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MAPPING MISCONCEPTIONS OF SENIOR HIGH SCHOOL STUDENTS IN PHYSICS: A QUALITATIVE PERSPECTIVE

Rodika Utama[1]*, Moh. Toifur[2], Carissa Viola Putri Alfian[3], Nisrina Karimah[4]
Master of Physics Education, Ahmad Dahlan University, Yogyakarta, Indonesia[1]
Master of Physics Education, Ahmad Dahlan University, Yogyakarta, Indonesia[2]
Al-Wildan Islamic School 1 Gading Serpong, Grade 12 Science Program, Banten, Indonesia[3]
Al-Wildan Islamic School 1 Gading Serpong, Grade 12 Science Program, Banten, Indonesia[4]
E-mail: rodika@ruangguru.com

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Abstract

Misconceptions in physics represent a persistent barrier in students' learning processes, influencing how they interpret and apply fundamental principles. These misconceptions are often robust, deeply rooted in everyday experiences, cultural beliefs, or misleading linguistic expressions, making them resistant to traditional forms of instruction. The present study aims to map senior high school students' misconceptions across a wide range of core physics topics—including mechanics, energy, waves, and optics—through a qualitative lens. The research employed a four-tier diagnostic test and semi-structured interviews administered to 45 eleventh-grade students from a public high school in South Tangerang, Indonesia. The diagnostic test allowed for the identification of misconceptions by probing students' answers, reasoning, confidence levels, and justifications, while follow-up interviews provided deeper insights into students' thought processes. Data were analyzed thematically to classify the most dominant misconceptions and to uncover the underlying reasoning patterns that sustain them. Findings revealed that the most prevalent misconceptions were associated with Newton's third law, where students believed that action and reaction forces cancel each other out; with energy conservation, where energy was perceived as a consumable entity that "runs out"; with sound propagation, where students assumed sound could travel in a vacuum; and with optics, particularly shadow formation, where students believed that light rays could stop or bend arbitrarily in space. These misconceptions were not isolated errors but rather formed coherent alternative frameworks that strongly influenced students' conceptualizations. The implications of this study are twofold. First, mapping misconceptions across different physics domains provides a comprehensive overview of the conceptual challenges faced by students, which can inform teachers' pedagogical strategies. Second, the results emphasize the need for instructional approaches that combine multiple representations—verbal, graphical, and experimental—along with inquiry-based activities that explicitly challenge students' existing ideas. Such approaches are expected to foster conceptual change and support students in developing a more scientifically accurate understanding of physics.

Keywords: ***Misconceptions, High School Physics, Qualitative Analysis, Diagnostic Test, Physics Education***

INTRODUCTION

Physics is widely regarded as one of the most fundamental branches of science, providing explanations for a vast range of natural phenomena and forming the basis for technological innovation. Despite its importance, physics is also considered one of the most challenging subjects for students at the secondary school level. A consistent challenge identified in physics education research is the presence of misconceptions, or alternative conceptions, which are ideas that deviate from scientifically accepted views but are nevertheless strongly held by learners (Soeharto & Csapó, 2022). Misconceptions are not merely random errors; rather, they represent coherent frameworks of reasoning that students often use to interpret the physical world (Duit & Treagust, 2020). These misconceptions can arise from multiple sources. Everyday experiences often reinforce intuitive but scientifically inaccurate ideas, while language—such as the metaphor of energy being "used up"—may further consolidate flawed conceptualizations. Textbooks, classroom explanations, and instructional materials can unintentionally contribute to these misunderstandings if they fail to emphasize the distinction between scientific models and real-world analogies (Kaltakci-Gurel et al., 2022). As a result, misconceptions tend to be robust, persisting even after formal instruction and creating significant barriers to conceptual change (Widodo & Duit, 2021). Prior research has revealed that misconceptions in physics are widespread and cut across various domains. In mechanics, students often misinterpret Newton's laws of motion, particularly believing that forces acting in pairs cancel each other out. In energy topics, students tend to view energy as a tangible substance that can be consumed or destroyed, rather than as a conserved quantity. In wave physics, misconceptions include the assumption that sound can travel in a vacuum, while in optics, students frequently misunderstand the nature of light propagation and the formation of shadows (Salmadhia et al., 2021). Such misconceptions are not isolated errors but interrelated ideas that shape students' overall reasoning patterns, making them particularly resistant to change.

