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A Systematic Review of Misconceptions in Particle Dynamics: Identification, Causes, and Remediation

Muhammad Faldi Maliqi[1], Emiliannur[1]*, Festiyed[1], Hayyu Yumna[1]

[1] *Department of Physics, Universitas Negeri Padang, Jl. Prof. Dr. Hamka Air Tawar Padang 25131, Indonesia*
Corresponding author. Email:emiliannur@fmipa.unp.ac.id

ABSTRACT

Particle dynamics is a foundational branch of physics, yet students frequently struggle with abstract concepts, leading to persistent misconceptions that hinder scientific reasoning. This study aims to analyze the specific concepts prone to misconceptions in particle dynamics, identify their primary causes, and evaluate the effectiveness of various remediation strategies to improve conceptual understanding. This research employed a descriptive quantitative design using the Systematic Review method following the PRISMA 2020 guidelines. A total of 20 scientific articles published between 2020 and 2025, indexed in national and international databases, were analyzed. The study integrated a bibliometric approach using VOSviewer software to visualize research trends and keyword networks, ensuring a robust and objective synthesis of the current literature. The findings indicate that misconceptions are most prevalent in Newton's Laws (45%), followed by the Law of Conservation of Momentum (35%), and force and net force (30%). The primary cause of these errors is students' internal prior conceptions (65%), often derived from intuitive daily experiences that conflict with scientific principles. Effective remediation strategies identified include active learning models such as guided inquiry, generative learning, and cognitive conflict approaches. Furthermore, the integration of interactive simulations like PhET and E-LKPD significantly enhanced the remediation process by providing essential visual scaffolding. Misconceptions in particle dynamics remain a major challenge, predominantly rooted in intuitive reasoning regarding force and motion. Successful remediation requires pedagogical shifts toward active student involvement and the use of technology-based visualizations to facilitate conceptual change. These results provide a vital scientific reference for educators to design targeted interventions and for curriculum developers to address conceptual gaps early in physics education.

Keywords: Misconception, Particle Dynamics, Newton's Laws, Systematic Review, VOSviewer, PRISMA.

I. INTRODUCTION

Conceptual mastery is recognized as the primary benchmark for success in physics education, as it facilitates the development of higher-order scientific, logical, and critical thinking skills. Physics requires students to move beyond surface-level observations to understand natural phenomena through a rigorous framework of systematic principles. However, the educational landscape frequently encounters a persistent obstacle: misconceptions. These are conceptual misunderstandings that diverge significantly from established scientific consensus [36]. Unlike simple errors, misconceptions are deeply embedded in a student's cognitive structure because they are often derived from intuitive experiences. Such frameworks are notoriously resistant to change, meaning they can rarely be eliminated through traditional instruction alone. When students carry these "alternate frameworks" into problem-solving, they struggle to apply scientific laws correctly, leading to a fragmented understanding of physical reality.

Within the broader field of mechanics, particle dynamics serves as a cornerstone, bridging the gap between kinematics and the more complex study of energy and momentum. It focuses on the fundamental relationship between force, mass, and motion, primarily through the lens of Newton's Laws. Despite its foundational importance in engineering and modern technological applications, particle dynamics remains one of the most abstract and difficult topics for students. Empirical evidence suggests that this difficulty is rooted in deep-seated misunderstandings of basic concepts such as net force, acceleration, and the physical meaning of momentum [15]. These misconceptions manifest in specific, predictable patterns: students often assume that an object's motion implies the existence of a continuous force in the same direction, or they conflate the concepts of "action-reaction" by assuming both forces act on a single body. Furthermore, many students rely on an "impetus theory" of motion, viewing force as something "consumed" by an object rather than a cause of acceleration as defined by Newton's Second Law.

