

Transforming physics misconceptions into conceptual understanding: A narrative review of conceptual change theory, diagnostic assessment, and classroom-based instructional strategies

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Abstract. Persistent misconceptions in physics can impede students' conceptual understanding, contributing to fragmented knowledge, lower academic achievement, and reduced engagement in STEM disciplines. This narrative review synthesises conceptual change theory, diagnostic assessment approaches, and classroom-based instructional strategies for addressing misconceptions in physics education. Drawing on the literature on mechanics and electricity, the review discusses misconception-centred approaches, including cognitive-conflict tasks, refutational texts, Peer Instruction, Tutorials in Introductory Physics, interactive PhET simulations, and formative feedback. The reviewed literature points to several conditions that may support conceptual change, including deliberate instructional sequencing, the use of multiple representations, structured peer collaboration, and continuous formative feedback. The review also examines implementation challenges, including teacher expertise, time constraints, resource disparities, and technology integration, and considers context-sensitive approaches for diverse educational settings. Based on the narrative nature of the review, the synthesis is intended to provide context-dependent insights rather than a comprehensive or universally generalisable account of misconception-centred instruction. The review offers practical considerations for educators seeking to support the transformation of students' intuitive ideas into more coherent scientific understanding.

Keywords: misconceptions, conceptual change, physics education, diagnostic assessment, active learning

1. Introduction

Learning difficulties in physics education remain a persistent and widely documented challenge [19], largely due to students' deeply ingrained misconceptions about abstract scientific concepts. These misconceptions, defined as coherent yet scientifically inaccurate mental models constructed from prior knowledge and intuitive reasoning, pose significant cognitive barriers to meaningful engagement with physics content [1, 27]. Across core domains such as mechanics and electricity, students frequently develop alternative conceptions that conflict with established scientific explanations. Evidence from large-scale assessments, particularly the Force Concept Inventory (FCI), consistently shows that even after conventional instruction, many learners fail to internalise fundamental Newtonian principles [13, 15]. In the domain of electricity, persistent alternative models, such as the “attenuation” model, where current is believed to diminish as it flows, and the “constant-source current” model, where a battery is assumed to supply a fixed current regardless of circuit configuration, continue to resist traditional lecture-based instruction [9, 10].

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Addressing these misconceptions is critical because their persistence contributes to fragmented conceptual understanding, poor academic achievement, and reduced motivation to pursue science, technology, engineering, and mathematics (STEM) disciplines. Traditional instructional approaches, which often emphasise passive content delivery, are insufficient for promoting conceptual change, as they fail to actively engage with students' pre-existing ideas [8, 40]. It is important to know that there is increasing consensus in physics education research that effective teaching must move beyond transmission-based models toward misconception-centred approaches that prioritise the diagnosis, confrontation, and restructuring of students' alternative conceptions through active learning and targeted interventions [20].

Misconceptions are not uniformly distributed but vary across contextual and demographic factors, including school type, access to instructional resources, and learners' prior experiences. Students in under-resourced educational settings, for instance, often exhibit a higher prevalence of misconceptions due to limited exposure to laboratory activities and high-quality instructional materials [2, 8, 32]. Additionally, gender-related differences have been observed in certain domains such as electricity and circuits, where sociocultural influences and disparities in early exposure to technical experiences may shape conceptual development [34; 3]. These variations underscore the need for differentiated and context-sensitive instructional approaches.

The theoretical foundation for addressing misconceptions is rooted in conceptual change theory, which posits that meaningful learning requires restructuring existing cognitive frameworks rather than merely accumulating new information. According to the seminal model proposed by Posner et al. [26], conceptual change occurs when learners experience dissatisfaction with their existing conceptions and find alternative explanations to be intelligible, plausible, and fruitful. Subsequent refinements of this framework have further emphasised the role of cognitive conflict, metacognition, and instructional scaffolding in facilitating conceptual transformation [30].

