assimilating and accommodating newly received knowledge (Fridatama, 2021), the way teachers deliver material that is less effective and does not use textbooks optimally in learning (Rohmah et al., 2023), to limitations in the use of learning media (Andini & Kurniawati, 2024), and teaching materials (Nuraina & Rohantizani, 2023). In addition, teaching methods that are too oriented toward memorizing formulas without conceptual understanding can also strengthen misconceptions (Bistari, 2024). Students may be able to solve problems mathematically, but they do not understand the meaning behind the calculations. When they face new situations that require the application of concepts, they often experience confusion or use the wrong concepts.

Many students rely on their intuition to understand physics phenomena, which often contradicts scientific laws. For example, many students believe that heavier objects fall faster than lighter objects, even though in the absence of air resistance, all objects fall with the same acceleration according to Newton's law of gravity (Potvin et al., 2023). These misconceptions are often difficult to eliminate because they come from their personal experiences and are embedded in their mindsets for a long time (Bessas et al., 2024). These misconceptions can negatively impact their understanding of advanced material and their effectiveness in teaching physics concepts to students in the future.

If these misconceptions are not identified and corrected, students will have difficulty understanding more complex concepts, such as dynamics of motion, energy, and momentum. In addition, uncorrected misconceptions can have an impact on students' low ability to apply physics concepts in problem-solving, resulting in low student learning outcomes. They may have difficulty connecting theory to real phenomena so that the concepts they learn are only memorized without deep understanding. As a result, when faced with problems that are slightly different from the examples they have studied, they tend to be confused and make mistakes in analysis and calculation.

For student teachers, the impact of these misconceptions can be even broader. If they do not understand physics concepts correctly, they risk conveying incorrect information to students in class. This can lead to ongoing misunderstandings and hinder students' interest and motivation in learning physics. Therefore, it is important for lecturers and educators to actively identify and address misconceptions early, through methods such as formative assessments, conceptual discussions, or experimental and simulation-based learning (Udma et al., 2024). Some students may master the formula mathematically but have a weak conceptual understanding. This proves that physics learning is not enough to only focus on solving numerical problems, but must also emphasize deep conceptual understanding.

One method that can be used to detect misconceptions more accurately is the Three-Tier Diagnostic Test. This method not only tests students' answers but also evaluates the reasons they chose the answer and their level of confidence in the answer given. With this approach, educators can distinguish between students who truly understand the concept, students who have misconceptions, and students who are just guessing the answer. By implementing the Three-Tier Diagnostic Test, educators can obtain more comprehensive data on the patterns of misconceptions that occur among students. This test consists of three levels: The first level, multiple-choice questions to identify student responses, the second level, conceptual explanations supporting the answers, and the third level, the level of student confidence in their responses (Maisyaroh et al., 2022). This approach provides a more in-depth picture of the extent to which students truly understand the concept or are simply guessing the answer without a strong understanding.

Previous studies have shown that the application of diagnostic tests is effective in revealing students' misconceptions in various fields of science, including physics. Testing with graded diagnostic tests can help teachers design learning strategies that are more appropriate to students' needs (Ünlü & Dökme, 2020). Diagnostic tests have advantages over ordinary multiple-choice tests because they can distinguish the level of confidence in the answers and the level of confidence in the students' reasons for the questions, so that they can dig deeper into students' conceptual understanding and can diagnose students who understand the concept, do not understand the concept and misconceptions (Paramitha et al., 2021). Diagnostic tests can quickly identify misconceptions and weaknesses in students' learning with a wide range of materials (Nisa & Sudrajat, 2023). In addition, the results obtained from diagnostic tests can help teachers determine which parts of the material require more emphasis so that teachers can prepare better learning plans and can help reduce the occurrence of misconceptions in students (Yuliana, 2023).

Diagnostic tests conducted by previous researchers found that misconceptions in basic physics are quite high, especially in mechanical concepts, such as force, motion, energy, and Newton's laws (Nainggolan et al., 2023). Misconceptions were also detected in students' problem-solving process in representing the concept of force (Suban & Hidayatullah, 2024), in the material on elasticity and Hooke's Law (Wahyudi et al., 2021), in the topic of Pascal's Law (Maisyaroh et al., 2022), Geometric Optics material (Sholikah et al., 2020), Earth and Space Science courses (Ananda & Syuhendri, 2021), and Static Electricity material (Hatika Genesa et al., 2022). These various studies show that misconceptions in physics do not only occur in one or two topics but extend to various fundamental concepts with various triggering factors that have been explained previously.

