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EXPLORING SENIOR HIGH SCHOOL STUDENTS' MISCONCEPTIONS IN NEWTONIAN MECHANICS: A QUALITATIVE INVESTIGATION

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Abstract

Newtonian mechanics remains a fundamental yet conceptually challenging domain for high school students. Numerous studies have shown that students consistently hold alternative conceptions that contradict scientific understanding, particularly in relation to Newton's laws of motion. This study aimed to explore senior high school students' misconceptions in Newtonian mechanics through a qualitative investigation. Data were collected from 28 Grade 11 students in an Indonesian high school using open-ended diagnostic tests, semi-structured interviews, and classroom observations. Thematic coding identified four major categories of misconceptions: inertia, force–motion relationships, action–reaction interactions, and free-body diagram representations. Among these, misconceptions of Newton's third law were the most dominant, with the majority of students believing that the object with greater mass exerts a greater force during interaction. Inertia misconceptions, such as the belief that motion requires continuous force, were also widespread. The findings confirm that students' misconceptions are robust cognitive frameworks reinforced by everyday experiences and traditional teaching practices. Pedagogically, the results highlight the importance of incorporating inquiry-based learning, multiple representations, and cognitive conflict strategies to promote conceptual change. This study contributes to the literature on physics education by providing context-specific insights into persistent misconceptions in Newtonian mechanics and suggesting implications for more effective teaching practices.

Keywords: ***misconceptions, newtonian mechanics, Newton's Laws, physics education, qualitative study***

INTRODUCTION

Newtonian mechanics forms the conceptual foundation of classical physics and is central to the secondary school curriculum worldwide. Its principles particularly Newton's laws of motion serve as the basis for understanding force, motion, and interactions that extend to more advanced domains such as rotational dynamics, energy conservation, and electromagnetism. Despite its central importance, a considerable body of research over the last four decades has revealed that students consistently struggle with these concepts and develop alternative frameworks that contradict accepted scientific understanding (Driver, Guesne, & Tiberghien, 1994; McDermott, 1999; Halloun & Hestenes, 1985). These difficulties persist even after formal instruction, suggesting that misconceptions in Newtonian mechanics are robust and resistant to traditional teaching methods. One of the most prevalent misconceptions concerns the relationship between force and motion. Many students intuitively believe that force is required to maintain motion, a viewpoint rooted in everyday experiences of friction and resistance, but inconsistent with Newton's first law of motion (diSessa, 1993; Viennot, 1979). This "impetus" view of force often leads to the misinterpretation that velocity is proportional to applied force rather than acceleration. Such misconceptions hinder students' ability to apply Newton's laws correctly in problem-solving contexts. Another common area of difficulty involves Newton's third law. Numerous studies have shown that students frequently assume action–reaction forces act on the same object or that the larger or more massive object exerts a greater force than the smaller one (Clement, 1982; Trowbridge & McDermott, 1981). For example, when asked to analyze a collision between a truck and a car, many students argue that the truck exerts a larger force because it is "stronger" or "heavier." These misconceptions reveal deep-seated intuitive reasoning patterns that diverge from formal physics. Misinterpretations of free-body diagrams and vector representation also pose challenges. Students often confuse net force with individual forces, fail to distinguish between balanced and unbalanced forces, or apply gravitational concepts inconsistently (Gunstone & Watts, 1985; Maloney, 1984). Such misunderstandings result not only in incorrect answers but also in fragmented conceptual frameworks, where students may switch between inconsistent models depending on context. Addressing these persistent misconceptions requires more than traditional lecture-based approaches. Researchers in physics education have emphasized the role of qualitative investigations to uncover the reasoning patterns behind students' responses. Unlike quantitative assessments that measure correctness, qualitative methods such as semi-structured interviews, written reflections, and classroom observations provide deeper insights into students' thought processes, enabling the identification of underlying mental models (Linder, 1993; Duit & Treagust, 2003). By analyzing students' language, reasoning, and justifications, educators can design targeted instructional strategies that foster conceptual change. Conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982) offers a framework for addressing misconceptions in science learning. According to this perspective, students' preconceptions act as entrenched "mini-theories" that compete with scientific concepts. For new knowledge to be accommodated, students must first become dissatisfied with their existing ideas and then recognize the plausibility and fruitfulness of the scientific explanation. Qualitative research plays a crucial role in this process, as it documents the specific forms of preconceptions that must be challenged in classroom practice.

