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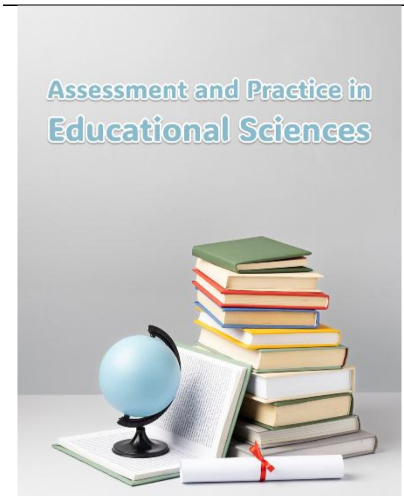

Examining and Addressing Tenth-Grade Students' Misconceptions in Basic Physics Concepts (Phenomenon, Modeling, Quantities, Measurement Accuracy, Density)

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ABSTRACT

This study was conducted with the aim of identifying and analyzing tenth-grade students' misconceptions in fundamental physics concepts such as phenomenon, modeling, the distinction between law and principle, physical quantities, accuracy of measuring instruments, units, and density. The statistical population consisted of 85 tenth-grade students from the experimental sciences and mathematics–physics tracks, selected through cluster random sampling. The research instrument was a questionnaire comprising eight multiple-choice questions, whose validity was confirmed by subject-matter experts, and whose reliability was calculated using Cronbach's alpha coefficient ($\alpha = 0.91$). The results showed that more than 50% of students had misconceptions in concepts such as modeling, the distinction between law and principle, as well as in differentiating between vector and scalar quantities. Furthermore, 45% of students demonstrated significant errors in understanding density, the accuracy of measuring instruments, and the concept of phenomenon. Additionally, 30% of students exhibited misconceptions in the discussion of units. This research emphasizes the necessity of revising teaching methods and presenting concrete examples to reduce misconceptions.

Keywords: Misconceptions, Basic Physics, Tenth-Grade Students, Modeling, Density.

Introduction

The teaching and learning of physics as a foundational science has long been associated with conceptual challenges, particularly in secondary education. Students often encounter difficulties in grasping basic physics concepts such as phenomena, modeling, physical quantities, measurement accuracy, units, and density, leading to persistent misconceptions that hinder deeper learning. Misconceptions are not merely fleeting mistakes but systematically organized beliefs that conflict with established scientific theories, yet often appear to be supported by logical reasoning or limited empirical observations (1, 2). For instance, the common belief that "heavier objects fall faster" persists because it is grounded in everyday experiences and seemingly logical interpretations, though it contradicts Newtonian mechanics (3).

A large body of research in science education has highlighted the resilience of misconceptions and their negative impact on students' ability to acquire and apply advanced scientific knowledge (4, 5). Misconceptions are resistant to change because they are embedded in students' pre-existing mental models and conceptual frameworks. They often emerge before formal instruction, supported by intuitive reasoning and daily experiences (6, 7). These findings underscore the importance of systematic investigation into students' misconceptions, as well as the design of instructional strategies aimed at fostering conceptual change (8, 9).

The conceptual change framework provides a powerful lens through which to analyze and address misconceptions in physics education. Research in this domain suggests that conceptual change can occur through three main processes: belief revision, mental model transformation, and categorical shift (2). For example, helping students recognize the inadequacy of their intuitive explanations and confronting them with cognitive conflict can motivate the restructuring of their mental models (5). However, as Vosniadou (4) emphasizes, such change is not straightforward; it requires carefully designed instructional interventions that support students' gradual movement from naïve theories toward scientifically accurate models.

Etkina and Van Heuvelen (10) argue that physics instruction should integrate investigative science learning environments where students actively engage in experimentation, reasoning, and reflection. By designing tasks that directly challenge students' misconceptions and by guiding them through model-based reasoning, teachers can facilitate deeper understanding (11, 12). Similarly, research on interactive engagement methods has demonstrated significant gains in conceptual understanding compared to traditional lecture-based approaches (13).