Although numerous studies have investigated misconceptions in specific physics topics, there remains a need for research that provides a broader mapping of misconceptions across multiple core domains within a single population. Mapping these misconceptions systematically can generate a comprehensive understanding of the conceptual difficulties faced by students, thereby offering valuable insights for teachers, curriculum developers, and policymakers. Such studies are particularly relevant in the Indonesian context, where the ongoing implementation of the Merdeka Curriculum emphasizes inquiry, scientific reasoning, and conceptual understanding rather than rote learning. Therefore, the present study seeks to explore and map the misconceptions of senior high school students in physics using a qualitative approach. By employing a four-tier diagnostic test combined with semi-structured interviews, this research aims to identify dominant misconceptions across mechanics, energy, waves, and optics, and to analyze the reasoning patterns that underlie them. The ultimate goal is to provide a detailed picture of students' alternative conceptions, which can inform the design of instructional interventions that foster conceptual change and support the development of scientifically accurate understanding.

LITERATURE REVIEW

Misconceptions in Science and Physics Education

Misconceptions are widely recognized as a major challenge in science education. They are often defined as ideas or conceptions that deviate from accepted scientific knowledge but are held with confidence by learners (Kaltakci-Gurel, Eryilmaz, & McDermott, 2022). In physics education research, the term "alternative conceptions" is also used to emphasize that these are not random mistakes but rather consistent frameworks that students use to interpret phenomena (Soeharto & Csapó, 2022). Misconceptions can significantly hinder conceptual understanding, as students interpret new information through the lens of their pre-existing flawed models (Chi, 2013).

Sources and Robustness of Misconceptions

The origins of misconceptions are diverse. Everyday experiences often reinforce intuitive beliefs that conflict with scientific principles, such as the notion that heavier objects fall faster than lighter ones (McDermott, 1993). Language and cultural metaphors may also strengthen incorrect ideas—for example, the expression that energy is "used up" implies that energy disappears rather than being conserved (Brook & Driver, 1984). Instructional materials, such as textbooks or teachers' explanations, can unintentionally perpetuate these misunderstandings if they oversimplify or fail to clarify scientific models (Clement, 1982). These factors contribute to the robustness of misconceptions, making them resistant to traditional instruction and persistent even among advanced learners (Duit & Treagust, 2020).

Persistence Across Physics Domains

Research has consistently documented misconceptions across multiple areas of physics. In mechanics, students often misunderstand Newton's laws of motion, particularly believing that action and reaction forces cancel each other (Halloun & Hestenes, 1985). In the domain of energy, learners frequently view energy as a material-like substance that can be consumed, depleted, or lost (Liu & McKeough, 2005; Salmadhia, Sutopo, & Sunaryo, 2021). In wave physics, misconceptions include the belief that sound can propagate in a vacuum or that particles of the medium move along with the wave (Eshach & Schwartz, 2006). Optics is another area rich in alternative conceptions, such as the misunderstanding that light rays stop in mid-air or that shadows are formed solely by the object rather than by the interaction of light with the object (Métioui et al., 2020).

Approaches to Addressing Misconceptions

Various instructional approaches have been proposed to address misconceptions. Conceptual change theory emphasizes the need for instruction to challenge students' pre-existing frameworks and to provide conditions for restructuring (Posner et al., 1982). Multi-representational teaching—integrating verbal, graphical, mathematical, and experimental modes—has been shown to help students coordinate different views of the same concept, reducing the persistence of alternative ideas (Sutopo & Waldrip, 2020). Diagnostic assessments, such as two-tier or four-tier tests, are increasingly used to identify misconceptions systematically and to inform targeted interventions (Gurel, Eryilmaz, & McDermott, 2015). In the Indonesian context, recent studies highlight the effectiveness of virtual laboratories and inquiry-based learning in surfacing and addressing misconceptions (Saputri, Nugroho, & Permanasari, 2021; Susanti & Sari, 2023).