In the Indonesian context, challenges in learning Newtonian mechanics are compounded by curriculum demands, limited laboratory resources, and the dominance of exam-oriented instruction. Previous studies in Indonesian high schools (Suparno, 2013; Sari & Sutopo, 2018) suggest that misconceptions in force and motion are widespread, particularly due to the reliance on rote problem-solving rather than conceptual understanding. Furthermore, students' everyday language and cultural experiences often reinforce non-Newtonian intuitions, making it more difficult for teachers to correct misconceptions. This study seeks to contribute to the growing body of research on student conceptions in physics by exploring the misconceptions held by senior high school students in Newtonian mechanics through a qualitative investigation. Specifically, the research aims to identify the types of misconceptions present, analyze the reasoning patterns behind these misconceptions, and compare them with findings from prior international studies. By focusing on the qualitative dimension, the study provides nuanced insights into how students think about forces and motion, thereby offering implications for instructional design in physics education. The significance of this research lies in two aspects. First, it provides empirical evidence about the persistence and variety of misconceptions among Indonesian high school students, enriching the global literature on physics education. Second, it highlights the pedagogical importance of addressing misconceptions not merely as errors to be corrected but as windows into students' reasoning processes. Such understanding is essential for designing effective strategies such as inquiry-based learning, conceptual conflict approaches, and multiple-representation teaching that can promote genuine conceptual change in physics classrooms. In summary, Newtonian mechanics continues to pose conceptual challenges for students at the senior high school level. Misconceptions in force, motion, and interactions remain robust despite instruction, underscoring the need for detailed qualitative research. This study, therefore, investigates the misconceptions of senior high school students in Newtonian mechanics through interviews, open-ended tasks, and classroom observations, aiming to shed light on the cognitive barriers that hinder conceptual understanding and to inform more effective teaching practices.

LITERATURE REVIEW

The Nature of Misconceptions in Physics

Research in science education has consistently demonstrated that students enter the classroom with pre-existing ideas that shape their interpretation of new concepts. These ideas, often referred to as misconceptions or alternative conceptions, are robust, internally coherent, and resistant to change (Driver, Guesne, & Tiberghien, 1994; Duit & Treagust, 2003). Misconceptions are not merely random errors but represent deeply rooted frameworks derived from everyday experiences, cultural beliefs, and linguistic expressions (diSessa, 1993; Suparno, 2013). In physics, misconceptions are especially prevalent in mechanics, as students often draw upon intuitive understandings of motion and force that are inconsistent with Newtonian principles. For example, the common belief that a continuous force is required to sustain motion reflects an Aristotelian view of dynamics that conflicts with Newton's first law (Viennot, 1979; Clement, 1982).

Misconceptions in Newton's Laws of Motion

- Newton's First Law (Inertia):

Students frequently believe that moving objects naturally come to rest unless sustained by a force, overlooking the role of friction and external resistance (Halloun & Hestenes, 1985). This misconception reflects an impetus theory, where force is seen as an inherent property of motion (McCloskey, 1983).

- Newton's Second Law (Force and Acceleration):

A recurring misconception is that force is proportional to velocity rather than acceleration. Students often describe faster-moving objects as experiencing greater force, failing to recognize that it is acceleration, not velocity, that is directly related to net force (Trowbridge & McDermott, 1980; Thornton & Sokoloff, 1998).