Beyond cognitive implications, the persistence of misconceptions also carries significant affective and structural consequences. When physics is perceived as a collection of disconnected formulas or problem-solving tricks rather than a coherent system of ideas, students' motivation, confidence, and persistence decline [42]. This challenge is particularly pronounced in contexts where access to practical resources and inquiry-based learning opportunities is limited, such as in many developing educational systems. Empirical studies conducted in such contexts, including parts of sub-Saharan Africa, have reported elevated levels of misconceptions, reinforcing the need for cost-effective diagnostic tools, collaborative learning strategies, and adaptable instructional technologies [13].

Despite the extensive body of research on misconceptions and conceptual change, there remains a need for integrative syntheses that connect theoretical frameworks, diagnostic approaches, and classroom-validated instructional strategies into a coherent model for practice. Many existing studies focus on isolated interventions or specific content areas, with limited attention to how these elements can be systematically combined to support sustained conceptual development across diverse learning environments. This study provides a narrative synthesis of conceptual change theory, diagnostic assessment tools, and evidence-based instructional strategies to address misconceptions in physics.

1.1. Objectives of the study

The main objective of the study is to synthesise theory and classroom evidence on misconception-centred physics instruction and to provide practical, equitable guidance that helps teachers transform robust everyday ideas into durable scientific understanding. Specifically, the study focused on the following objectives:

- (i) Consolidate and compare major conceptual-change perspectives to explain why particular misconceptions persist, and to derive design principles for instruction.
- (ii) Synthesise classroom-validated approaches, refutational texts, cognitive-conflict tasks, Peer Instruction, Tutorials in Introductory Physics, and PhET simulations, and specify conditions of

effectiveness (sequencing, prompts, representations, peer roles, formative feedback loops) that lead to conceptual change.

- (iii) Review, map, and exemplify diagnostic instruments that reliably distinguish gaps from misconceptions across topics (mechanics and DC circuits), including two-/three-/four-tier tests, FCI, and CRI, and guide when and how to deploy each in under-resourced and well-resourced contexts.

2. Theoretical foundations

2.1. Conceptual change theory in physics education

Conceptual change theory provides a foundation for understanding how students' deeply held misconceptions in physics can be reorganised into scientifically accurate knowledge structures. Rooted in the cognitive development theories of Piaget and later expanded by Ausubel, this framework emphasises that learning involves restructuring existing mental models rather than simply accumulating new information [5, 25]. In physics education, this perspective is particularly important because students often bring a wide range of preconceptions to the classroom, formed through intuitive reasoning and real-world experiences. These preconceptions tend to be coherent and contextually sensible for the learner, making them resistant to change and difficult to override through traditional instruction.

A central feature of conceptual change theory is the role of cognitive conflict. For meaningful learning to occur, students must experience a sense of dissonance between their existing beliefs and new, scientifically accurate information. This state of “conceptual disequilibrium” compels students to question their prior assumptions and consider alternative explanations [23]. However, this process cannot be triggered effectively through passive instruction alone. Simply delivering correct content does little to disrupt well-established intuitive frameworks. Instruction must instead actively surface these preconceptions and engage students in comparing them with physical evidence or formal models. Misconceptions, when viewed through this lens, are not mere errors or gaps in understanding. Rather, they often result from students applying internally consistent but scientifically inappropriate reasoning strategies. For instance, the belief that a constant force is required to maintain motion stems from repeated real-world experiences in which friction is present, despite contradicting Newton's First Law. Similarly, the idea that electric current is “used up” in a circuit reflects a familiar logic of flow and consumption, which, although intuitive, misrepresents how current actually behaves [9, 10]. Because these ideas are grounded in everyday contexts and analogies, they persist even after instruction and often coexist with scientifically correct responses, depending on the situation [40].