Research Gap

While many studies have investigated misconceptions in specific domains, there is a growing need for broader studies that map misconceptions across multiple physics topics within a single cohort of students. Such mapping can provide a more holistic understanding of students' conceptual difficulties and offer insights for curriculum design and instructional practices. This research addresses that gap by qualitatively mapping senior high school students' misconceptions in mechanics, energy, waves, and optics, contributing both to the theoretical understanding of alternative conceptions and to practical strategies for improving physics education.

METHOD

Research Design

This study employed a qualitative descriptive design to explore and map senior high school students' misconceptions in physics. A qualitative approach was selected because it allows for an in-depth investigation of students' reasoning processes and provides rich descriptions of their alternative conceptions. Rather than focusing on statistical generalization, this design emphasizes the exploration of patterns of thought and meaning-making processes. Diagnostic assessments were combined with semi-structured interviews in order to triangulate data sources and enhance the credibility of findings.

Participants

The participants of the study were 45 eleventh-grade students (aged 16–17) from a public senior high school in South Tangerang, Indonesia. The selection of participants followed purposive sampling, with the primary consideration being their prior exposure to core physics topics in the grade X and XI curriculum. At the time of the study, the participants had completed instruction on mechanics, energy, waves, and optics—topics known to be conceptually demanding and prone to misconceptions. Participation was voluntary, and students provided informed consent prior to data collection. To maintain confidentiality, pseudonyms were used in reporting, and no identifiable personal information was included.

Instruments

To capture both the breadth and depth of students' misconceptions, this study utilized a combination of diagnostic testing and interview techniques. The diagnostic test provided a structured overview of students' conceptual understanding across multiple physics domains, while the semi-structured interviews allowed for deeper exploration of the reasoning processes underlying their responses. By integrating these two instruments, the study ensured a comprehensive and triangulated approach to data collection. Two primary instruments were employed in this study:

1. Four-Tier Diagnostic Test.
   The diagnostic test consisted of 24 items distributed across four physics domains: mechanics (6 items), energy (6 items), waves (6 items), and optics (6 items). Each item was structured in four tiers: (1) a multiple-choice question assessing content knowledge, (2) a multiple-choice reasoning statement, (3) a confidence rating scale (sure/unsure), and (4) an open-ended justification. This structure enabled the identification of not only incorrect answers but also the reasoning patterns and confidence levels underlying students' conceptions.
2. Semi-Structured Interview Protocol.
   Following the diagnostic test, 12 students were purposively selected for in-depth interviews based on the variety and consistency of their misconceptions. The interview protocol consisted of open-ended questions

designed to probe students' thought processes, clarify ambiguous responses, and elicit more detailed reasoning. Interviews lasted 20–30 minutes each and were audio-recorded with students' permission for transcription and analysis.

Procedure

The study was conducted in three stages. First, the diagnostic test was administered in a classroom setting under exam-like conditions, with 60 minutes allocated for completion. Students were encouraged to provide detailed justifications for their answers, even if they were uncertain. Second, responses were scored and analyzed to identify patterns of misconceptions. Students who demonstrated persistent misconceptions across multiple items were then invited for follow-up interviews. Finally, the interviews were conducted individually in a quiet room within the school premises. The interviewer followed the semi-structured guide but also allowed flexibility to explore unanticipated lines of reasoning.

Data Analysis

To ensure a comprehensive understanding of students' misconceptions, the collected data were analyzed using a two-phase procedure that combined quantitative categorization with qualitative interpretation. This approach allowed the researchers to map the prevalence of misconceptions systematically while also exploring the reasoning patterns underlying students' responses in greater depth.