This study has several key differences compared to previous studies. The main focus of this study is to identify misconceptions in Basic Physics courses, which are the foundation for understanding more advanced physics concepts. Unlike previous studies that often focus on specific topics such as mechanics, static electricity, elasticity, or optics, this study is broader in scope in revealing misconceptions that occur in various basic physics concepts. In addition, this study also highlights the implications of the results for learning methods by providing recommendations for strategies that can be used to overcome misconceptions, such as conceptual understanding-based learning and interactive methods. This study stands out from most previous research, which primarily focuses on identifying misconceptions, by not only addressing these misconceptions but also providing concrete solutions, thereby contributing to the advancement of the field. Thus, it not only reveals the misconceptions but also offers broader insights into effective strategies for improving students' understanding of basic physics.

Method

This study employs a descriptive quantitative method to identify students' misconceptions in the Basic Physics course through the use of the Three-Tier Diagnostic Test, which was chosen for its ability to accurately diagnose misconceptions by assessing not only students' answers but also their reasoning and confidence levels. The research design used is an evaluative study, which aims to analyze students' conceptual understanding and determine the implications of the research results for the learning process. This study measures the level of students' conceptual understanding, detects misconceptions, and examines parts of the physics material that experience misconceptions.

The sample in this study amounted to 82 students selected using the purposive sampling technique, namely considering that participants are students who have taken Basic Physics courses in UIN Ar-Raniry Banda Aceh. The data collection technique was carried out using a test, namely the Three-Tier diagnostic, consisting of three levels: (1) multiple-choice questions to test students' conceptual understanding, (2) conceptual reasons to identify in-depth understanding, and (3) the level of student confidence in the answers given. The research instrument used was an instrument that had been developed previously, namely the Three-Tier Diagnostic Test, which had been validated by physics education experts and tested before being used in the main study. Validity tests, specifically content validity and construct validity, were conducted to ensure that each item effectively measures students' understanding of the concepts being assessed. Reliability tests were also carried out to ensure the consistency of test results in measuring misconceptions.

The data analysis technique in this study used the Certainty of Response Index (CRI), which is a method to measure the level of students' confidence in the answers they give in diagnostic tests. CRI is used to distinguish between correct answers based on actual understanding and correct answers, but only the result of guesswork (Hasan, 1999). The CRI criteria are shown in Table 1 below:

Table 1 Certainty of Response Index (CRI) Scale Criteria

CRI	Criteria
0	totally guessed
1	almost guessed
2	not sure
3	sure
4	almost certain/almost confident
5	certain/confident

To differentiate students who know the concept, have misconceptions, and do not know the concept, you can follow the provisions in Table 2 as follows:

Table 2 Assessment Criteria with CRI Modification Technique

Answer Criteria	Reason	CRI Index	Explanation
Correct	Correct	≥2,5	Understand the concept
Correct	Correct	≤2,5	Understand the concept but is less sure
Correct	Incorrect	≥2,5	Misconception
Incorrect	Correct	≥2,5	Misconception
Incorrect	Incorrect	≥2,5	Misconception
Correct	Incorrect	≤2,5	Do not understand the concept
Incorrect	Correct	≤2,5	Do not understand the concept
Incorrect	Incorrect	≤2,5	Do not understand the concept

The percentage based on each category is determined using the formula:

$$P = \frac{f}{N} x\ 100\%$$

P = Percentage of each category
f = Number of test participants with each category
N = Total number of test participants

To determine the percentage category of misconceptions for each topic in the basic physics course (Handayani, 2018), see Table 3 below.

Table 3 Misconception Percentage Categories

Percentage Range	Category
0% – 30%	Low
31% – 60%	Medium
61% – 100%	High

Results and Discussion

The results of this study provide an overview of students' conceptual understanding of Basic Physics and highlight the prevalence of misconceptions. The findings are based on the Three-Tier Diagnostic Test, which was analyzed using the Certainty of Response Index (CRI) to categorize students' understanding levels.