Several domains of physics are particularly prone to misconceptions. One recurring issue is students' misunderstanding of the nature of *phenomena*. Many students equate phenomena only with extraordinary or unusual events, failing to recognize that every observable and measurable occurrence, such as boiling water or planetary motion, constitutes a phenomenon. Such limited interpretations restrict students' ability to generalize physics principles to diverse contexts (14).

Another critical area is *modeling*, which lies at the heart of scientific reasoning. Models are simplifications of reality designed to highlight essential features while disregarding minor effects (11, 12). Yet, many students struggle to distinguish between physical reality and the assumptions of models. They may incorrectly assume, for example, that air resistance is always negligible in motion problems, or that all objects can be treated as point particles. These misunderstandings not only distort students' grasp of modeling as a scientific practice but also impede their ability to apply models to new situations (15).

The distinction between *laws* and *principles* in physics is another subtle but important conceptual challenge. Laws are broad, universal generalizations often expressed mathematically, such as Newton's laws of motion, while principles typically apply to more restricted domains, such as Pascal's principle in fluids. Many students mistakenly view principles as axiomatic truths without proof, akin to postulates in geometry. This confusion has been observed across educational systems worldwide and highlights the need for explicit instructional clarification (16).

Understanding *measurement* and *quantities* presents further difficulties. Mari et al. (17) emphasize that quantities and their units are the foundation of scientific measurement. Nevertheless, misconceptions are common, especially in differentiating between scalar and vector quantities. For example, some students incorrectly believe that electric current is a vector simply because it has direction, ignoring that its mathematical properties do not conform to vector addition. Research confirms that misconceptions in measurement accuracy and significant figures further complicate students' engagement with experimental data (18-20). Many students assume that the precision of an instrument can be inferred directly from a single reported measurement, neglecting the role of instrument design and calibration.

The concept of *density* is another frequent source of misunderstanding. Students often confuse density with weight, assuming that heavier objects are necessarily denser. Smith and Metz (7) showed that this misconception persists despite repeated instruction, suggesting the need for targeted conceptual interventions. Moreover, misconceptions extend to misunderstandings of how density varies with temperature, pressure, and solute content (21-23). For instance, while students may know that oil generally floats on water, they often generalize incorrectly, unaware that some oils are denser than water under certain conditions. Such errors demonstrate the necessity of integrating reference data into instruction to confront students' overgeneralizations.

Educational research highlights that misconceptions are deeply rooted, systematic, and resistant to simple correction (1, 6). Potvin and Hasni (9) found that students' interest in physics is strongly related to their conceptual understanding; when misconceptions persist, disengagement follows. Therefore, addressing misconceptions is not only an epistemic necessity but also a motivational one.

Instructional strategies for addressing misconceptions include the use of bridging analogies (3), conceptual conflict tasks (2), and model-based teaching (12). Duit and Treagust (8) argue that conceptual change requires carefully sequenced instruction that explicitly acknowledges students' prior knowledge, confronts them with inconsistencies, and supports the reconstruction of understanding. In practice, this means embedding scientific modeling in curricula, incorporating authentic laboratory experiences, and employing digital technologies to visualize abstract concepts.

In recent years, virtual physics education has emerged as a promising approach for addressing misconceptions. Research by Delavar et al. (24, 25) and Rahbar and Ahmadi (26) demonstrates that digital platforms, when designed according to cognitive principles, can significantly enhance students' conceptual understanding. Virtual environments allow for dynamic visualizations, immediate feedback, and repeated experimentation, all of which are effective in dismantling entrenched misconceptions.

Given the persistence and educational consequences of misconceptions in physics, this study investigates tenth-grade students' misconceptions in core physics concepts, specifically phenomena, modeling, laws and principles, quantities, measurement accuracy, units, and density.