- Diagnostic Test Analysis. Responses were first categorized as scientifically correct, misconception, or lack of knowledge. A response was classified as a misconception if the student chose an incorrect option but expressed confidence and provided a justification consistent with known alternative conceptions (e.g., "forces in action-reaction pairs cancel each other out"). Frequency counts were used to map the prevalence of each misconception.
- Interview Coding. Interview transcripts were subjected to inductive thematic analysis (Braun & Clarke, 2006). The coding process involved (1) familiarization with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, and (5) defining and naming themes. Two independent coders analyzed the transcripts to ensure inter-rater reliability, with discrepancies resolved through discussion. Themes identified from the interviews were cross-referenced with diagnostic test results to triangulate findings.

Trustworthiness

To ensure the trustworthiness of the study, several strategies were employed. Credibility was enhanced through triangulation between test results and interview data. Member checking was conducted by sharing interview summaries with participants to confirm the accuracy of interpretations. Dependability was addressed by maintaining a clear audit trail of data collection and analysis procedures. Transferability was supported by providing thick descriptions of the context, participants, and instruments, enabling readers to assess the applicability of findings to other educational settings.

Ethical Considerations

This study was conducted in accordance with established ethical standards for educational research. Prior to data collection, approval was obtained from the school administration, and informed consent was sought from all participants. Students were informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any time without penalty. For participants under the age of 18, parental consent was also secured through formal letters distributed by the school. Confidentiality and anonymity were maintained throughout the study. Students' names and any identifiable information were replaced with pseudonyms in all transcripts, notes, and reports. Audio recordings of interviews were stored securely on password-protected devices and were accessible only to the research team. After transcription and verification, recordings were deleted to protect participants' privacy. To minimize potential discomfort, interview sessions were designed to be conversational and supportive, ensuring that students felt safe in expressing their ideas—even when those ideas were scientifically inaccurate. By treating misconceptions as meaningful insights rather than mistakes, the study sought to respect students' perspectives while maintaining academic rigor. These ethical measures contributed to the credibility, trustworthiness, and integrity of the research process.

RESULTS AND DISCUSSION
Mapping of Misconceptions
Analysis of the four-tier diagnostic test revealed that misconceptions were prevalent across all four domains: mechanics, energy, waves, and optics. Table 1 summarizes the dominant misconceptions identified in the study, along with representative student responses and the percentage of students holding each misconception.

Table 1. Mapping of Students' Misconceptions in Physics

No	Domain	Misconception (Summary)	Representative Student Response	% of Students
1	Mechanics	Action and reaction forces cancel each other, resulting in no motion.	"If the table pushes upward with the same force as the book pushes down, the forces cancel, so there is no force acting on the book."	58
2	Energy	Energy is a consumable entity that can run out or disappear.	"The ball loses energy after rolling for a while because it is used up by friction."	64
3	Waves	Sound can travel in a vacuum, or sound particles move along with the wave.	"Sound can still be heard in space because it is very loud."	49
4	Optics	Shadows are caused only by the object, not by the interaction of light with the object.	"The shadow appears because the object produces it, not because light is blocked."	52

These results confirm that misconceptions are not isolated misunderstandings but represent consistent alternative frameworks that strongly shape students' reasoning.

Detailed Analysis of Misconceptions
The analysis revealed several recurring misconceptions across the four domains of mechanics, energy, waves, and optics.

1. Mechanics
   Misconceptions in mechanics were among the most frequently reported. A total of 58% of students believed that action and reaction forces cancel each other, thereby preventing motion. One student stated: "If the wall pushes me back with the same force, the two forces cancel and nothing happens."
   This reflects a persistent confusion between Newton's third law (forces acting on different objects) and the principle of equilibrium (forces acting on a single body). In addition, 42% of students subscribed to the "impetus" view, suggesting that an object in motion requires continuous force to keep moving. As one student explained: "The cart will stop because no one is pushing it anymore." Furthermore, 31% of students maintained that heavier objects fall faster than lighter ones, attributing speed to weight rather than gravitational acceleration. Misconceptions about centripetal and centrifugal forces were also common, with 47% of students describing an outward "centrifugal force" as stronger than gravity in circular motion situations. These findings align with international research documenting intuitive but inaccurate reasoning about force and motion.
2. Energy
   Energy-related misconceptions were equally widespread. Approximately 64% of students viewed energy as a consumable entity that "runs out" or "disappears." A representative response was: "The moving ball stops because its energy is used up by friction." This reflects substance-like reasoning, where energy is imagined as tangible matter rather than a conserved quantity. More than half of students (53%) also believed that conservation of energy does not apply in systems with friction or non-conservative forces. Another 22% equated energy directly with force, explaining that "greater force means greater energy." Similarly, 36% of students assumed potential energy exists only during motion, denying its presence in stationary configurations. Finally, 31% displayed confusion between heat and temperature, treating heat as an intrinsic property of objects rather than energy transfer.