Active learning strategies are especially effective in promoting conceptual change because they create conditions for students to confront the limitations of their existing reasoning. Peer discussions, guided inquiry, and hands-on experiments help learners express and evaluate their mental models in light of new evidence. In particular, research-based physics tutorials have been shown to facilitate conceptual shifts by prompting students to explain phenomena, test predictions, and resolve contradictions collaboratively. This kind of engagement not only stimulates cognitive conflict but also supports the development of more robust conceptual frameworks through sustained reflection and feedback. Recognising the intuitive roots of student thinking encourages a more empathetic and effective instructional response, one that goes beyond merely replacing misconceptions with correct information. Conceptual change theory underscores the importance of teaching strategies that engage with students' intuitive reasoning rather than dismissing it. By transforming intuitive ideas into scientifically consistent understanding through active, reflective, and student-centred instruction, educators can foster lasting conceptual growth.

2.2. Understanding student thinking in physics: misconceptions and intuitive reasoning

Misconceptions in physics are persistent, incorrect understandings of scientific concepts that differ from accepted explanations. They are not simply random errors or gaps in knowledge, but often

emerge from students' efforts to interpret unfamiliar content using their intuitive reasoning and everyday experiences [9, 40]. In this sense, misconceptions can be seen as logical within the learner's frame of reference – they represent mental models that, while scientifically inaccurate, are constructed from patterns that seem reasonable based on the student's prior observations. For instance, students frequently hold the belief that electric current is “used up” as it moves through a circuit (the attenuation model), or that a battery delivers a constant current regardless of the circuit configuration (the constant-current source model) [10, 40]. These ideas are typically rooted in analogies drawn from daily life, such as comparing electric current to water flowing through pipes. While such analogies help students relate to abstract concepts, they often oversimplify the underlying principles, leading to stable yet flawed mental models that persist even after instruction. A similar pattern is observed in mechanics, where many students believe that a continuous force is required to keep an object in motion.

This belief aligns with everyday experiences involving friction, where objects eventually stop unless pushed. Though it contradicts Newton's First Law, it reflects a commonsense view that motion naturally fades without sustained effort. In the domain of energy, students often conflate concepts such as energy, work, and power, or assume that energy is lost rather than transformed. These misconceptions, again, are attempts to apply intuitive reasoning to complex systems in ways that make sense experientially, but not scientifically. Such intuitive models are not only persistent but often coexist with scientifically correct ideas. A student may correctly use Ohm's Law to calculate current but still believe that bulbs further from a battery are dimmer because “the current gets weaker with distance”. This coexistence highlights the context-dependent nature of student reasoning, in which intuitive and formal models are applied inconsistently across tasks and situations [40]. These mixed mental models suggest that learning physics involves more than acquiring correct information; it requires reorganising the underlying thought patterns that support students' interpretations.

The influence of demographic and contextual factors further shapes how students form and retain these ideas. Learners in under-resourced schools may have limited exposure to hands-on experiments or high-quality instructional materials, reinforcing their dependence on everyday logic to make sense of scientific ideas [8]. Similarly, studies have shown that gender differences can influence the development of misconceptions, with female students more likely to hold alternative conceptions in areas like electric circuits, potentially due to reduced prior exposure to technical tasks or persistent gender stereotypes in STEM learning environments [32]. These points highlight the importance of viewing students' misconceptions as part of a broader pattern of intuitive reasoning rather than as isolated misunderstandings. Students often draw on familiar patterns of thought, shaped by personal experience, environment, and educational context, to make sense of unfamiliar physics concepts. These patterns, while not always scientifically accurate, are coherent within the students' cognitive frameworks. Understanding this process provides a foundation for developing teaching approaches that engage directly with students' reasoning, rather than simply replacing incorrect ideas. By exploring the structure of intuitive thinking, educators can better interpret the origins of misconceptions and support deeper, more lasting conceptual development.

Based on the conceptual change literature, the process of transforming misconceptions into scientific understanding can be viewed as a cyclical sequence of diagnosis, cognitive conflict, conceptual reconstruction, application, reflection, and reassessment. Figure 1 presents a conceptual change cycle synthesised from the reviewed literature and illustrates how diagnostic assessment, instructional interventions, and formative feedback interact to support sustained conceptual development in physics learning.

The cycle illustrates the progression from the diagnosis of misconceptions through cognitive conflict, conceptual reconstruction, application, reflection, and reassessment, culminating in sustained conceptual understanding.