Methods and Materials

This study was conducted using a descriptive–analytical approach with the aim of examining tenth-grade students' misconceptions in fundamental physics concepts. The statistical population consisted of 85 students (47 in the experimental sciences track and 38 in the mathematics–physics track) from different schools, selected through cluster random sampling. The main research instrument was a researcher-made questionnaire consisting of eight multiple-choice questions that covered key concepts, including phenomenon, modeling, law and principle, quantities, measurement accuracy, and density.

The questionnaire included eight multiple-choice questions, each addressing one of the fundamental physics concepts (phenomenon, modeling, law and principle, quantities, accuracy of measuring instruments, units, and density). The validity of the questionnaire was confirmed by five experts in the field of physics education, and its reliability was calculated using Cronbach's alpha ($\alpha = 0.91$).

The questionnaires were administered in the classroom setting within 15 minutes, without prior notice to the students. Participants were assured that the results would have no effect on their academic grades. The responses were independently reviewed and scored by two evaluators. The collected data were classified using frequency indices, percentages, and mean values. The results were presented in the form of tables, bar charts, and pie charts.

The data were analyzed at three levels: descriptive, analytical, and comparative. At the descriptive level, the mean and standard deviation of scores were calculated. At the analytical level, an independent t-test was applied to compare intergroup differences. The results showed that the difference between the two groups was statistically significant ($p < 0.05$). Finally, the findings were compared and analyzed against similar studies. All ethical considerations, including informed consent and confidentiality of information, were observed.

Findings and Results

The results obtained from data analysis are presented in the following tables and charts. The percentage and number of students in the experimental sciences and mathematics–physics tracks are as follows:

Table 1. Percentage and Number of Students in Experimental Sciences and Mathematics–Physics Tracks

Field of Study	Percentage	Number of Students	Central Angle
Experimental Sciences	55%	47	198°
Mathematics–Physics	45%	38	162°

Table 2. Frequency and Percentage of Students' Responses to Questionnaire Items

Concept	Full Understanding (%)	Misconception (%)	No Understanding (%)	No Response (%)
Phenomenon	40	45	10	5
Modeling	25	65	5	5
Law and Principle	30	55	10	5
Vector Quantities	35	50	10	5
Accuracy of Tools	20	45	30	5
Units	50	30	15	5
Density	25	45	25	5

Table 3. Results of Responses by Field of Study

Concept	Experimental Sciences (%)	Mathematics–Physics (%)
Phenomenon	42	38
Modeling	68	62
Law and Principle	58	52
Vector Quantities	55	45
Accuracy of Tools	48	42
Units	35	25
Density	50	40

