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Characteristics of Classical Mechanics Misconceptions and the Effectiveness of Problem-Based Learning: A Systematic Literature Review

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ABSTRACT

Students' misconceptions in classical mechanics are often resistant to change and may persist after conventional instruction, while Problem-Based Learning (PBL) is frequently recommended as a potential solution. However, evidence from Indonesia concerning both issues remains fragmented across small-scale studies using different instruments. This systematic literature review, reported with reference to PRISMA 2020, addressed two questions: (1) what characteristics of misconceptions have been reported in kinematics and Newtonian dynamics, and (2) what evidence exists regarding the effectiveness of PBL for conceptual understanding and misconception reduction in classical mechanics. Peer-reviewed journal articles published from 2016 to 2026 in Indonesian or English were identified through Google Scholar and supplementary databases, screened according to eligibility criteria, and synthesized thematically alongside descriptive comparisons of reported statistics. Six studies met the main inclusion criteria, supplemented by one PBL retention study on a non-mechanics topic. In kinematics, reported misconception rates ranged from 26.7% (general kinematics) to 40.67% (free-fall motion). In dynamics, the average misconception rate reached 61.10%, while misconceptions concerning weight force reached 86.36%, primarily because of confusion between mass and weight. PBL studies consistently reported higher posttest scores or N-gain values than conventional instruction (N-gain 0.67 vs. 0.42). However, none of the intervention studies used misconception-specific diagnostic tests, reported standardized effect sizes, or conducted delayed posttests. Thus, the available evidence supports the cautious conclusion that PBL improves conceptual understanding in mechanics, whereas claims concerning misconception reduction and long-term retention remain insufficiently supported. Future research should integrate scaffolded PBL with tiered diagnostic assessments, report standardized effect sizes and include delayed measurements to distinguish immediate learning gains from sustained conceptual change.

Keywords: Problem-Based Learning; Misconceptions; Classical Mechanics; Kinematics; Newtonian Dynamics

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I. INTRODUCTION

Classical mechanics constitutes a conceptual foundation for nearly all physics topics taught at secondary and higher education levels, yet it is also a domain in which students' intuitive ideas are particularly persistent. Classic studies have shown that students enter physics instruction with "common-sense" beliefs about motion that often conflict with Newtonian mechanics (Halloun & Hestenes, 1985), including the belief that a moving object must be acted upon by a force in the direction of its motion (Clement, 1982). Instruments such as the Force Concept Inventory have demonstrated that many of these beliefs persist after conventional instruction (Hestenes et al., 1992). A survey involving more than six thousand introductory physics students likewise found that classes employing interactive engagement achieved an average normalized gain approximately twice that of traditional classes (0.48 ± 0.14 vs. 0.23 ± 0.04) (Hake, 1998). These findings make the question of which instructional strategies can transform students' conceptions a central concern in physics education.

Theoretically, misconceptions in mechanics can be understood through two complementary perspectives. The knowledge-in-pieces perspective views students' intuitions as collections of phenomenological primitives (p-prims), namely simple abstractions derived from everyday experience that are inappropriately generalized (diSessa, 1993). The ontological perspective explains that the most resistant misconceptions emerge when students assign a concept to an inappropriate ontological category (Chi, 2005). Both perspectives have implications for instruction: conceptual change requires students to experience dissatisfaction with their existing conceptions and to perceive the new conception as

intelligible, plausible, and fruitful (Posner et al., 1982). However, cognitive-conflict strategies, which are frequently used to generate such dissatisfaction, do not always succeed because students may fail to recognize the conflict or may respond to it only superficially (Limón, 2001).

Problem-Based Learning (PBL) is frequently proposed as an instructional strategy that is compatible with these requirements. In PBL, students learn through complex and authentic problems, work collaboratively, identify gaps in their knowledge, and reflect on their learning processes with teacher facilitation (Hmelo-Silver, 2004). Meta-analytic evidence concerning the effectiveness of PBL is not entirely consistent.Dochy et al. (2003)reported strong positive effects on skills but a tendency toward negative effects on knowledge. In contrast, the meta-synthesis by Strobel and van Barneveld (2009) indicated that PBL was advantageous for long-term retention and skills development, whereas conventional instruction was more advantageous for short-term knowledge outcomes. Debate has also concerned the degree of guidance required: Kirschner et al. (2006) argued that minimally guided instruction is ineffective for novices, whereas Hmelo-Silver et al. (2007) emphasized that well-designed PBL incorporates substantial scaffolding.Strobel dan van Barneveld (2009)Kirschner et al. (2006)Hmelo-Silver et al. (2007)