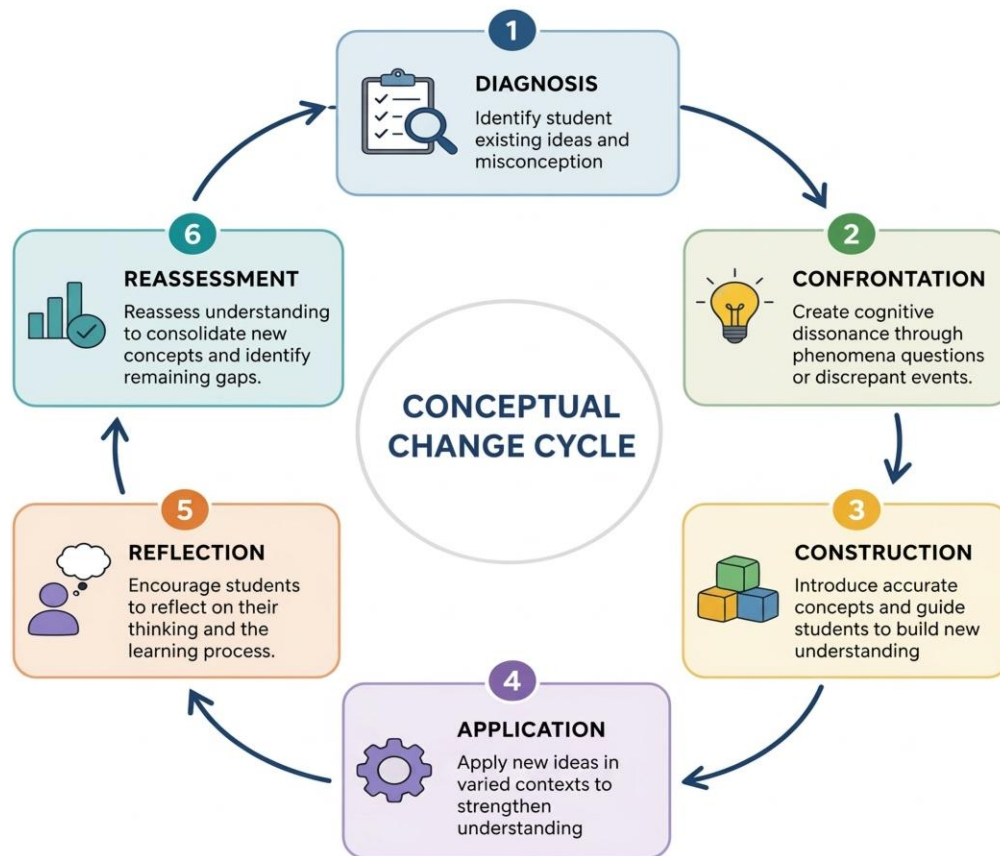


Figure 1: A conceptual change cycle for transforming physics misconceptions into scientific understanding.

3. Methodology

3.1. Narrative review design

This study employed a narrative literature review design to synthesise theoretical perspectives, diagnostic assessment approaches, and instructional strategies on misconceptions and conceptual change in physics education. A narrative review approach was considered appropriate because it allows the integration of diverse forms of literature, including empirical studies, theoretical papers, review articles, and foundational instructional resources, to provide a broad and interpretive understanding of misconception-centred instruction [36]. Unlike highly structured systematic reviews, narrative reviews allow flexibility in examining interdisciplinary evidence and identifying conceptual relationships across studies [12]. This approach was particularly suitable for the present study because the review aimed not only to summarise findings but also to connect conceptual change theory, diagnostic assessment practices, and classroom-based instructional interventions into a coherent framework for improving conceptual understanding in physics.

3.2. Literature search and source selection

Relevant literature was identified through searches conducted in academic databases including Scopus, Web of Science, ERIC, and Google Scholar. Search terms included combinations of keywords such as “physics misconceptions”, “conceptual change”, “physics education”, “diagnostic assessment”, “concept inventories”, “active learning”, and “instructional strategies”.