- Newton's Third Law (Action–Reaction):

Studies show that students struggle to accept the symmetry of action–reaction pairs. Many argue that a heavier object exerts a greater force on a lighter one, as in collisions between a truck and a car (Maloney, 1984; Trowbridge & McDermott, 1981). Others mistakenly believe the two forces act on the same object rather than on different interacting bodies (Clement, 1982; Bao et al., 2002).

Diagnostic Tools for Investigating Misconceptions

The development of diagnostic instruments has played a crucial role in identifying student misconceptions. Halloun and Hestenes (1985) pioneered this work through the Force Concept Inventory (FCI), a multiple-choice test specifically designed to probe conceptual understanding of Newtonian mechanics. Numerous studies since then have confirmed the persistence of misconceptions across diverse student populations, from high school learners to university undergraduates (Hestenes, Wells, & Swackhamer, 1992; Bao & Redish, 2006). While quantitative tools like the FCI reveal prevalence, qualitative methods provide richer insights into students' reasoning. Interviews, open-ended responses, and classroom observations uncover the thought processes underlying misconceptions, showing how students justify their answers and how their ideas shift in response to instruction (Linder, 1993; Scott, Asoko, & Leach, 2007).

Conceptual Change Theory

The persistence of misconceptions has led researchers to emphasize the need for instructional strategies that promote conceptual change. According to Posner et al. (1982), learners must experience dissatisfaction with their prior conceptions before adopting scientific alternatives. The new concept must be intelligible, plausible, and fruitful in explaining phenomena. In practice, this requires instructional approaches that confront students' intuitive beliefs while guiding them toward scientifically accepted explanations (Duit & Treagust, 2003).

Several pedagogical strategies have been proposed:

- Cognitive conflict approaches, where students encounter phenomena that contradict their expectations (Chinn & Brewer, 1993).
- Multiple representations, such as diagrams, analogies, and simulations, to reinforce conceptual understanding (Ainsworth, 2006).
- Inquiry-based learning, encouraging students to test predictions, analyze evidence, and reconstruct their conceptual frameworks (White & Gunstone, 1992).

Qualitative Research in Physics Education

Qualitative research provides a powerful lens to capture the complexity of students' learning processes. By analyzing discourse, reasoning, and classroom interactions, researchers can identify not only what misconceptions exist but also why they persist (Linder, 1993; Yeo & Gilbert, 2017). Case studies, for instance, allow for in-depth exploration of how individual students or groups negotiate meaning in physics contexts. Recent studies emphasize the importance of exploring misconceptions within specific cultural and educational contexts. For example, Sari & Sutopo (2018) found that Indonesian high school students often misinterpret Newton's laws due to language-related ambiguities and teacher-centered instruction. Similarly, Gunawan et al. (2019) highlighted how local teaching practices influence the persistence of misconceptions in force and motion. These findings underline the need for context-specific research that informs localized teaching strategies.

Summary of Literature Review

The reviewed literature establishes that misconceptions in Newtonian mechanics are widespread, robust, and resistant to traditional instruction. While tools such as the FCI have identified common patterns, qualitative studies provide deeper insight into students' reasoning and the persistence of alternative conceptions. Conceptual change theory offers a framework for addressing these challenges, but effective instructional strategies require a thorough understanding of the misconceptions themselves. This study builds on prior research by conducting a qualitative investigation of Indonesian high school students, aiming to identify, categorize, and interpret their misconceptions in Newtonian mechanics.

METHOD

Research Design

This study employed a qualitative descriptive approach to explore senior high school students' misconceptions in Newtonian mechanics. A qualitative methodology was chosen because the aim was not to quantify the prevalence of misconceptions but to uncover the underlying reasoning, thought processes, and conceptual frameworks that students use when interpreting force and motion. This approach allows for a deeper examination of how misconceptions manifest in language, explanations, and problem-solving strategies (Linder, 1993; Scott, Asoko, & Leach, 2007). The research design was framed as a case study (Yin, 2003), focusing on a single cohort of Grade 11 students within the Indonesian high school context. A case study design was considered appropriate to capture the richness of the classroom context, the cultural background of learners, and the interaction between teaching practices and student understanding.