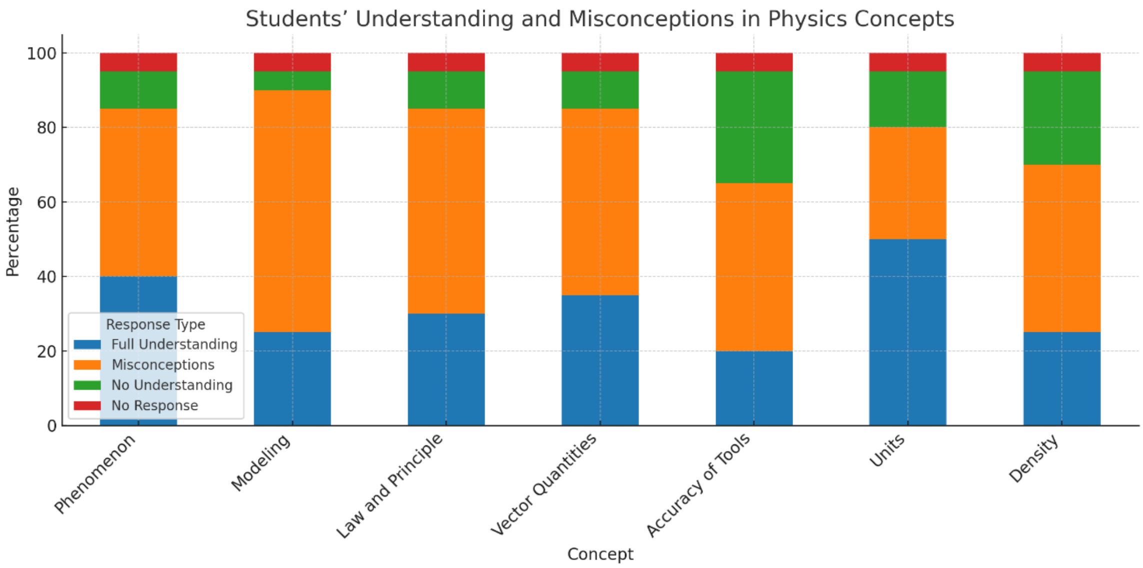

Figure 1. Overall Student Responses by Concept

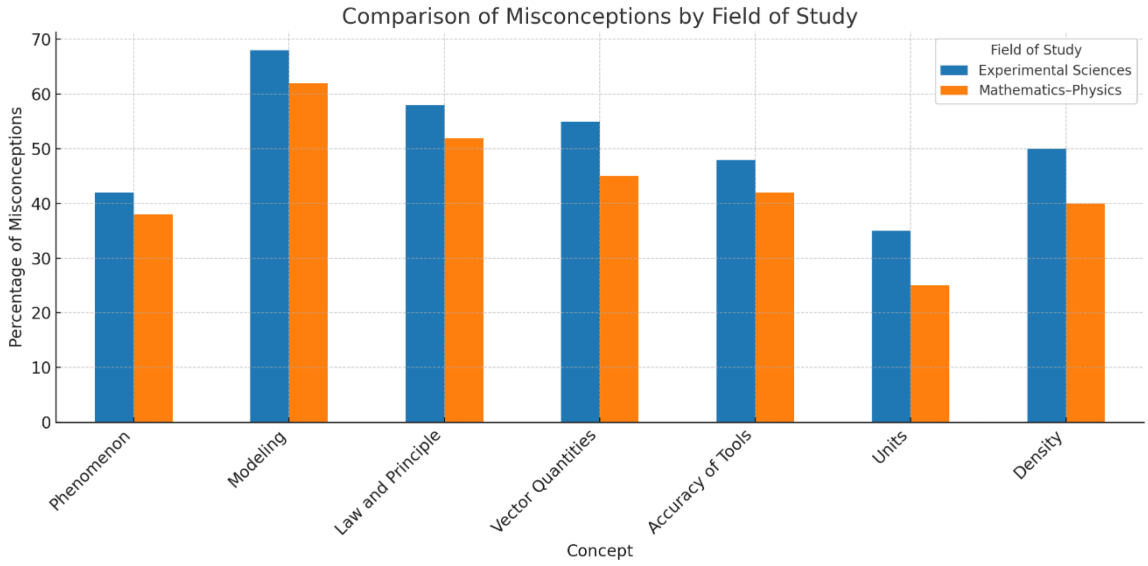

Figure 2. Misconceptions by Field of Study

The findings reveal that misconceptions among tenth-grade students are most prevalent in the concept of *modeling* (65%), followed closely by misunderstandings in *law and principle* (55%) and *vector quantities* (50%). The lowest level of full understanding is observed in *measurement accuracy* (20%), highlighting a critical weakness in students' grasp of experimental and practical aspects of physics. Conversely, the concept of *units* shows the highest rate of full understanding (50%), suggesting that more straightforward and routinely used concepts are less prone to misconceptions.

When analyzing by academic track, both groups of students—those in experimental sciences and mathematics–physics—exhibited high levels of misconceptions in *modeling* (68% and 62%, respectively). However, experimental sciences students showed consistently higher percentages of misconceptions across most concepts compared to mathematics–physics students, particularly in *density* (50% vs. 40%) and *law and principle* (58% vs. 52%). This indicates that while misconceptions are widespread, the depth and distribution differ slightly across academic tracks.