Although the primary focus of the review was physics education, studies from broader science education and related educational contexts were also considered where they provided transferable insights into misconceptions, conceptual understanding, diagnostic assessment, and instructional

interventions relevant to physics learning. Priority was given to peer-reviewed journal articles, foundational theoretical works, and widely cited instructional studies that significantly contributed to the understanding of misconceptions and conceptual change.

3.3. Data analysis and synthesis

The selected literature was analysed using thematic narrative synthesis. Studies were examined and organised into major themes, including conceptual change theory, students' intuitive reasoning and misconceptions, diagnostic assessment tools, classroom-validated instructional strategies, formative feedback practices, and implementation challenges in misconception-centred instruction. Findings across studies were compared and synthesised to identify recurring instructional patterns, conditions for effective conceptual change, and practical implications for physics teaching and learning.

4. Findings and discussion

4.1. Addressing challenges in the misconception-refinement approach

4.1.1. Teacher training

Specialised teacher training is essential for the successful implementation of misconception-centred instruction, as it equips educators with the skills required to identify and address student misconceptions in real time. Misconceptions are often deeply rooted in prior knowledge, making them difficult to uncover without carefully designed and implemented diagnostic tools. Teachers, however, frequently lack experience or preparation in using these tools effectively or interpreting their results to inform instruction. For example, Kabadaş and Mumcu [16] found that many teachers resorted to superficial assessments of student errors and struggled to focus on students' underlying thinking processes. Without professional development opportunities focused on common misconceptions in their subject areas and strategies for addressing them, teachers may default to traditional approaches, such as directly correcting errors, which do not always promote deep learning or conceptual change.

To address this issue, teacher training programs should prioritise active learning techniques, such as cognitive conflict strategies and collaborative learning, which are effective in reducing misconceptions [11]. Training should include hands-on practice with diagnostic tools such as concept inventories, multi-tiered tests, and the Certainty of Response Index (CRI), as well as strategies for providing timely and meaningful formative feedback [13, 43]. Furthermore, teachers must be supported in developing metacognitive awareness so they can critically reflect on and address their own misconceptions about scientific and mathematical concepts, thereby improving instructional effectiveness and responsiveness to students' thinking [33]. Incorporating these elements into teacher preparation and ongoing professional development ensures educators are not only equipped to detect misconceptions but also empowered to foster conceptual change using active learning strategies. Furthermore, scaffolds such as scripted interventions or technology-enhanced tools can help teachers respond to student errors more effectively, building their confidence and proficiency over time. By investing in comprehensive teacher training, schools can ensure that misconception-centred approaches become an integral and effective part of classroom practice.

4.1.2. Time constraints

One of the key challenges in implementing misconception-centred instruction is the additional time and resources it often requires compared to traditional teaching approaches. Identifying misconceptions through activities like diagnostic assessments takes significant instructional time, as does providing timely and nuanced formative feedback or engaging students in active, collaborative learning tasks. Misconception-focused approaches, such as the Conceptual Change Model (CCM) and cognitive conflict strategies, often necessitate iterative cycles of teaching, diagnosis, intervention,

and reassessment [41]. These methods, while highly effective, may strain the limited classroom time available to educators, particularly in curricula that are already densely packed with content.

To address this challenge, integrating misconception identification and remediation into existing curricula is a practical approach. Instead of treating misconception-centred activities as supplementary, they should be woven into everyday instruction. For example, diagnostic tools can be simplified and administered in short bursts at key points in the curriculum, such as prior to introducing challenging foundational concepts [35]. Similarly, formative assessments and feedback loops can be aligned with standard lesson objectives, ensuring that efforts to address misconceptions do not come at the expense of covering required content. In addition, teachers can adapt technology to save time and streamline misconception-centred activities. Interactive tools such as digital simulations and adaptive learning platforms provide students with opportunities to experiment and receive immediate feedback, thereby reducing misconceptions without consuming excessive class time [43].