Participants

The participants were 28 Grade 11 students (aged 16–17 years) from a public senior high school in Indonesia. The class was selected purposively, as the students had recently completed a unit on Newton's laws of motion within the national physics curriculum. The selection ensured that all participants had prior exposure to the relevant concepts, making it possible to investigate how their understanding developed during and after instruction. Participation was voluntary, and ethical protocols were observed, including informed consent from students and parental permission. Anonymity was maintained by assigning pseudonyms to all participants.

Instruments and Data Sources

Three primary data sources were employed to triangulate findings:

1. Open-ended Diagnostic Test
   - A written instrument containing six open-ended questions was developed, adapted from the Force Concept Inventory (Halloun & Hestenes, 1985; Hestenes, Wells, & Swackhamer, 1992).
   - Questions targeted common misconceptions in inertia, force-motion relationships, and Newton's third law.
   - Students were required to explain their reasoning in addition to selecting answers, allowing insight into their thought processes.
2. Semi-Structured Interviews
   - Follow-up interviews were conducted with 10 students selected to represent a range of responses (high-achieving, average, and struggling students).
   - The interviews probed students' reasoning behind their test answers, encouraged elaboration, and clarified ambiguous responses.
   - Sample prompts included:
     "Why do you think an object in motion eventually stops?" or
     "In a collision between a truck and a car, which one exerts a greater force? Why?"
3. Classroom Observations
   - Observations were conducted during physics lessons to capture how students discussed and reasoned about Newtonian concepts in real time.
   - Field notes focused on misconceptions expressed during peer discussions and the strategies used by the teacher to address them.

Data Collection Procedure

Data collection took place over four weeks and followed these steps:

1. Students completed the open-ended diagnostic test under classroom conditions.
2. Responses were reviewed, and patterns of reasoning were noted.
3. Semi-structured interviews were conducted with selected students, each lasting 20–30 minutes.
4. Classroom observations were carried out in three consecutive lessons focusing on Newton's laws.
5. All written responses, interview transcripts, and field notes were compiled for analysis.

Data Analysis

Data were analyzed using thematic coding (Braun & Clarke, 2006). The process involved:

1. Familiarization: Reading through all responses and transcripts to gain an overview.
2. Initial Coding: Assigning descriptive codes to segments of text (e.g., "force sustains motion," "heavier object exerts more force").

3. Categorization: Grouping similar codes into broader themes that represent specific misconceptions (e.g., impetus theory, force-velocity confusion, action–reaction asymmetry).
4. Triangulation: Comparing data across diagnostic tests, interviews, and observations to validate themes.
5. Interpretation: Relating identified themes to existing literature and conceptual change theory.

To ensure validity, the coding process was reviewed by two physics education researchers independently. Inter-coder agreement was established at 87%, and discrepancies were resolved through discussion.

Trustworthiness of Data

To enhance the credibility and trustworthiness of the study, four strategies were implemented (Lincoln & Guba, 1985):

- Credibility: Triangulation of data sources (tests, interviews, observations).
- Transferability: Providing thick description of the context to enable application to similar settings.
- Dependability: Documenting the research process systematically to ensure consistency.
- Confirmability: Using peer debriefing and audit trails to minimize researcher bias.

Ethical Considerations

Ethical clearance was obtained from the school and local education authority. Participants were informed about the purpose of the research, assured that participation was voluntary, and informed of their right to withdraw at any time. Data were kept confidential, and pseudonyms were used in all reports and publications.

RESULTS AND DISCUSSION

Overview of Findings

Analysis of the diagnostic tests, interviews, and classroom observations revealed that misconceptions in Newtonian mechanics were pervasive among the students. Nearly all participants expressed at least one form of alternative conception regarding Newton's laws. Thematic coding produced four major categories of misconceptions, each with several subthemes:

1. Inertia misconceptions (Newton's First Law)
2. Force–motion misconceptions (Newton's Second Law)
3. Action–reaction misconceptions (Newton's Third Law)
4. Free-body diagram and vector misconceptions

Table 3 summarizes the categories and representative student statements.