The literature emphasizes that these misconceptions do not emerge in isolation but result from a complex interplay of internal and external factors. Primary internal triggers include prior conceptions and associative thinking, where students incorrectly map everyday linguistic terms such as "force" or "energy" onto scientific contexts. This internal confusion is often solidified by external instructional factors. Currently, many physics classrooms still rely on transmissive, lecture-based models that prioritize the memorization of mathematical algorithms over conceptual visualization. Such methods fail to create the "cognitive conflict" necessary for conceptual change. Additionally, the use of textbooks containing ambiguous diagrams and the lack of hands-on experimental verification contribute to students' inability to reconcile scientific laws with reality. Consequently, physics is perceived as an inaccessible subject, leading to decreased learning motivation and consistently low academic achievement in mechanics.

To address these systemic issues, the remediation of misconceptions has become a primary focus in physics education research. Effective remediation involves pedagogical interventions designed to create cognitive disequilibrium, forcing students to recognize the limitations of their existing frameworks and adopt scientifically valid ones. Previous research has explored various remediation pathways across different physics domains. For instance, systematic reviews have analyzed misconceptions in kinematics [32], temperature and heat [31], and static fluids [3], suggesting that generative learning models, virtual laboratories, and inquiry-based approaches are highly effective in fostering conceptual change. Furthermore, generalized reviews in science education highlight that physics suffers from the highest rates of misconceptions compared to other sciences, largely due to the persistence of traditional instruction [9].

Despite these significant contributions, a critical research gap persists. While there is a wealth of individual studies and reviews focusing on various sub-topics of mechanics, there is a lack of a comprehensive, recent systematic review that specifically integrates the findings on particle dynamics from the last five years (2020–2025). The current body of research remains fragmented across different educational settings and geographical contexts. There is an urgent need to synthesize these scattered empirical data to compare the prevalence of specific misconceptions and to determine which modern remediation strategies yield the highest impact specifically for Newton's Laws and related concepts.

Addressing this gap, the present study introduces a novel methodological framework by integrating the PRISMA 2020 guidelines with advanced bibliometric analysis using VOSviewer software. The use of PRISMA 2020 ensures that the literature selection process is objective, transparent, and reproducible, minimizing the bias often found in traditional reviews. By incorporating VOSviewer, this study moves beyond qualitative synthesis to provide a multi-dimensional visualization of the research landscape. This includes mapping network clusters to identify shifting topic trends and utilizing overlay maps to trace the evolution of remediation interventions. Consequently, this study aims to: (1) identify the specific conceptual sources of misconceptions in particle dynamics; (2) analyze the primary causal factors driving these misunderstandings; and (3) synthesize the pedagogical methods and digital tools that have proven most effective as remediation solutions. Through this synthesis, the research provides a robust state-of-the-art reference for educators and curriculum developers to design more targeted and scientifically grounded physics instruction.

II. METHOD

This study employed a descriptive research design with a quantitative approach, specifically utilizing the Systematic Literature Review (SLR) method. This approach was selected to systematically identify, critically evaluate, and synthesize findings from existing research to provide a comprehensive overview of misconceptions in particle dynamics [11]. By integrating data from multiple empirical studies, this research ensures that the final conclusions regarding misconception patterns and remediation effectiveness are robust and evidence-based. The data collection followed the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, ensuring a transparent and reproducible four-stage process: identification, screening, eligibility, and inclusion [24]. Literature was sourced from reputable digital databases, including Google Scholar, Scopus, and Web of Science. The search was conducted using a combination of specific keywords and Boolean operators to optimize retrieval relevance: ("misconception" OR "conceptual error") AND ("particle dynamics" OR "Newton's laws") AND ("remediation" OR "conceptual change").