Another solution is to use small-group activities, such as peer-led discussions or cooperative problem-solving, to identify and correct misconceptions without requiring significant teacher-led intervention [28]. This approach not only saves time but also leverages social interactions to increase student engagement. Professional development can further aid teachers in learning efficient strategies for managing time while addressing misconceptions, such as focusing on the most common or critical areas of misunderstanding, while scaffolding additional investigation for students who need it. Also, adopting a spiral curriculum design, where key concepts are revisited multiple times over the course of a program, allows for sustained exposure to and reinforcement of correct ideas, reducing the need for exhaustive interventions within a single instructional period. By leveraging such strategies, time constraints can be alleviated, allowing educators to balance their commitment to addressing misconceptions with the realities of limited instructional time.

4.2. Synthesising classroom-validated approaches

Across the studies reviewed, a convergent body of evidence supports the effectiveness of several classroom-validated instructional approaches for addressing students' misconceptions in physics. These include refutational texts, cognitive-conflict tasks, Peer Instruction, Tutorials in Introductory Physics, and interactive simulations such as PhET. Rather than functioning in isolation, these approaches are most effective when implemented under specific instructional conditions that promote conceptual change.

Refutational texts and cognitive-conflict tasks are frequently used as initial interventions to surface and challenge students' prior conceptions. Studies indicate that learning gains are strongest when instruction begins with activities that explicitly elicit misconceptions, followed by refutational explanations that contrast students' naïve ideas with scientifically accepted models [4, 41]. The sequencing of these tasks, diagnosis, conflict induction, and resolution, emerges as a critical condition for effectiveness.

Peer instruction and collaborative discussion play a central role in consolidating conceptual change. Classroom studies show that structured peer interaction, particularly when students are assigned clear roles (e.g. explainer, challenger, summariser), promotes deeper reasoning and sustained correction of misconceptions [11, 28]. Conceptual questions, accompanied by carefully designed prompts, encourage students to articulate, defend, and revise their reasoning, thereby strengthening conceptual understanding through social negotiation.

Research-based tutorials, including Tutorials in Introductory Physics and related guided inquiry materials, provide scaffolded pathways for conceptual reconstruction. These tutorials are effective when they incorporate multiple representations, verbal explanations, diagrams, graphs, and equations, and when feedback is embedded at each stage of problem solving [20]. Iterative feedback loops enable students to test emerging ideas and correct errors before misconceptions become reinforced.

Interactive simulations, particularly PhET-based activities, support both cognitive conflict and individualised exploration. The literature consistently highlights that simulations are most effective when paired with structured worksheets or guiding questions rather than used as open-ended

demonstrations [41, 43]. Such scaffolding directs students' attention to key variables, supports representational fluency, and facilitates formative assessment of conceptual change.

Across these approaches, several conditions of effectiveness recur in the literature:

- (i) deliberate instructional sequencing that moves from misconception elicitation to resolution;
- (ii) the use of conceptually focused prompts rather than procedural questions;
- (iii) the integration of multiple representations to support abstract reasoning;
- (iv) clearly defined peer roles to structure collaborative engagement; and
- (v) continuous formative feedback loops that allow students to monitor and revise their understanding.

The instructional approaches align closely with the conceptual change cycle presented in Figure 1, particularly through the use of diagnostic assessment, cognitive conflict, conceptual reconstruction, and continuous feedback mechanisms.