Categories of Misconceptions

Table 3. Categories of Misconceptions in Newtonian Mechanics

Category	Category	Student Statement
Inertia	Motion requires continuous force	"An object will stop if we don't keep pushing it."
Inertia	Rest as a natural state	"Every object will eventually stop because that's its natural condition."
Force-Motion	Force proportional to velocity	"If the car is moving faster, the force must be greater."
Force-Motion	Heavier objects fall faster	"The heavier ball will reach the ground first because it has more force."
Action-Reaction	Larger mass exerts larger force	"The truck gives a bigger force on the car than the car on the truck."
Action-Reaction	Forces act on the same object	"The table pushes down and up on the book at the same time."
Force-Body Diagrams	Confusion of net vs. individual forces	"There are three forces on the ball, so the net force is three."
Force-Body Diagrams	Gravity misunderstood	"Gravity only works when objects are moving downward."

Inertia Misconceptions

Students demonstrated widespread adherence to an impetus view of motion, where force is considered necessary to sustain motion. For instance, one student remarked:
"If you stop pedaling the bicycle, it stops because the force disappears." (S4) This reasoning shows a failure to recognize friction as the cause of deceleration rather than the absence of force. Several students also described "rest" as the natural state of objects, consistent with Aristotelian dynamics (Viennot, 1979; Halloun & Hestenes, 1985).

Force–Motion Misconceptions

Many students interpreted force as proportional to velocity rather than acceleration. In response to a question about two objects moving at different constant speeds, one student explained:
"The faster ball has more force, because speed and force always go together." (S11)
This misconception was reinforced by everyday experiences, such as feeling a stronger impact when hit by a faster object. Another widespread error was the belief that heavier objects fall faster. Despite prior instruction, several students maintained that a heavy ball dropped from the same height would reach the ground earlier than a lighter one:
"If both balls are dropped, the heavier one will arrive first because it has more force of gravity." (S17)

Action–Reaction Misconceptions

Newton's third law proved to be the most challenging concept. In the truck–car collision problem, almost all students claimed that the truck exerted a greater force because of its mass:
"The truck is bigger and stronger, so it hits the car with more force." (S9)
Only a minority of students correctly identified the forces as equal and opposite. Additionally, several students confused the objects on which the forces act, describing action–reaction pairs as occurring on the same body:
"The book experiences two forces from the table: one pushing up and one pushing down." (S21)
This aligns with findings by Trowbridge & McDermott (1981) and Maloney (1984).

Free-Body Diagram and Vector Misconceptions

Analysis of students' drawings revealed fundamental misunderstandings. Several participants failed to distinguish between individual forces and net force, adding vectors arithmetically rather than considering direction. For example:
"There are three forces on the object, so the net force is three." (S14)
Other students restricted gravity to downward motion only, neglecting its constant effect:
"Gravity only works when the object is falling, not when it's on the table." (S19)
Such misconceptions highlight difficulties in connecting symbolic representations (arrows, diagrams) with conceptual understanding.

Cross-Source Triangulation

Triangulation of test responses, interviews, and classroom observations confirmed that these misconceptions were not isolated errors but consistent reasoning patterns. For example:

- Students who wrote that "motion requires force" on the test repeated similar statements in interviews.
- In classroom discussions, when the teacher posed a question about collisions, peers reinforced the belief that the heavier object "wins" in terms of force.

This consistency indicates that misconceptions are deeply rooted cognitive frameworks rather than surface-level mistakes.

Categories of Misconceptions (with Frequencies)

The analysis revealed four main categories of misconceptions. Each category consisted of several subthemes with their frequency of occurrence among the 28 students.