The selection of articles was performed purposively based on strict inclusion and exclusion criteria. Inclusion criteria required that articles: (1) focused on particle dynamics misconceptions at the secondary education level; (2) were published in reputable national or international journals; and (3) were issued within the last five years (2020–2025). Articles were excluded if they: (1) fell outside the domain of particle dynamics (e.g., thermodynamics or optics); (2) were published prior to 2020; or (3) consisted of gray literature such as non-peer-reviewed conference abstracts or popular articles. Following this rigorous filtration process, a final set of 20 high-quality articles was selected for analysis. The primary research instrument was a structured data extraction sheet designed to categorize four main dimensions: misconception topics, forms of conceptual errors, causal factors, and remediation outcomes. The extracted data were analyzed using descriptive statistical techniques to calculate the frequency and percentage of occurrence for each category [1]. The percentage was determined using the following formula:

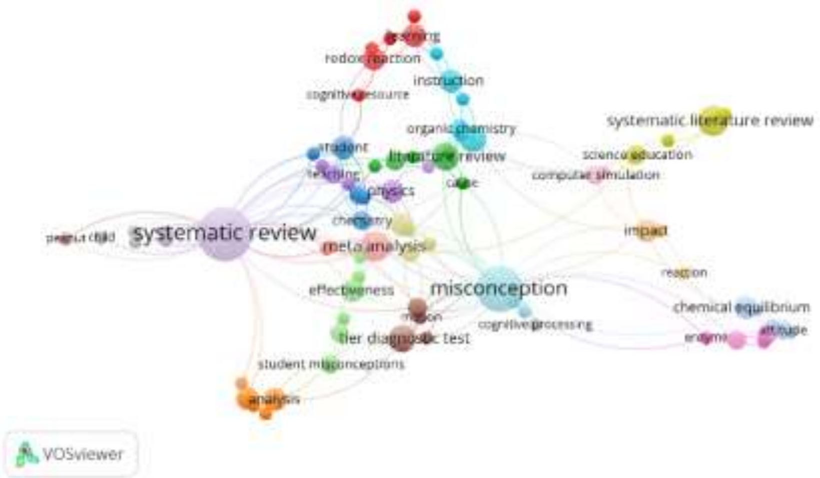
$$p = \frac{f}{N} \chi 100\%$$

Description:
p: percentage value
f: frequency being sought (the number of articles from each category in the table)
N: total frequency (the total number of articles used in each table)

To complement the descriptive synthesis, this study integrated bibliometric analysis using VOSviewer. This software was employed to construct and visualize network maps based on keyword co-occurrence and thematic clusters. Specifically, network visualization was used to map the interconnectedness of research topics, while density visualization helped identify saturated research areas versus unexplored "gaps" within the physics misconception domain. The combination of qualitative content synthesis and quantitative bibliometric mapping provides a multidimensional landscape of current trends in particle dynamics research.

III. RESULTS AND DISCUSSION

This systematic review analyzed 20 scientific articles published in national and internationally indexed journals between 2020 and 2025. Data synthesis focused on three main dimensions: the identification of concepts vulnerable to misconceptions, the tracing of triggering determinant factors, and the effectiveness of remediation interventions on particle dynamics material. To understand the global research landscape regarding misconceptions in science education, a bibliometric network analysis was conducted using VOSviewer. The



visualizations (Network, Overlay, and Density) reveal the intellectual structure and emerging trends in this field.

Fig. 1. Network Visualization

The network visualization illustrates the clustering and relationship between keywords. The nodes representing "systematic review" and "misconception" emerge as the largest, indicating their central role in recent literature. A strong linkage is observed between "misconception" and terms like "science education," "learning," and "cognitive processing." Analytically, this strong interconnectedness reflects a paradigm shift in science education research: scholars are no longer merely identifying errors, but are deeply investigating the underlying cognitive mechanisms. The prominent presence of "tier diagnostic test" in the network signifies a methodological maturation within the field. Researchers are increasingly relying on sophisticated, multi-tier psychometric instruments to differentiate between genuine misconceptions and a mere lack of knowledge, aligning with Treagust's foundational theories on diagnostic assessment.