4.3. Designing instruction to support conceptual refinement

4.3.1. Diagnostic assessment tools

Diagnostic assessment forms a central part of misconception-centred pedagogy because it exposes both the accuracy of students' answers and the underlying reasoning structures that sustain alternative conceptions. As illustrated in figure 1, diagnostic assessment serves as the entry point for identifying misconceptions and guiding subsequent instructional interventions. Teachers can effectively identify student misconceptions early in the learning process by using diagnostic assessment tools specifically designed to uncover gaps in understanding or erroneous mental models. Pre-assessments are commonly employed to gauge students' prior knowledge and potential misconceptions before instruction begins. These assessments allow educators to tailor their lesson plans to address the unique needs of their students. Concept inventories, such as those used in physics and biology classrooms, are another reliable diagnostic method. These inventories include questions designed to reveal common misunderstandings tied to critical concepts, enabling teachers to identify areas where students' prior knowledge conflicts with scientific principles [35]. In mechanics, the *Force Concept Inventory* (FCI) set the global benchmark by documenting the tenacity of pre-Newtonian commonsense beliefs and demonstrating that conventional instruction often leaves these beliefs largely intact. The FCI's enduring influence is evident across diverse contexts, including large-scale cohorts and longitudinal designs, where pre/post patterns make the *Dominant Misconceptions* (DMs) that impede conceptual learning visible. Reviews of studies such as Hestenes, Wells and Swackhamer [15], Hasan, Bagayoko and Kelley [14], Gurel, Eryilmaz and McDermott [13], and Chrysostomou, Cornell and Naylor [7] consistently show that inventories work best when embedded in formative cycles (discussion, reflection, feedback) rather than administered as isolated tests. Treagust's seminal two-tier approach, which focused on pairing a content item with a reasoning probe, remains a powerful method for distinguishing naïve gaps from durable misconceptions that require conceptual restructuring rather than simple reteaching [39]. The method has since evolved into three- and four-tier instruments that add justification or confidence tiers to strengthen validity and interpretive power, reflecting a wider movement toward mixed-method diagnostic ecosystems in science education. One notable example is the use of multi-tier diagnostic tests, which consist of primary questions paired with follow-up questions that probe the reasoning behind a student's chosen answer. This structure helps distinguish between a lack of knowledge and true misconceptions [13]. Such diagnostic tools not only provide detailed insights into the prevalence of specific misconceptions but also empower teachers to design interventions to correct them before they become entrenched throughout the learning process.

The format of these diagnostic tools is crucial for accurately detecting misconceptions. For instance, certain tools integrate distractor options derived from research on common errors in student reasoning, as seen in well-crafted multiple-choice tests [13]. Additionally, Certainty of Response Index (CRI) tools guide teachers in determining students' confidence levels in their answers, offering deeper insights into students' conceptions and the robustness of their misconceptions [29]. Digital platforms further enhance such assessments, enabling adaptive triage of responses that dynamically adjust questions to probe specific misunderstandings in greater depth [41]. Recent advances in adaptive artificial intelligence (AI) platforms further enhance misconception-centred instruction by supporting the personalised identification of students' conceptual difficulties. AI-driven learning systems can analyse students' response patterns, diagnose persistent misconceptions in real time, and provide targeted feedback tailored to individual learning needs. Such technologies have the potential to strengthen formative assessment practices and support more effective conceptual change by enabling timely and adaptive instructional interventions. However, the successful implementation of diagnostic tools requires teacher training to effectively interpret students' responses and address their erroneous thinking [37]. Without such expertise, the potential of these tools to inform targeted interventions may not be fully realised, underscoring the need for professional development. By integrating diagnostic tools early in the instructional process, teachers can proactively pinpoint misconceptions and begin fostering conceptual change before they impede further learning. Some popular diagnostic tools used to evaluate and address misconceptions in physics are shown in table 1.

Table 1

Diagnostic tools to target misconceptions.

Instrument/approach	Primary target concepts	Key feature	Evidence
Force Concept Inventory (FCI)	Newtonian mechanics (force, motion, laws)	Validated concept inventory exposing robust alternative beliefs	Hestenes, Wells and Swackhamer [15]
Two-/Three-/Four-tier tests	Varied topics (mechanics, electricity, chemistry)	Answer + reasoning + confidence tiers to distinguish misconception vs. gap	Treagust [39]; Kartimi et al. [17]
CRI (Certainty of Response Index)	Cross-topic misconceptions	Confidence rating flags “confidently wrong” responses	Hasan, Bagayoko and Kelley [14]
DC circuits diagnostics	Current, potential difference, resistance models	Items keyed to common distractors (e.g., “current is used up”)	Engelhardt and Beichner [9]
Refutational text segments	Counterintuitive topics across science	Name → refute → replace misconception with scientific model	Tippett [38]; Schroeder and Kucera [31]
Peer instruction (ConcepTests)	Course-level threshold concepts	Peer discussion + rapid feedback cycles	Mazur [21]
Tutorials in Introductory Physics	Mechanics, E&M, waves/optics	Research-based worksheets addressing known difficulties	McDermott, Shaffer and Physics Education Group, University of Washington [22]
PhET simulations	Electricity, waves, energy, quantum, etc.	Implicit scaffolded exploration with multiple linked representations	Wieman, Adams and Perkins [42]; Perkins et al. [24]; Banda and Nzabahimana [6]