In Indonesia, research on mechanics misconceptions and the implementation of PBL is relatively extensive, but the evidence is dispersed across small-scale studies employing diverse instruments, ranging from three-tier and four-tier diagnostic tests to general concept-understanding tests (Rahayu & Hariyono, 2019;Silaban et al., 2024;Sutrisno, 2019;Ubaidilah, 2025). This instrument diversity is important because each diagnostic tool has particular strengths and limitations, meaning that results cannot be directly compared without careful consideration (Gurel et al., 2015). To the authors' knowledge, no previous synthesis has systematically connected the characteristics of misconceptions across mechanics subtopics with evidence concerning the effectiveness of PBL. There is also no synthesis assessing whether PBL studies in Indonesia actually measure misconceptions and retention, rather than merely general learning outcomes or conceptual understanding. This methodological gap is critical for determining the extent to which the claim that "PBL reduces misconceptions" can be empirically justified.

Based on these gaps, this review addresses two research questions (RQs). RQ1: What characteristics of students' misconceptions in the subtopics of kinematics and Newtonian dynamics have been reported in studies published from 2016 to 2026? RQ2: What evidence exists regarding the effectiveness of PBL in improving conceptual understanding and reducing misconceptions in classical mechanics, and to what extent do the designs and measurements of the reviewed studies support such claims? This review is expected to contribute empirically by mapping the available local evidence, methodologically by identifying measurement weaknesses that should be addressed, and practically by informing physics teachers' design of PBL for mechanics instruction. In addition, by distinguishing evidence of conceptual improvement from evidence of misconception reduction and retention, the review seeks to clarify what can and cannot currently be concluded from the Indonesian literature.

II. RESEARCH METHODS

This study employed a systematic literature review (SLR). Reporting of each stage, from identification through synthesis, followed the PRISMA 2020 guidelines (Page et al., 2021) to promote transparency and reproducibility through a PICOS-based protocol. The inclusion criteria were: (1) articles published between 2016 and 2026; (2) peer-reviewed journal articles, excluding books, book chapters, undergraduate or graduate theses, and conference proceedings; (3) articles written in Indonesian or English; (4) studies addressing misconceptions or the implementation of PBL in classical mechanics (kinematics and dynamics) at secondary or higher education levels; and (5) studies reporting

quantitative data on misconceptions, conceptual understanding, or conceptual retention. The exclusion criteria were: (1) interventions other than PBL, such as Project-Based Learning without a clearly identifiable PBL syntax; (2) topics outside classical mechanics; (3) inaccessible full texts; and (4) literature reviews. One PBL-based retention study on sound waves was retained only as supporting evidence and was excluded from the main synthesis.

The search was conducted through Google Scholar on July 12, 2026, with a publication-year range of 2016–2026 and the following search string: ("Problem-Based Learning" OR "PBL") AND ("miskonsepsi" OR "misconception") AND ("mekanika" OR "kinematika" OR "hukum Newton" OR "Newtonian dynamics" OR "kinematics"). An additional search using a similar string without PBL-related terms was conducted to identify diagnostic studies on misconceptions. Google Scholar has limitations as a primary source for systematic reviews, including limited reproducibility of its search results and restricted Boolean functionality (Gusenbauer & Haddaway, 2020). Therefore, supplementary searches were also conducted through the Scopus, ERIC, and Garuda websites. Study selection followed four stages consistent with the PRISMA 2020 flow: identification and removal of duplicates, title and abstract screening, full-text eligibility assessment, and determination of the studies to be included (Table 1). Screening was conducted by two reviewers who focused on article quality.

Table 1. Summary of the Study Selection Process Based on PRISMA 2020

PRISMA 2020 Stage	Number	Description
Records from Data base	21	Search date: July 3, 2026
Records removed before screening	6	Duplicate articles
Title and abstract screening	15	Seven excluded because they were outside of keywords
Full-text eligibility assessment	8	Two excluded because of weak paper quality
Studies included in the main synthesis	6	Misconception diagnostics: 3; PBL interventions: 3. One additional supporting study (PBL retention, non-mechanics)

Because the included studies employed quantitative designs (surveys, quasi-experiments, and instrument-development studies), methodological quality was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018, which provides separate criteria for qualitative, randomized quantitative, non-randomized quantitative, quantitative descriptive, and mixed-methods designs (Hong et al., 2018). The assessment focused on clarity of research design, sample representativeness, instrument validity and reliability, control of potential confounding variables, and completeness of statistical reporting. In addition to these criteria, particular attention was given to whether intervention studies used diagnostic measures capable of distinguishing misconceptions from incomplete or incorrect conceptual understanding.