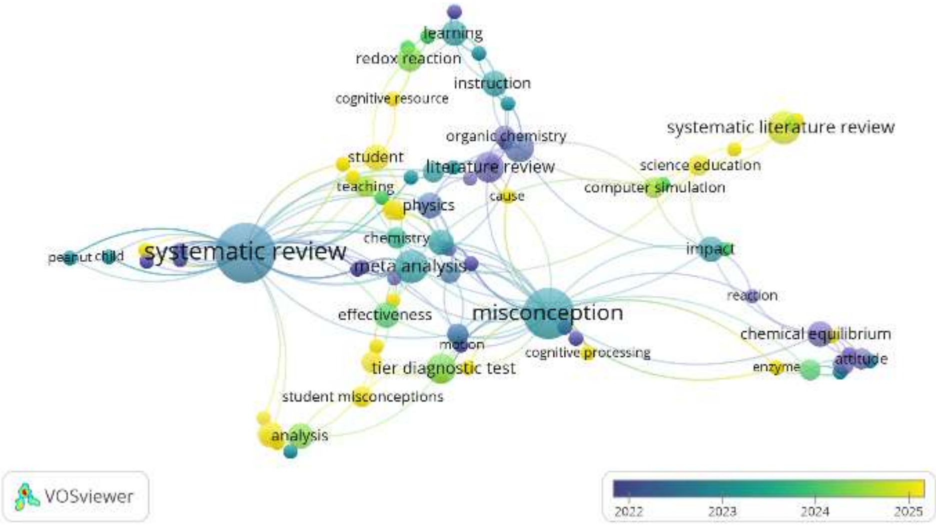


Fig. 2. Overlay Visualization

The overlay visualization, which maps keyword occurrences over time, indicates a clear evolutionary trajectory in educational research. Earlier studies predominantly focused on broad keyword clusters like "analysis" and "student misconceptions" (identifying the problem). However, more recent nodes indicate a pivot towards technological interventions, highlighted by terms such as "computer simulation." This temporal shift reflects the integration of the TPACK (Technological Pedagogical Content Knowledge) framework in physics education. As distance learning and digital pedagogy expanded between 2020 and 2025, researchers transitioned from traditional classroom identification to exploring how digital environments can disrupt deep-rooted cognitive biases.

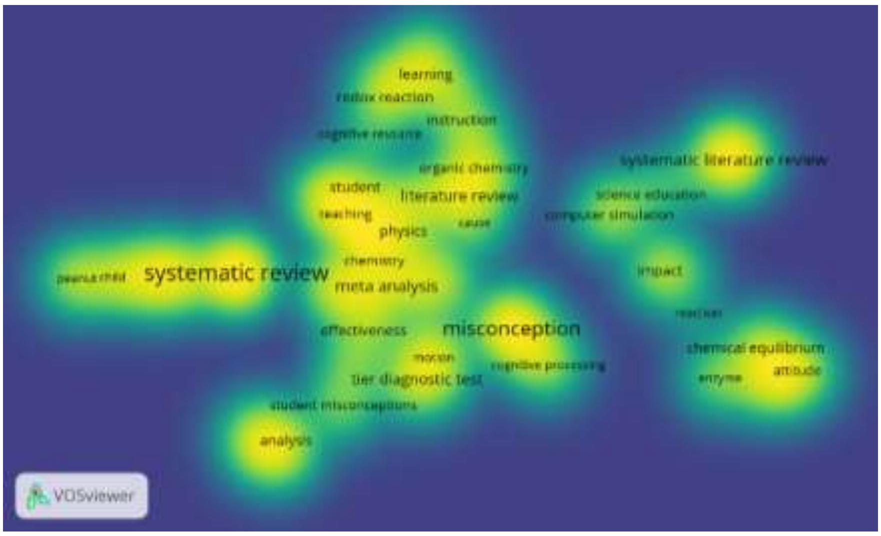


Fig. 3. Density Visualization

The density visualization highlights the concentration of research focus. Areas colored yellow (high density) around "misconception" and "systematic review" represent saturated, well-established domains. Conversely, topics such as "computer simulation" and "instructional effectiveness" reside in the green-to-blue (lower density) zones. Theoretically, these lower-density areas represent the "frontier" of particle dynamics research. While the existence of misconceptions is well-documented, empirical studies validating the long-term effectiveness of specific digital remediation strategies remain an emerging, fertile ground for future investigation.