Students' Conceptual Understanding Level

The results of the Three-Tier Diagnostic Test that have been analyzed using the Certainty of Response Index (CRI), it was found that students are divided into several categories of conceptual understanding. The following table (Table 4) presents the distribution of the diagnostic test results. This table is significant as it illustrates the proportion of students who demonstrate accurate understanding, misconceptions, or lack of understanding of the Basic Physics concepts, providing insights into the effectiveness of the Three-Tier Diagnostic Test in identifying students' conceptual challenges.

Table 4 Distribution of Students' Conceptual Understanding Table

Category of Concept Understanding	Number of Students	Percentage (%)
Understand the Concept	7	8.75%
Misconception	45	55.58%
Understands the Concept but is Less Sure	3	2.25%
Do Not Understand the Concept	27	33.82%
Total	**82**	**100%**

Based on the data presented in the table, the majority of students (55.58%) exhibit misconceptions regarding the concept being assessed. This finding is critical because it highlights a significant gap in students' understanding, which may hinder their progress in mastering more advanced concepts in Basic Physics. This indicates that while they may have some level of understanding, their comprehension is incorrect or inconsistent with the actual concept. Meanwhile, 33.82% of students do not understand the concept at all, suggesting a significant portion of the class struggles with grasping the material. On the other hand, only 8.75% of students fully understand the concept, which is a relatively low percentage. Additionally, 2.25% of students understand the concept but lack confidence in their understanding, which may indicate uncertainty or a lack of deep conceptual mastery. Overall, these findings underscore the need for targeted instructional interventions to address misconceptions and enhance students' conceptual understanding. Strategies such as interactive learning, formative assessments, and conceptual discussions are critical in improving student comprehension and mitigating misunderstandings.

Misconception Analysis Based on Each Basic Physics Topic

The results of the analysis also show that misconceptions occur in various topics of Basic Physics. The following table illustrates the percentage of student misconceptions for each topic tested:

Table 5 Categories of Misconceptions for Each Basic Physics Topic

No	Topics	Misconception Percentage	Category
1	Quantities and Measurement	60,00 %	Medium
2	Kinematics	63,34%	High
3	Dynamics and Newton's Laws	66,19%	High
4	Work and Energy	43,33%	Medium
5	Impulse and Momentum	51,11%	Medium
6	Fluid	55,24%	Medium
7	Temperature and Heat	43,33%	Medium
Average		**55,58**	**Medium**

The table above shows that the levels of misconceptions across various physics vary, ranging from moderate to high categories. The average level of misconceptions is 55.58%, which is included in the moderate category. However, several topics have quite high levels of misconceptions, which can be a major concern in the learning process. The topics with the highest levels of misconceptions are Kinematics (63.34%) and Motion and Newton's Laws (66.19%). These two topics are closely related to the understanding of motion and force, which is often a challenge for students because it requires a strong conceptual understanding and the ability to think abstractly and analytically. Students may have difficulty distinguishing between acceleration, velocity, and force, and in understanding how Newton's laws are applied in various situations. Meanwhile, several other topics have levels of misconceptions that fall into the moderate category, such as Quantities and Measurement (60.00%), Work and Energy (43.33%), Impulse and Momentum (51.11%), Fluids (55.24%), and Temperature and Heat (43.33%). Although the level of misconceptions in these topics is not as high as in kinematics and dynamics of motion, it still shows that students have difficulty in understanding basic physics concepts. For example, the concepts of fluid and work-energy are often difficult to understand because they involve the concepts of pressure, viscosity, the law of conservation of energy, and complex mathematical calculations.

Misconception Samples Based on Student Answers

Based on the analysis of student's answers, several forms of misconceptions were found that commonly occur in various physics topics. The following are some examples of misconceptions.

Table 6 Examples of Student Misconceptions in Basic Physics Concepts

Topic	Misconception	Correct Concept
Quantities and Measurement	SI and CGS units can be used interchangeably without conversion.	In physics calculations, SI and CGS units must be correctly converted according to their conversion factors.
	The accuracy of measuring instruments does not affect measurement results.	The accuracy of measuring instruments determines the precision and accuracy of measurement results, so using instruments with higher accuracy yields more precise data.
Kinematics	A stationary object has neither velocity nor acceleration.	A stationary object has zero velocity but can have acceleration if its velocity changes.
	If velocity is zero, then the object has no acceleration.	An object can have acceleration even if its velocity is zero, such as at the turning point of parabolic motion.
Dynamics and Newton’s Laws	If an object is moving, there must be a force acting on it.	According to Newton's First Law, an object can move at a constant velocity without any external force acting on it.