The overall analysis highlights a pressing need to revise teaching methods, especially through practical examples and modeling exercises, to bridge the gaps in understanding and reduce persistent misconceptions.

Discussion and Conclusion

The findings of this study provide compelling evidence that misconceptions remain a pervasive challenge in the teaching and learning of basic physics concepts among tenth-grade students. Analysis of the collected data revealed that more than 50% of students held misconceptions in areas such as modeling, the distinction between laws and principles, and differentiating between scalar and vector quantities. Additionally, 45% of students demonstrated significant misunderstandings related to density, the accuracy of measuring instruments, and the general concept of phenomena, while 30% struggled with units. These results underscore the fact that misconceptions are not confined to isolated topics but are distributed across multiple foundational concepts in physics, highlighting the systemic nature of the problem.

The most striking result was the prevalence of misconceptions in *modeling* (65%), which aligns with the extensive literature documenting difficulties students face in distinguishing between reality and the simplified assumptions underlying scientific models (11, 12). Many students, for instance, failed to recognize when it is appropriate to treat an object as a point particle or when air resistance should be considered significant. Such misunderstandings reflect a deeper problem: students often perceive models as literal representations of physical systems rather than as epistemic tools designed for specific contexts (15). This confirms the assertion of Vosniadou (4) that students' mental models are deeply rooted in everyday reasoning and resistant to transformation without carefully designed instructional interventions.

The difficulty in distinguishing between *laws* and *principles* was another area where students exhibited widespread misconceptions (55%). This mirrors findings from McComas (16), who argued that the subtleties in scientific terminology are often overlooked in curricula, leading learners to conflate terms that have distinct meanings within the philosophy of science. Laws are intended to provide universal generalizations often represented mathematically, whereas principles are conditional statements with narrower applicability. Yet, many students believed that principles are axioms accepted without proof, akin to postulates in geometry, which reveals a fundamental misunderstanding of the epistemological foundations of physics. The persistence of such confusion echoes prior research showing that students across diverse educational contexts encounter difficulties in differentiating among scientific constructs (3).

Another noteworthy finding is the substantial difficulty students experienced with *vector and scalar quantities*. Nearly half of the participants demonstrated misconceptions in identifying whether a given physical quantity was scalar or vector, and a common error was the assumption that electric current must be a vector simply because it has direction. This result resonates with earlier studies reporting similar challenges (7, 27). Misconceptions about the mathematical properties of physical quantities not only hinder students' understanding of mechanics but also affect their comprehension of more advanced fields such as electromagnetism, where conceptual clarity is essential.

The results also highlight students' struggles with *measurement accuracy and significant figures*. Only 20% of students achieved full understanding in this area, while 45% revealed misconceptions. These outcomes confirm the findings of Allie et al. (18) and Becker and Rivera (19), who reported that students frequently misinterpret the role of measurement instruments and often assume that the precision of a device can be inferred directly from a reported value. Kaminski and Sloutsky (20) further noted that young learners tend to struggle with transferring knowledge of measurement across contexts, reinforcing the idea that misconceptions about accuracy are systematic rather than incidental. The prevalence of such misunderstandings in this study underscores the necessity for explicit instruction in measurement theory and practice, as emphasized by Mari et al. (17).

The concept of *density* proved to be another domain of confusion, with 45% of students holding misconceptions. A recurring error was the conflation of density with weight or heaviness, leading students to assume, for example, that iron is inherently denser than wood simply because iron objects are often heavier. This result is consistent with the findings of Smith and Metz (7), who demonstrated that students often anchor their reasoning about density in everyday experiences rather than scientific definitions. Furthermore, misconceptions about the dependence of density on temperature, solutes, or state of matter reflect a lack of integration of empirical reference data into instruction. Standardized sources such as the CRC Handbook (21) and IAPWS tables (22) provide clear evidence that density varies systematically with physical conditions, yet students appear to lack exposure to these resources. Perry's Chemical Engineers' Handbook (23) also emphasizes the importance of contextualizing density within real-world applications, suggesting that the absence of practical data in curricula contributes to misconceptions.