Table 1. Article Findings in 2020-2025

Year	Article Code	Amount	Percentage (%)
2020	A07, A10, A13	3	15%
2021	A06, A08, A09, A17, A18	5	25%
2022	A03, A20	2	10%
2023	A04, A14, A15	3	15%
2024	A01, A05, A12, A19	4	20%
2025	A02, A11, A16	3	15%

Based on literature data extraction, students' misconceptions were distributed across seven fundamental topics in particle dynamics. Data trends showed that misconceptions predominantly centered on Newton's Laws concepts (45%), followed by applications of particle dynamics (35%), and the concepts of force and net force (30%). The high prevalence of errors regarding Newton's Laws indicated that the students' conceptual foundation of basic mechanics had not been optimally developed. As fundamental concepts, erroneous understanding of Newton's Laws has a hierarchical impact on students' ability to analyze advanced motion phenomena scientifically. These findings corroborated previous literature asserting that abstract physics materials were highly susceptible to conceptual errors [32].

Table 2. Misconceptions, Causes, and Remediation on the Topic of Particle Dynamics

Topics	Article Code	Literature	Persentage (%)
Newton's First, Second, and Third Laws	A2	(Menchón et al., 2025)	45%
	A5	(Barniol et al., 2024)	
	A11	(Taibu & Mataka, 2025)	
	A17	(Gumay, 2021)	
	A19	(Paramita & Jauhariyah, 2024)	
	A4	(Wancham et al., 2023)	
	A8	(Rahayu et al., 2021)	
	A9	(BaniSalameh, 2021)	
	A12	(Sarkim, 2024)	
Force and Resultant Force	A6	(Leta et al., 2021)	30%
	A11	(Taibu & Mataka, 2025)	
	A1	(Pozuelo-Muñoz et al., 2024)	
	A4	(Wancham et al., 2023)	
	A8	(Rahayu et al., 2021)	
	A9	(BaniSalameh, 2021)	
Applications of Particle Dynamics	A6	(Leta et al., 2021)	15%
	A11	(Taibu & Mataka, 2025)	
	A3	(Ceuppens et al., 2022)	
	A7	(Wibowo & Sunarti, 2020)	
	A10	(Nasir, 2020)	
	A12	(Sarkim, 2024)	
	A16	(Rahmadani, 2025)	
Friction	A5	(Barniol et al., 2024)	15%
	A20	(Jannah et al., 2022)	
	A4	(Wancham et al., 2023)	
Circular Motion	A15	(Admoko & Suliyanah, 2023)	15%
	A20	(Jannah et al., 2022)	
	A18	(Daud et al., 2021)	
Momentum and Impulse	A13	(Putri et al., 2020)	15%

	A14	(Rahmadani et al., 2023)	
	A20	(Jannah et al., 2022)	
Law of Conservation of Momentum	A13	(Putri et al., 2020)	35%
	A14	(Rahmadani et al., 2023)	
	A20	(Jannah et al., 2022)	

The data reveals that Newton's Laws of Motion is the most widely reported area of difficulty, featured in 45% of the reviewed literature. From an analytical perspective, this high prevalence is strongly supported by the theory of Naive Physics or Aristotelian Thinking. Students navigate their daily lives experiencing friction and air resistance, leading to the intuitive—but scientifically incorrect—belief that a continuous force is required to maintain constant motion (the "impetus theory"). When taught Newton's First Law (Inertia), students experience severe cognitive dissonance because the formal Newtonian construct directly contradicts their lifelong experiential observations. Similarly, the Law of Conservation of Momentum (35%) poses significant challenges. The literature indicates that misconceptions here stem from an ontological miscategorization (as theorized by Michelene Chi). Students frequently treat momentum as a scalar "substance" rather than a vector quantity. They struggle to comprehend that momentum can be conserved in a system even when the velocities and masses of individual colliding objects change drastically, often confusing momentum with kinetic energy in inelastic collisions. [36].