	Action and reaction forces always act on the same object.	Action and reaction forces always act on two different objects with equal magnitude and opposite directions (Newton's Third Law).
Work and Energy	If an object does not move, work is still being done.	Work is only done if there is displacement in the direction of the force. If the object does not move, the work done is zero.
	Energy exists only in moving objects.	Energy is not only present in moving objects but also in stationary objects in the form of potential energy.
Impulse and Momentum	A heavier object always has greater momentum.	Momentum depends on both mass and velocity. A lighter object can have greater momentum if its velocity is high enough.
	When two objects collide, the momentum of the larger object remains unchanged.	In a closed system, the total momentum is always conserved, but the momentum of each object can change due to collision forces.
Temperature and Heat	Temperature is a measure of the amount of heat in an object.	Temperature is a measure of the average kinetic energy of particles in an object, whereas heat is the energy transferred due to temperature differences.
	An object that feels colder has no thermal energy.	All objects have thermal energy, including those that feel cold. The amount of thermal energy depends on the object's temperature and mass.

Referring to the data presented, it is apparent that students still have difficulty understanding some basic physics concepts, leading to misconceptions about various topics. One common mistake occurs in Quantity and Measurement, where students assume that units in the SI and CGS systems can be used interchangeably without conversion. In fact, in physics, unit conversion is very important to ensure accuracy in calculations. In addition, many students are unaware that the level of accuracy of measuring instruments affects the accuracy of measurement results. In the concept of Kinematics, some students have an inaccurate understanding of the relationship between velocity and acceleration. They assume that a stationary object has no acceleration, whereas in certain conditions, such as when at a turning point in a parabolic motion, an object can have acceleration even though its velocity is zero.

In Dynamics and Newton's Laws, many students still assume that every moving object must have a force acting on it. In fact, according to Newton's First Law, an object can continue to move at a constant speed without any external force if there is no friction or other resistance. In addition, a misunderstanding of the law of action-reaction also often occurs, where students think that the action and reaction forces work on the same object, when in fact the two forces always work on two different objects.

Another mistake was found in Work and Energy, where students tend to assume that work is still done even though there is no displacement of the object. In fact, in the concept of physics, work only occurs if there is displacement in the direction of the applied force. In addition, many still think that energy is only possessed by moving objects, while in reality, energy is also present in stationary objects in the form of potential energy. In Impulse and Momentum, a common misconception is the assumption that heavier objects must have greater momentum. Momentum is influenced by two factors, namely mass and velocity so that lighter objects can have greater momentum if they move at high speed. In the field of Temperature and Heat, many students misunderstand the difference between temperature and heat. They think that temperature is a measure of the amount of heat in an object, when in fact temperature measures the average kinetic energy of the particles in the object. In addition, there is still the assumption that objects that feel cold do not have thermal energy, while all objects, both hot and cold, still have thermal energy that depends on their temperature and mass.

The results of this study indicate that misconceptions are still a major problem in Basic Physics learning. With only 8.75% of students truly understanding the concept, while 55.58% have misconceptions and 33.82% do not understand the concept at all, this indicates a gap in the teaching methods used. Misconceptions in physics are not just conceptual errors, but can also hinder the understanding of advanced materials, such as dynamics of motion, energy, and momentum. This shows that conventional approaches to teaching physics are not effective enough in eliminating misconceptions and building strong conceptual understanding for students.