Data were extracted using a standardized matrix containing study identification, mechanics subtopic, research design, sample, instrument, reported statistics, and the presence or absence of a delayed posttest. Qualitative data, such as the types and causes of misconceptions and learning mechanisms, were synthesized thematically through coding of findings, development of descriptive themes, and formulation of analytical themes (Thomas & Harden, 2008). Reported statistics were compared descriptively. A meta-analysis was not conducted because none of the intervention studies reported standardized effect sizes or sufficient standard-deviation information to calculate them. The synthesis therefore emphasized the direction, magnitude, and measurement basis of reported findings while explicitly distinguishing direct evidence from supporting or inferential evidence.

III. RESULTS AND DISCUSSION

Six studies were included in the main synthesis (Table 2), comprising three diagnostic studies of misconceptions (A1–A3) and three PBL intervention studies (B1–B3). One retention study (C1) was used as supporting evidence. All studies were conducted in Indonesia at the secondary-school level and

were published in national journals. Sample sizes ranged from several dozen to 100 students. The evidence base was therefore relatively narrow, and the synthesis was interpreted primarily as a mapping of reported patterns rather than as a pooled estimate of intervention effects.

Table 2. Characteristics and Main Findings of the Included Studies

No.	Study	Subtopic	Design & Sample	Instrument	Main Findings
A. Misconception diagnostic studies					
A1	Sutrisno (2019)	Kinematics of motion	Diagnostic survey (posttest only); 100 Grade X–XII senior high school students, Bandung	Three-tier test + interview	Conceptual understanding 49.6%; misconceptions 26.7%; causes: personal understanding and low interest in learning physics
A2	Rahayu & Hariyono (2019)	Free-fall motion (kinematics)	Descriptive, embedded mixed methods; 50 Grade X students, Bojonegoro	Four-tier diagnostic test	Misconceptions 40.67%; conceptual understanding 15.33%; partial understanding 26.67%; lack of understanding 16.67%; causes: low conceptual understanding and inappropriate teaching methods
A3	Silaban et al. (2024)	Newton's laws (dynamics)	Development study (Tessmer); field testing with Phase E senior high school students, Medan	Four-tier diagnostic test	Average misconceptions 61.10%; weight force 86.36% (mass–weight confusion); understanding of Newton's laws 62.98%; application 52.35%
B. PBL intervention studies					
B1	Rizqi et al. (2020)	Mechanics	Quasi-experimental pretest–posttest control group; 60 Grade XI students	Conceptual-understanding essay test (C1–C5)	PBL was more effective than lecture-based instruction in improving conceptual understanding
B2	Mayanti et al. (2022)	Newton's laws	Posttest-only control group; vocational high school students	Learning-outcome test	PBL combined with demonstrations and experiments influenced learning outcomes for Newton's laws
B3	Ubaidilah (2025)	Mechanics	Quasi-experimental; 60 Grade XI students	Conceptual-understanding test	Posttest 81.53 vs. 67.12 ($p = 0.001$); N-gain 0.67 (moderate) vs. 0.42
C. Supporting study (retention)					
C1	Hermanto et al. (2022)	Sound waves (not mechanics)	Non-randomized control group experiment;	Multiple-choice test	Knowledge retention in the GC-PBL group was better than in the conventional class

Characteristics of Misconceptions in Kinematics and Dynamics (RQ1)

The reviewed studies reported moderate levels of misconceptions in kinematics, accompanied by relatively low levels of complete conceptual understanding.Sutrisno (2019)found conceptual understanding of kinematics at 49.6% and misconceptions at 26.7%. For free-fall motion, Rahayu and Hariyono (2019) reported a misconception rate of 40.67%, while only 15.33% of students demonstrated complete conceptual understanding. This pattern is consistent with international literature showing that students experience difficulty distinguishing related kinematic quantities and connecting graphs with physical motion (McDermott et al., 1987). The belief that heavier objects fall faster is also one of the long-documented common-sense conceptions about motion (Halloun & Hestenes, 1985). From a knowledge-in-pieces perspective, this phenomenon can be understood as the inappropriate generalization of everyday experiences—for example, observing that paper falls more slowly than a stone because of air resistance—to contexts in which that explanation is not applicable (diSessa, 1993). However, this interpretation remains theoretical because the reviewed studies did not directly analyse

students' reasoning at that level.Rahayu dan Hariyono (2019)McDermott et al., 1987Halloun & Hestenes, 1985diSessa, 1993