Table 4. Thematic Coding of Student Misconceptions in Newtonian Mechanics

Category	Subtheme	Number of Students	Percentage	Student Statement
Inertia	Motion requires continous force	19	67.9%	"An object will stop if we don't keep pushing it." (S4)
	Rest as natural state	15	53.6%	"Every object will eventually stop because that's its natural condition." (S7)
Force Motion	Force proportional to velocity	17	60.7%	"If the car is moving faster, the force must be greater." (S11)
	Heavier objects fall faster	14	50.0%	"The heavier ball will reach the ground first because it has more force." (S17)
Action-Reaction	Larger mass exerts larger force	21	75.0%	"The truck gives a bigger force on the car than the car on the truck." (S9)
	Forces act on the same object	16	57.1%	"The table pushes down and up on the book at the same time." (S21)
Free-Body Diagrams	Confusion of net vs. forces	12	42.9%	"There are three forces on the ball, so the net force is three." (S14)
	Gravity misunderstood	10	35.7%	"Gravity only works when the object is falling." (S19)

Interpretation of Frequencies

1. Action–Reaction misconceptions were the most prevalent, with three-quarters of students incorrectly asserting that a larger mass exerts a larger force. This finding echoes international studies (Trowbridge & McDermott, 1981; Bao et al., 2002).
2. Inertia misconceptions were also widespread, with over half of the students perceiving rest as a "natural state." This reflects Aristotelian reasoning patterns (Viennot, 1979).
3. Force–motion misconceptions persisted despite explicit instruction. More than half of the students linked force to velocity rather than acceleration, and half believed heavier objects fall faster.
4. Free-body diagram errors were less frequent but still significant. About one-third of students struggled to distinguish between net force and individual forces, indicating representational difficulties.

Triangulation Evidence

The consistency of misconceptions across instruments reinforces their robustness:

1. Diagnostic Test: Students often selected incorrect answers and justified them with Aristotelian reasoning.
2. Interviews: Students expanded on their justifications, providing detailed but flawed reasoning (e.g., "trucks are stronger because they are heavier").
3. Observations: During classroom discussions, peer-to-peer interactions often reinforced misconceptions, suggesting a collective cognitive framework.

CONCLUSION

This qualitative study explored the misconceptions held by Indonesian senior high school students regarding Newtonian mechanics. Analysis of diagnostic tests, semi-structured interviews, and classroom observations revealed that misconceptions were pervasive and robust across the sample of 28 students. Four major categories emerged: (1) misconceptions about inertia, (2) misconceptions linking force and motion, (3) misconceptions concerning Newton's third law of action–reaction, and (4) misconceptions in interpreting free-body diagrams and vector representations. Among these, action–reaction misconceptions proved to be the most dominant, with three-quarters of students asserting that the object with larger mass exerts a greater force. Inertia misconceptions and force–motion confusions were also widespread, reflecting students' reliance on intuitive, Aristotelian reasoning. Free-body diagram errors, though less frequent, demonstrated significant difficulties in connecting symbolic representations to conceptual understanding. The findings confirm that students' misconceptions are not isolated errors but coherent alternative frameworks reinforced by everyday experiences, peer discussions, and traditional classroom instruction. These results are consistent with previous international research, suggesting that misconceptions in Newtonian mechanics are universal in nature but also shaped by local cultural and educational contexts. Pedagogically, the study highlights the urgent need for instructional strategies that go beyond rote problem-solving. Teachers should incorporate approaches that foster conceptual change, such as inquiry-based learning, multiple representations, cognitive conflict, and peer discussion. Furthermore, diagnostic assessment tools should be integrated into classroom practice to identify misconceptions early and provide targeted interventions. In conclusion, Newtonian mechanics remains a conceptual challenge for senior high school students. Addressing misconceptions requires both awareness of their persistence and pedagogical innovation to promote genuine understanding. Future research could extend this study by examining the effectiveness of specific instructional interventions in reducing misconceptions, thereby contributing to improved physics education in both Indonesian and international contexts.

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