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Misconceptions in Physics Education from Childhood to Teacher Preparation: Evidence, Pedagogical Strategies, And Research Gaps

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ABSTRACT: Misconceptions in physics are persistent explanatory systems that develop in early infancy and can continue through primary, secondary, university and teacher education. These intuitive ideas often co-exist with scientific concepts, rather than being automatically replaced by formal instruction, resulting in fragmented or context-dependent understanding that can be revealed when learners are presented with problems, they are not familiar with, or when they are asked to explain, rather than just calculate. This narrative review integrates the recent work on genesis, maintenance, diagnosis and evolution of misunderstandings across levels of education and core physics topics, including mechanics, thermal phenomena, energy, electromagnetism and beginning Einsteinian physics. It studies the part played by perceptual experience, daily language, the ordering of instruction, and assessment systems which frequently reward procedural fluency rather than conceptual reasoning in the development of misunderstandings. The paper also examines instructional strategies that can assist conceptual transformation, including hands-on and virtual experimentation, guided inquiry, analogical reasoning, diagnostic assessment, and digital or AI-supported learning aids. Three themes are particularly salient across the literature: the necessity to elicit and challenge learners' current beliefs; the importance of cohesive conceptual development across courses; and the centrality of instructors as facilitators of conceptual change. Key research needs include the need for longitudinal studies, delayed and transfer-based assessments of conceptual change, and a more in-depth examination of teacher education as a site for conceptual transformation. Overall, the research contends that sustained conceptual comprehension in physics requires conceptually purposeful instruction, evaluation that rewards explanation, and teacher training that clearly tackles misconceptions.

KEYWORDS: physics education; misconceptions; conceptual change; teacher education

1. INTRODUCTION

One of the most persistent problems in physics education is misconceptions, often called alternative conceptions, naïve ideas or alternative frameworks. Decades of research have shown that students in all grades come to the classroom with intuitive frameworks that help them understand common physical phenomena, even if such frameworks do not match scientific explanations. These notions are not random errors, but complex systems of explanation formed by perceptual experience, language expressions, cultural standards and corporeal engagement with the physical world. Recent theoretical contributions highlight that misunderstandings survive because they are cognitively economical, providing easy and convincing explanations that minimize cognitive load, particularly in domains characterized by abstraction and counterintuitive mechanisms (Chi & Ohlsson, 2024). Physics is likely more susceptible to such problems than the other sciences, as many of its fundamental concepts—force, energy, heat, electric fields—lack any direct counterpart with visible objects. Learners must connect invisible causal systems with observable consequences, and this connection is rarely spontaneous.

Research on misconceptions has often been undertaken at particular educational levels or within narrowly specified content domains, resulting in a rich but fragmented evidence base. However, several recent cross-level research provide strong evidence that the same alternative ideas are found in infancy, adolescence and adulthood, albeit with greater language sophistication and entrenched in increasingly elaborate procedural repertoires. A youngster who says a moving ball "has force in it" and a university student who asserts that constant velocity implies a sustained force are expressing the same impetus-like sense, but in different registers. The continuity implies that misconceptions are not replaced but instead are restructured and contextualized, often becoming implicit as learners acquire formal procedures for problem solving without necessarily altering their conceptual understanding (Vosniadou et al., 2023). The fact that such notions are still present in teacher education programs highlights the need for a holistic, developmental viewpoint in which conceptual change is viewed as a trajectory rather than an event.

The implications of correcting misconceptions have much wider implications than the scores on tests. Notions of force, energy, and field that underlie scientific literacy impact the way citizens evaluate data about climate, technology, and risk in situations as diverse as energy policy and medical decision-making. When learners exit formal education with hybrid frameworks in which scientific language overlays intuitive thinking,

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the understanding they develop is brittle, supporting problem resolution in familiar contexts but failing when transfer is necessary (Duit et al., 2023; Kotsis, 2024). In turn, teachers become an important mediating variable because the conceptual frameworks they bring to the classroom influence how phenomena are framed, which student ideas are heard, and which alternative beliefs are unintentionally reinforced.

The processes of learning and the practices of instruction are influenced by misunderstandings; the objective of this narrative review is to integrate recent research in the field of physics and at different levels of education. It draws together research from diagnostic investigations, classroom interventions and new digital and AI-supported learning settings to find common trends, successful instructional strategies and key gaps in the literature. The paper discusses the need to approach conceptual transformation as a long-term developmental process, which requires cohesive curriculum design, targeted instruction and explicit attention to teachers' own conceptual frameworks. Our synthesis is organized around three key questions: How do misconceptions manifest and persist across educational levels and physical domains? What evidence-based instructional practices encourage conceptual change? And where are the most important research gaps in expanding theory and practice in physics education?