Table 3. The Use of Causes in Percentage Misconceptions

Causes	Number of Articles	Percentage
Students	13	65%
Teachers	2	10%
Textbooks	2	10%
Teaching Methods	3	15%

Identifying the root cause of an educational problem is a prerequisite for effective remediation. The reviewed literature attributes the origins of misconceptions in particle dynamics to several factors, with internal cognitive factors being the most dominant. Out of the 20 articles, 13 articles (65%) explicitly cite students' internal prior conceptions as the primary cause of misconceptions. According to Constructivist learning theory (Piaget and Vygotsky), students do not enter the classroom as "blank slates" (tabula rasa). They bring pre-instructional conceptual frameworks built from everyday experiences. When new, formal physics concepts are introduced, students often do not replace their old beliefs; instead, they assimilate the new information into their flawed existing frameworks, creating "synthetic models" (Vosniadou's Conceptual Change framework). Other contributing causes identified in the review include flawed textbook representations, inadequate instructional language (where everyday terms like "force" or "weight" clash with strict physics definitions), and passive teacher-centered learning environments that fail to challenge students' pre-existing beliefs.

Table 4. The Use of Learning Models in Remediation Strategy and Conceptual Change

Method/Strategy/Model	**Code**	**Remediation Results**
Generative Model	A1	Significantly reduced misconceptions regarding force and Newton's laws.
Guided Inquiry	A2	Reduced students' misconceptions on the concepts of force and net force.
STAD	A3	Effectively reduced particle dynamics misconceptions through group discussions.
Demonstration	A4	Helped students understand the relationship between force and acceleration.
Wondering–Exploring–Explaining	A5	Improved conceptual understanding of Newton's laws.
Inquiry	A7	Reduced misconceptions regarding friction force concepts.
Problem Posing	A8	Improved understanding of force concepts and applications.
Delay Feedback	A9	Gradually reduced students' misconceptions.

Project-Based Learning	A10	Reduced misconceptions regarding force concepts.
Generative Model	A11	Effectively remediated Newton's laws misconceptions.
Demonstration + Guided Note	A12	Reduced misconceptions regarding force and acceleration.
Interactive Demonstration	A13	Effectively overcame force misconceptions.
Blended Learning	A14	Moderately reduced misconceptions.
Cognitive Conflict	A16	Significantly reduced force misconceptions.
E-LKPD Guided Inquiry	A17	Helped students understand force and motion.
Learning Model	A18	Reduced particle dynamics misconceptions.
Inquiry Learning	A19	Corrected momentum and force misconceptions.
Discovery Learning	A20	Improved conceptual understanding of force.

This review identified the effectiveness of various instructional approaches in facilitating the remediation of misconceptions. Approaches that prioritized active student involvement, such as the Generative Model, Guided Inquiry, and Project-Based Learning, demonstrated a high success rate. The generative model was consistently able to guide students in reorganizing their knowledge structures through the integration of new scientific facts [32], while guided inquiry stimulated concept discovery through authentic experimentation. Mechanistically, the success of remediation depended on the creation of cognitive conflict a condition where students were confronted with physics phenomena that contradicted their preconceptions, thereby encouraging the accommodation process and conceptual change. This process proved to be accelerated through the integration of technology, such as the use of Physics Education Technology (PhET) and electronic student worksheets (E-LKPD). Interactive simulations provided essential visual scaffolding, allowing students to manipulate abstract variables (force, mass, acceleration) in real-time, thereby transforming their conceptual mechanics understanding from an intuitive level to an analytical and comprehensive one.