Comparative analysis between students in the experimental sciences track and the mathematics–physics track revealed noteworthy differences. Misconceptions were consistently higher among experimental sciences students, particularly in topics such as modeling (68% versus 62%) and density (50% versus 40%). These findings may be explained by the more descriptive nature of the experimental sciences curriculum, which often places less emphasis on mathematical formalism compared to the mathematics–physics track. Potvin and Hasni (9) argue that conceptual understanding in physics is closely linked to students' level of engagement and interest; thus, curricular differences may foster varying levels of cognitive challenge and conceptual growth.

Taken together, these results reinforce the idea that misconceptions are not merely superficial errors but are deeply embedded in students' cognitive structures. Duit and Treagust (5, 8) have long argued that conceptual change requires deliberate instructional strategies that acknowledge students' preconceptions and provide opportunities for restructuring. Interactive engagement methods, such as those proposed by Hake (13), and investigative science learning environments (10), have demonstrated success in fostering conceptual growth, but this study suggests that their integration into classroom practice remains limited.

Moreover, the integration of technology and virtual platforms presents a promising pathway. Recent work by Delavar and colleagues (24, 25) demonstrated that cognitive-based virtual physics instruction can significantly improve conceptual understanding, while Rahbar and Ahmadi (26) showed that digital content designed with cognitive load principles enhances students' comprehension of complex topics. These studies resonate strongly with the current findings, suggesting that innovative pedagogical tools could play a crucial role in addressing persistent misconceptions in Iranian classrooms.

While this study provides valuable insights into students' misconceptions in fundamental physics concepts, several limitations must be acknowledged. First, the sample size of 85 students, though sufficient for preliminary analysis, limits the generalizability of the findings across broader populations. Future studies involving larger and more diverse samples would allow for more robust conclusions. Second, the study relied exclusively on multiple-choice questions, which may not capture the full range of students' reasoning processes. Misconceptions are often nuanced and context-dependent, and open-ended assessments or interviews could have provided richer data. Third, the cross-sectional design prevents causal inferences about the development of misconceptions. Longitudinal studies would be necessary to track how misconceptions evolve over time and how they respond to instructional interventions. Finally, while the study identified differences between the experimental sciences and mathematics–physics tracks, it did not account for potential confounding variables such as teaching style, prior knowledge, or access to supplementary resources.

Future research should pursue several directions. One priority is to employ mixed-methods approaches that combine quantitative surveys with qualitative interviews or think-aloud protocols to provide a deeper understanding of students' reasoning. Longitudinal designs could illuminate the persistence and transformation of misconceptions across different grade levels. Additionally, experimental studies testing the effectiveness of specific instructional strategies—such as conceptual conflict tasks, model-based learning, or virtual simulations—would help identify the most effective interventions for addressing particular misconceptions. Comparative studies across cultural and educational contexts could also shed light on whether certain misconceptions are universal or context-specific. Finally, future research should examine the role of teacher knowledge and instructional practices, as teachers' own misconceptions and pedagogical approaches play a crucial role in shaping students' understanding.

From a practical perspective, the findings of this study suggest several actionable strategies for educators. Teachers should place greater emphasis on explicitly distinguishing between scientific constructs such as laws, principles, and models, ensuring that students understand their epistemological differences. Instruction should also incorporate real-world data and examples, such as density tables and measurement standards, to contextualize abstract concepts. Classroom activities should include more interactive engagement methods, such as hands-on experiments, group discussions, and modeling exercises, to confront misconceptions directly. Teachers should also leverage digital tools and virtual platforms to provide dynamic visualizations and simulations that can make invisible phenomena more tangible. Finally, curriculum developers should consider revising textbooks to include clearer definitions, practical examples, and scaffolding tasks designed to challenge misconceptions systematically.

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Authors' Contributions

Not applicable.

Declaration of Interest

The author of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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