Effective implementation of this approach depends on teachers' knowledge of diagnostic assessment, which includes interpreting multi-tier data, recognising misconception profiles, and translating them into strategically varied responses. Gurel, Eryilmaz and McDermott [13] urge professional development that builds the teaching facility with two- / three- / four-tier tools, FCI and CRI, and with qualitative probes that make reasoning patterns visible.

4.3.2. Formative feedback

Formative feedback is critical for helping students reflect on and correct misconceptions during the learning process, rather than waiting until the end of a unit. High-quality formative feedback helps students understand why their existing mental models are incorrect and what steps they can take to revise their thinking. Feedback mechanisms that incorporate elaborative interrogation strategies, asking students to explain their reasoning, have been shown to deepen understanding and foster conceptual change [18]. By challenging students to think critically about their errors and encouraging metacognitive reflection, teachers can engage students in reconstructing their understanding. For example, mobile technology has been shown to support effective feedback delivery, provide personalised guidance, and promote active student engagement in their learning through interactive platforms [43].

Timely and specific feedback is essential for addressing misconceptions effectively. One of the most successful strategies involves pairing feedback with cognitive conflict. By presenting students with evidence or reasoning that contradicts their mistaken beliefs, teachers can provoke cognitive dissonance, creating an opportunity to restructure knowledge [41]. This feedback must be carefully scaffolded to avoid reinforcing misconceptions or causing confusion. For instance, feedback should include explanations that not only refute incorrect ideas but also introduce correct alternatives, as seen in interventions using refutational texts and audiovisual aids. Additionally, simulations and interactive assessments can provide immediate feedback, allowing students to test and refine their ideas in real time while experiencing discrepancies between their predictions and outcomes [41]. Although these methods are effective, their success relies heavily on teachers' ability to implement feedback loops consistently throughout the instructional process. This ensures continuous reinforcement of correct concepts and gradual elimination of misconceptions.

Incorporating formative feedback into daily instruction also allows for iterative cycles of improvement. For example, diagnostic assessments can identify misconceptions, formative feedback can address them, and subsequent reassessments can evaluate whether the feedback successfully resolved the issue [16]. This process ensures that misconceptions are addressed and corrected before they interfere with cumulative learning across a topic. Teachers leveraging formative feedback foster a classroom culture of growth and self-reflection, equipping students with the tools to monitor and adjust their learning independently.

5. Conclusion

Learning difficulties in physics are often associated with persistent misconceptions that can impede students' understanding of abstract concepts and their meaningful application. The literature reviewed suggests that misconception-centred, student-focused approaches, including diagnostic assessment, cognitive conflict, refutational texts, Peer Instruction, research-based tutorials, interactive simulations, and formative feedback, can support students' conceptual change. However, the extent of their effectiveness may depend on factors such as teacher preparation, the quality and purposeful integration of active learning activities, and access to appropriate instructional resources, particularly in under-resourced contexts. However, based on the narrative nature of this review, these observations should be interpreted within the scope of the literature examined and should not be regarded as a comprehensive or universally generalisable account of misconception-centred instruction in physics education. Rather, the reviewed evidence provides context-dependent insights that may inform educators' efforts to help students refine intuitive ideas into more coherent scientific

understanding. Addressing misconceptions may contribute to improved conceptual learning and academic engagement, although outcomes are likely to vary across learners, instructional settings, and educational contexts. Future research should investigate scalable models of professional development and context-sensitive technology integration using systematic and contextually diverse empirical approaches to further establish the effectiveness and transferability of misconception-centred instruction across educational settings.

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