Table 5. The Use of Learning Approach in Remediation Misconceptions

Learning Approach	**Code**	**Remediation Results**
Physics Education Technology (PhET)	A6	The use of Physics Education Technology (PhET) media was able to help students visualize the relationship between force, mass, and acceleration interactively, so that students' misconceptions regarding particle dynamics concepts, especially in Newton's laws and friction, could be significantly reduced.
Guided Inquiry Electronic Worksheet (E-LKPD)	A17	The utilization of guided inquiry-based electronic worksheets encouraged students to actively investigate particle dynamics concepts, thereby being capable of reducing misconceptions regarding Newton's laws and their applications in daily life.
Kokami Game Media	A15	Kokami game media was able to increase student involvement in particle dynamics learning, so that conceptual understanding increased and students' misconceptions could be reduced.
Interactive Simulations	A13	The use of interactive simulations provided visual and contextual learning experiences for students, so that misconceptions regarding circular motion concepts in the study of particle dynamics could be reduced.
Project-Based Media	A10	Project-based learning media provided opportunities for students to apply particle dynamics concepts practically, so that conceptual understanding increased and misconceptions could be minimized.

The final objective of this review is to evaluate remediation strategies. In alignment with the VOSviewer findings (which highlighted "computer simulations"), the systematic review shows that traditional didactic teaching is insufficient for conceptual change. Successful remediation, as reported in the contemporary literature, fundamentally relies on Cognitive Conflict Strategies. Based on Posner's Theory of Conceptual Change, for a student to abandon a misconception, they must first experience dissatisfaction with their current belief. Interventions utilizing PhET simulations or interactive physics demonstrations proved highly effective because they visually and instantly confront students with phenomena that their "naive physics" cannot explain. Once dissatisfaction is achieved, the new Newtonian concept presented must be intelligible, plausible, and fruitful to ensure a permanent cognitive shift.

IV. CONCLUSION

This systematic review and bibliometric analysis conclude that misconceptions in particle dynamics remain deeply entrenched and systematically patterned. The findings specify that student difficulties are highly concentrated in Newton's Laws of Motion (45%) and the Law of Conservation of Momentum (35%). Supported by VOSviewer network mapping, the analysis reveals that these errors are not primarily caused by instructional deficits, but rather by students' robust, internally formed prior conceptions (65%) rooted in daily experiential "naive physics." Consequently, the remediation of these misconceptions requires a departure from traditional didactic teaching towards active cognitive conflict strategies, particularly those leveraging technology such as computer simulations, to effectively dismantle and reconstruct students' cognitive frameworks.

The findings of this review carry critical implications for physics curriculum development. Curricula can no longer treat students as "blank slates." Instead, curriculum developers must formally integrate multi-tier diagnostic instruments into foundational lesson plans to identify students' ontological miscategorizations prior to formal instruction. Furthermore, pedagogical frameworks should explicitly mandate the incorporation of technology-integrated interventions (such as PhET simulations) into the standard syllabus. This shift ensures that curricula are designed not merely for knowledge transmission, but for active conceptual change by systematically inducing cognitive dissonance.

Despite the rigor of the systematic approach using PRISMA guidelines, this study acknowledges several limitations. First, the analysis is constrained by a specific sample size of 20 highly relevant articles published within a narrow timeframe (2020–2025). While this ensures the recency of the pedagogical trends, it may not capture the full historical breadth of intervention strategies. Secondly, the bibliometric visualization was inherently limited by the specific search strings and the selected databases, which may have inadvertently excluded relevant literature published in non-indexed regional journals or related interdisciplinary fields such as cognitive psychology.

To address these limitations and advance the field of science education, future research should proceed in two main directions. First, future bibliometric studies should be expanded by utilizing multi-database extractions (e.g., merging Scopus, Web of Science, and Dimensions) over a broader temporal span to map macro-trends and global collaborations more comprehensively. Second, there is a critical need for rigorous meta-analysis studies. Future researchers should quantitatively calculate and compare the pooled effect sizes of various remediation strategies (e.g., virtual laboratories versus traditional conceptual change texts). A meta-analysis will provide definitive, statistically backed guidelines on the most efficacious interventions for permanently eradicating misconceptions in physics.

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