This study used the Three-Tier Diagnostic Test which is able to detect not only students' answers, but also the reasons behind their answers and their level of confidence. Using the Certainty of Response Index (CRI), it can be distinguished between students who truly understand the concept, those who have misconceptions, and those who are just guessing the answer. The results of the study showed that many students have a wrong understanding of basic physics concepts, especially in Kinematics (63.34%) and Dynamics and Newton's Laws (66.19%), which are the two topics with the highest levels of misconceptions. This indicates that the concept of motion and force remains challenging for students, likely due to a conflict between their intuitive understanding and the established laws of physics. For example, many students mistakenly believe that heavy objects fall faster than lighter ones, which contradicts the principle of gravity. In addition, students also experienced misconceptions in Fluids (55.24%), Impulse and Momentum (51.11%), and Temperature and Heat (43.33%), which shows that concepts that require abstract understanding and mathematical modeling are more difficult to understand than more concrete concepts. One of the contributing factors is the lack of a learning approach that emphasizes the relationship between concepts and real phenomena, as well as teaching methods that focus too much on memorizing formulas without in-depth understanding.

The results of this study are in line with previous studies that also found high levels of misconceptions about various physics concepts. For example, research by Nainggolan et al. (2023) showed that misconceptions often occur in mechanics materials such as force, motion, and energy. This finding is also in line with research by Potvin et al. (2023) which found that many students still believe that heavier objects fall faster than lighter objects, even though in conditions without air resistance, all objects experience the same gravitational acceleration. Compared to previous studies, this study is more comprehensive in revealing misconceptions in various basic physics topics, not just in one specific material such as mechanics or static electricity. In addition, this study not only identifies misconceptions but also highlights the implications of the findings for more effective learning strategies.

The results of this study have significant implications for Basic Physics learning strategies, especially in efforts to overcome student misconceptions. With the finding that more than 55% of students experience misconceptions, a more effective learning approach must be implemented immediately to ensure better conceptual understanding. One of the main implications is the need for conceptual understanding-based learning compared to conventional methods that tend to focus on memorizing formulas and solving problems procedurally. This can be realized through approaches such as Inquiry-Based Learning (IBL) or Problem-Based Learning (PBL) that encourage students to explore concepts and find their own understanding. In addition, the results of this study also emphasize the importance of using the Three-Tier Diagnostic Test as a more accurate evaluation tool in detecting misconceptions. With this tool, lecturers can identify not only students' answers but also the reasons behind their answers and their level of confidence. Thus, the interventions provided can be more targeted, either through additional guidance, conceptual discussions, or laboratory-based experiments that emphasize the relationship between theory and real phenomena.

Another implication that needs to be considered is the need to improve the quality of media and learning resources used in physics learning. This study shows that many misconceptions occur due to incorrect intuitive understanding or lack of clear visualization of concepts. Therefore, the use of technology-based simulations, interactive animations, and virtual experiments can help students build a more accurate understanding.

From an academic policy perspective, the results of this study also indicate the need to strengthen formative assessment in the Basic Physics curriculum. Students should not only be evaluated based on a final exam based on numbers, but also through regular formative assessments that can identify misconceptions before they become obstacles to further learning. This approach also supports the development of critical thinking skills, which are very important for students, especially future educators who will teach physics to the next generation.

Overall, these findings emphasize that addressing misconceptions in Basic Physics is not only about correcting students' mistakes, but also about designing more innovative, interactive, and conceptually-based learning strategies. If not addressed immediately, existing misconceptions can continue and hinder students' academic and professional development in the fields of science and physics education.

Conclusion

The results of this study indicate that misconceptions are still the main obstacle in learning Basic Physics, with 55.58% of students experiencing misconceptions and 33.82% not understanding the concept well, while only 8.75% understand the concept correctly. This shows that there is harmony in the learning methods used, which are not yet fully effective in building students' conceptual understanding. By using the Three-Tier Diagnostic Test and the Certainty Response Index (CRI), this study successfully identified that the highest misconceptions occurred in the topics of Kinematics (63.34%) and Dynamics and Newton's Laws (66.19%), which shows that the concept of motion and force is still difficult for students to understand. Meanwhile, misconceptions were also found in Fluids (55.24%), Impulse and Momentum (51.11%), and Temperature and Heat (43.33%), which indicates that concepts that require mathematical modeling and abstract understanding are more difficult to understand than more concrete concepts. The implications of this study emphasize the need for improvements in learning methods, especially through conceptual understanding-based approaches, such as Inquiry-Based Learning (IBL) or Problem-Based Learning (PBL), as well as the application of interactive learning media, technology-based simulations, and laboratory experiments that are more effective in connecting theory with real phenomena. In addition, periodic formative assessments are needed to detect and measure misconceptions early on.

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