3. Waves
   In wave phenomena, misconceptions were found in nearly half of the students. About 49% believed that sound can propagate in a vacuum, often reasoning that "sound is strong enough to travel anywhere." Others (33%) described sound waves as pushing particles forward, revealing naïve materialism. Moreover, 42% of students believed that amplitude (loudness) affects wave speed, while 38% linked wave speed to source strength rather than medium properties. Misunderstandings about superposition were also common: 27% of students thought overlapping pulses permanently cancel or average each other, indicating difficulties grasping transient interference. Finally, misconceptions about boundary behavior were identified, with 24% of students reversing fixed-end and free-end reflection rules.
4. Optics
   Misconceptions in optics also proved persistent. More than half (52%) asserted that shadows are "produced" by objects, not regions blocked from light. Some students also adhered to substance-like reasoning, claiming that light "sticks" to surfaces or "flows" like a fluid (33%). A frequent difficulty (38.9%) was the inability to differentiate between umbra and penumbra; students predicted only one dark shadow even when multiple light sources were present. About 22.2% confused brightness with geometry, arguing that "a stronger lamp makes larger shadows." Another 20% predicted that two lamps produce "one darker shadow," showing incomplete understanding of overlapping penumbrae. Additionally, 27% reported that light rays can "stop" when far from the source or "bend" spontaneously in air, inconsistent with rectilinear propagation. Finally, 29%–31% struggled with refraction and reversibility of light, rejecting angle equality or explaining bending as light "avoiding" the medium.

Cross-Domain Reasoning Patterns

While the misconceptions described above appear in different content areas, the analysis also revealed overarching reasoning patterns that cut across mechanics, energy, waves, and optics. These patterns show that students often rely on similar intuitive frameworks regardless of the topic, suggesting that misconceptions are not topic-specific errors but manifestations of deeper cognitive tendencies. Identifying these cross-domain schemas is important because it highlights the underlying structures that sustain students' alternative conceptions across multiple areas of physics learning. Across all domains, three reasoning patterns consistently appeared:

1. Substance-like thinking – treating energy, sound, or light as tangible substances that flow, stick, or get consumed.
2. Impetus-based intuition – believing motion requires continuous force, or that stronger pushes create inherently faster motion.
3. Single-variable dominance – relying on one salient factor (mass, brightness, loudness) to explain outcomes while neglecting system interactions.
4. These schemas illustrate that students' misconceptions are not isolated errors but rather coherent alternative frameworks rooted in everyday experience, language, and intuitive reasoning.

Grade-Level Comparison

A comparison across grade levels revealed differences in the nature of misconceptions. Grade X students tended to rely on everyday explanations, such as the notion that heavier objects fall faster, or that shadows are created by objects. They seldom used diagrams to justify their reasoning. In contrast, Grade XI students were more likely to attempt ray diagrams or mathematical reasoning, yet they still displayed persistent misunderstandings—for instance, misapplying Newton's third law or confusing energy with force. This suggests incremental improvement in representational strategies but not a complete resolution of misconceptions.

Interview Findings

Semi-structured interviews provided deeper insights into students' reasoning processes. Several students invoked everyday metaphors, such as energy being "used up" or sound being "carried like objects." One Grade XI student admitted: "I know energy cannot be destroyed, but when friction happens, the energy is gone, so the ball stops." This illustrates partial awareness of scientific principles coupled with persistent misconceptions. Interviews also revealed progression: Grade XI students mentioned terms like "reaction force" or "energy transformation," but their explanations still revealed incomplete integration of concepts. For example, when asked about shadows from two lamps, many students insisted there would only be "one darker shadow," failing to mentally coordinate overlapping penumbra regions.