Diagnostic studies of dynamics reported higher levels of misconceptions.Silaban et al. (2024)found an average misconception rate of 61.10%, with the highest rate occurring for the concept of weight force (86.36%), primarily associated with difficulty distinguishing mass from weight. Misconceptions in understanding Newton's laws reached 62.98%, while misconceptions in their application reached 52.35%. These findings are consistent with literature documenting the strength of the belief that motion requires force (Clement, 1982;Hestenes et al., 1992). Within Chi's (2005) framework, the persistence of misconceptions in dynamics may be explained by students' tendency to regard force as something possessed by an object rather than as an interaction between objects. This explanation is theoretically plausible, but it was not directly tested by the studies included in this review.Chi (2005)

The difference between the reported rates for kinematics (26.7–40.67%) and dynamics (61.10%) suggests a greater prevalence of misconceptions in dynamics and potentially greater conceptual resistance. This conclusion must nevertheless be interpreted cautiously because the three diagnostic studies used different instruments, numbers of items, and categorization criteria (three-tier versus four-tier tests), as well as non-equivalent samples (Gurel et al., 2015). Some studies also attributed misconceptions to instructional factors, including inappropriate teaching methods (Rahayu & Hariyono, 2019). These findings provide an important rationale for examining instructional strategies in RQ2. More importantly, the evidence indicates that misconception prevalence should not be interpreted independently of the diagnostic method used, because different instruments may classify uncertainty, partial understanding, and misconceptions differently.

Evidence of PBL Effectiveness (RQ2)

The three intervention studies showed a consistent direction of findings: PBL produced higher outcomes than conventional instruction.Rizqi et al. (2020)reported that PBL was more effective than lecture-based instruction in improving students' conceptual understanding of physics.Ubaidilah (2025)found a posttest score of 81.53 in the PBL group compared with 67.12 in the control group ($p = 0.001$), with N-gain values of 0.67 and 0.42, respectively. For Newton's laws,Mayanti et al. (2022)reported that PBL combined with demonstrations and experiments influenced students' learning outcomes. The difference in N-gain is directionally consistent with Hake's (1998) findings concerning the benefits of interactive learning in mechanics. Nevertheless, N-gain is not a standardized effect-size measure and cannot be directly compared with the results of meta-analyses.Hake (1998)

The strength of this evidence remains limited. None of the intervention studies used a diagnostic test specifically designed to identify misconceptions. The measured outcomes were conceptual understanding or general learning achievement; consequently, these findings cannot by themselves establish that PBL reduced misconceptions. No study reported a standardized effect size or conducted a delayed posttest on classical mechanics. In addition, two studies did not explicitly specify the mechanics subtopic taught, and one study employed a posttest-only design that did not control for baseline ability. Thus, the evidence supports an association between PBL and improved immediate learning outcomes, but it does not yet provide direct evidence of misconception change or long-term conceptual retention.

Table 3. Strength of Evidence from the PBL Intervention Studies

PBL Study	Control Group	Misconception Diagnostic Test	Standardized Effect Size	Delayed Posttest	Confirmed Mechanics Topic
Rizqi et al. (2020)	Yes	No	No	No	Yes
Mayanti et al. (2022)	Yes (posttest only)	No	No	No	Yes
Ubaidilah (2025)	Yes	No	No (N-gain)	No	Yes
Hermanto et al. (2022)	Yes	No	No	Yes (retention)	No

The theoretical advantages of PBL can be explained through its learning mechanisms: authentic problems and collaborative discussion provide students with opportunities to articulate and test their ideas (Hmelo-Silver, 2004). This process may create dissatisfaction with existing conceptions, as required by conceptual-change theory (Posner et al., 1982). However, cognitive conflict does not automatically produce conceptual change (Limón, 2001). The success of PBL may therefore depend substantially on the quality and timing of teacher scaffolding. This argument is supported by the meta-analysis of Lazonder and Harmsen (2016), which showed that guidance enhances activity, performance, and learning outcomes in inquiry-based learning, and is consistent with the response of Hmelo-Silver et al. (2007) to the critique presented by Kirschner et al. (2006). The findings of Mayanti et al. (2022), in which PBL was combined with demonstrations and experiments, can be interpreted as one form of such scaffolding.Lazonder dan Harmsen (2016)Hmelo-Silver et al. (2007)Kirschner et al. (2006)Mayanti et al. (2022)

Visual media may also strengthen PBL for abstract mechanics content. Computer simulations have been reported to enhance the effectiveness of science learning, particularly when used as a complement to laboratory activities (Rutten et al., 2012). PhET simulations are specifically designed to make otherwise invisible physics models interactively manipulable (Wieman et al., 2008). However, none of the studies in the present review met the inclusion criteria while specifically testing a PBL–simulation combination in mechanics; therefore, this potential remains a hypothesis requiring empirical examination.