Discussion

The findings confirm that misconceptions are deeply embedded and often consistent with earlier research (Halloun & Hestenes, 1985; Liu & McKeough, 2005; Salmadhia et al., 2021). The robustness of the "energy as substance" and "force cancellation" misconceptions highlights their intuitive appeal, rooted in everyday experience and reinforced by language. The persistence of these misconceptions even among Grade XI students suggests that formal instruction improves vocabulary and diagram use but does not always restructure underlying mental models (Chi, 2013; Duit & Treagust, 2020). This finding aligns with studies emphasizing the difficulty of achieving true conceptual change without strategies that directly challenge students' pre-existing frameworks (Posner et al., 1982).

Instructional Implications

The results suggest the need for targeted instructional interventions. Teachers should design tasks that explicitly contrast scientific explanations with common misconceptions, such as using discrepant events (e.g., objects falling at the same rate) or two-lamp experiments to reveal overlapping shadows. Multi-representational teaching, combining diagrams, graphs, and experiments, can help students integrate abstract models with observable phenomena (Sutopo & Waldrip, 2020). Additionally, embedding inquiry-based activities within the Kurikulum Merdeka framework would allow students to test predictions experimentally and revise their ideas through reflective dialogue.

Synthesis

This study demonstrates that misconceptions are not isolated mistakes but structured alternative frameworks that combine intuition, experience, and partial scientific reasoning. By mapping students' misconceptions across multiple physics domains, the study provides a holistic view of conceptual challenges in Indonesian classrooms. These findings emphasize the importance of designing learning environments that promote conceptual change by engaging students not only in receiving correct definitions but also in reflecting on and revising their own ideas. Ultimately, addressing misconceptions systematically contributes to the long-term goal of developing scientific literacy, as envisioned in PISA and Indonesia's national curriculum.

CONCLUSION

This This study set out to map senior high school students' misconceptions across four major domains of physics: mechanics, energy, waves, and optics. Using a four-tier diagnostic test complemented by semi-structured interviews, the research uncovered a wide range of persistent misconceptions. The most common included the belief that action and reaction forces cancel each other, that energy is a consumable entity which "runs out," that sound can propagate in a vacuum, and that shadows are "produced" by objects rather than caused by the obstruction of light. These findings confirm that misconceptions are not random errors but structured alternative frameworks that shape students' reasoning in consistent ways. Across all domains, three cross-cutting reasoning patterns were identified: substance-like thinking, impetus-based intuition, and single-variable dominance. These patterns illustrate how students rely on intuitive and everyday frameworks that are deeply resistant to change. The persistence of such misconceptions, even after formal instruction, highlights the limitations of conventional teaching approaches that focus on definitions and problem-solving without addressing students' underlying reasoning.

The educational implications of this study are significant. Teachers need to move beyond mere correction of wrong answers and instead design learning environments that encourage students to surface, reflect on, and reconstruct their alternative conceptions. Approaches such as discrepant events, inquiry-based investigations, multiple representations, and guided use of ray or force diagrams can help students coordinate scientific models with observable phenomena. Embedding these strategies within the flexible framework of the Kurikulum Merdeka can further support conceptual change by allowing extended time for exploration and reflection. Future research should expand this mapping approach to larger and more diverse student populations, including longitudinal studies that track conceptual development over time. Additional work is also needed to evaluate the effectiveness of specific interventions designed to target the cross-domain reasoning patterns identified in this study. By systematically documenting both the persistence and transformation of misconceptions, physics education research can contribute to the broader goal of fostering scientific literacy, as envisioned by international benchmarks such as PISA and by national curriculum reforms in Indonesia. In conclusion, misconceptions in physics represent not only a barrier to learning but also an opportunity: by recognizing them as coherent alternative frameworks, teachers and researchers can design targeted strategies that engage students in meaningful conceptual change. This study contributes to that effort by providing a comprehensive map of misconceptions across multiple physics domains and offering insights into the reasoning patterns that sustain them.

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