The claim that PBL can produce learning that is retained over time has support at the meta-synthesis level (Strobel & van Barneveld, 2009). One local study also found better knowledge retention in the GC-PBL group, although the topic was sound waves rather than mechanics (Hermanto et al., 2022). For classical mechanics, local evidence concerning retention was not available in the present corpus. Accordingly, claims about the long-term durability of mechanics understanding produced through PBL still require studies incorporating delayed posttests.

Theoretically, this synthesis indicates that both the knowledge-in-pieces and ontological perspectives are relevant for interpreting evidence of mechanics misconceptions in Indonesia, yet neither perspective has been explicitly integrated into the design and evaluation of PBL interventions in the reviewed corpus. Methodologically, future PBL research should (1) employ tiered diagnostic tests or standardized instruments such as the FCI at pretest, posttest, and delayed-posttest stages (Hestenes et al., 1992;Gurel et al., 2015); (2) report means, standard deviations, and effect sizes; and (3) specify the mechanics subtopics and PBL syntax in sufficient detail. Practically, teachers are encouraged to implement scaffolded PBL that combines contextual problems, prediction–observation–explanation activities, demonstrations or simulations, and brief conceptual explanations at strategically appropriate points, particularly for concepts involving force, mass, and weight.

This review has several limitations. The search was conducted primarily through Google Scholar, with supplementary searches through Scopus, ERIC, and Garuda, but the number of eligible studies remained small. All included studies were published in national journals, and the absence of standardized effect sizes prevented a meta-analysis. The findings should therefore be regarded as indicative and should not be generalized beyond the contexts represented in the reviewed studies. In addition, variation in diagnostic instruments limits direct numerical comparison across studies. These limitations underscore the need for broader database coverage, more rigorous reporting, and stronger measurement designs in future reviews and primary studies.Gusenbauer & Haddaway, 2020

Synthesis and implications. Taken together, the reviewed evidence points to an important distinction between improving conceptual performance and demonstrating conceptual change. The diagnostic studies document substantial alternative conceptions in mechanics, particularly in Newtonian dynamics, whereas the intervention studies primarily demonstrate improved post-instruction

performance. This distinction matters because a student may obtain a correct posttest response without having reorganized the underlying conception that generated an earlier misconception. Accordingly, future PBL studies should treat misconception change as a specific outcome rather than assuming that higher achievement scores represent misconception reduction. A stronger evidence chain would combine a validated tiered diagnostic instrument, a clearly scaffolded PBL sequence, process-oriented evidence from students' explanations or arguments, and both immediate and delayed measurements. Such a design would allow researchers to determine not only whether students answer mechanics problems more successfully, but also whether their underlying reasoning has become more scientifically coherent and remains stable over time.

IV. CONCLUSION

This review addressed two research questions. For RQ1, misconceptions in kinematics were reported at rates ranging from 26.7% to 40.67% and were associated with difficulties in distinguishing motion-related quantities and with intuitive beliefs about free-fall motion. Misconceptions in Newtonian dynamics were reported at a higher level, with an average rate of 61.10% and a peak of 86.36% for the concept of weight force, largely associated with confusion between mass and weight. These differences require confirmation using comparable diagnostic instruments. For RQ2, intervention studies consistently indicated that PBL produced higher conceptual-understanding or learning-achievement outcomes than conventional instruction. However, the evidence remains insufficient to conclude that PBL reduces misconceptions or produces long-term retention in classical mechanics because none of the reviewed intervention studies used misconception-specific diagnostic tests, reported standardized effect sizes, or conducted delayed posttests. Future research should examine scaffolded PBL using more rigorous designs and explicit misconception measures, while teachers may consider integrating demonstrations, experiments, or simulations as supporting components within PBL. More broadly, the evidence suggests that future intervention studies should distinguish immediate conceptual gains from genuine conceptual change by measuring students' alternative conceptions before, immediately after, and after a meaningful retention interval.

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