2. METHODOLOGICAL SCOPE OF THE REVIEW

This study uses a narrative synthesis approach to combine many types of research on misunderstandings in physics education. The review does not attempt a systematic or thorough examination but tries to give a thematically ordered synthesis of recent and influential work on the formation, persistence and correction of misunderstandings at different educational levels. The literature reviewed consisted mainly of peer-reviewed journal articles, review papers, diagnostic studies, and intervention studies, published mainly during the last decade. Older works were included when they provided important theoretical or methodological foundations for conceptual-change research.

Studies were included if they met three major criteria. First, studies focused on learners' or teachers' conceptual understanding of one or more domains of physics. Second, studies presented empirical, theoretical or review-based evidence on misconceptions, alternative conceptions, or conceptual change. Finally, studies directly informed how misconceptions emerge, persist, are diagnosed, or are addressed instructionally. Thus, the review covers quantitative diagnostic investigations, qualitative assessments of reasoning, mixed-methods research, and studies of instructional interventions. The studies that used validated diagnostic instruments, cross-level comparisons, teacher education, inquiry-based instruction, experimentation, virtual laboratories and digital or AI-assisted learning environments were given special consideration.

As this is a narrative review, our aim was not to determine effect sizes or comprehensively list all of the studies that have been published, but rather to uncover common trends, interpretive themes, instructional implications, and research gaps across a disparate body of literature. Narrative reviews are particularly useful when concepts are theoretically complex, and research designs are highly heterogeneous, and where the distinction between misconception, partial understanding, lack of knowledge and context-dependent reasoning is still an active area of inquiry (Greenhalgh et al., 2018). This strategy is therefore suitable for the synthesis of a field that draws evidence from several educational levels, distinct physics areas and different methodological traditions.

Studies were important if they showed evidence of conceptual reasoning by students or teachers in major physics fields. These include mechanics (force, motion, friction, weight), thermal phenomena (heat, temperature, thermal equilibrium), energy (forms, transformation, conservation), and electromagnetism (electric current, fields, electromagnetic radiation). Emerging domains include introductory Einsteinian physics, hydrostatics, and waves. Misconceptions were examined in terms of learners' explanatory theories, instructional experiences, language resources and assessment methods in these domains. In particular, the studies that employed diagnostic instruments with two-tier, three-tier and four-tier tests were highlighted as they can distinguish between misconceptions and lack of knowledge by probing the answer and confidence in the answer simultaneously (Kaltakci-Gurel et al., 2017; Istiyono et al., 2023).

Research from preschool through teacher education was included because misconceptions are increasingly acknowledged to be developmentally stable frameworks influenced by cumulative instructional experiences. Given their importance for curriculum design and teacher preparation (Kapon et al., 2023), special focus was given to comparative and cross-sectional studies that evidence the continuity of misconceptions across time. The study also discusses studies on the function of digital technology, simulations and artificial intelligence in conceptual learning. Inclusion criteria were studies specifically dealing with conceptual understanding, which reflects the recent trend to explore not only engagement and motivation but also the cognitive mechanisms underpinning the conceptual development (Sailer et al., 2024; Banda & Nzabahimana, 2025).

3. MISCONCEPTIONS ACROSS EDUCATIONAL LEVELS

Misconceptions are common in children's reasoning about the physical world and surprisingly persistent during schooling. At the beginning of elementary school, the students' idea about physical phenomena is based mainly on perceptual experience and daily language. Kids tend to think of force as something things * have *. Heat as a kind of stuff that moves around. Light as something that exists on its own, apart from its source. These ideas are functional for everyday experience, and they often persist in the face of being refuted by teaching (Vosniadou et al., 2023). Scientific theories that include invisible entities or systemic causality are sometimes counterintuitive since young learners rely on direct sensory information and phenomenological reasoning. Research with Greek primary school pupils has demonstrated the relationship between mental age and persistence of mechanical misconceptions, demonstrating that conceptual growth is not merely a function of instructional exposure, but also of cognitive preparation for abstraction (Stylos & Kotsis, 2023).

With the shift to secondary education, students are introduced to scientific models more explicitly through formal definitions, mathematical representations, and problem-solving procedures. However, the research suggests that formal instruction does not inevitably change underlying ideas. Instead, students often build hybrid explanatory systems where scientific language is placed atop intuitive frameworks. For example, learners may be able to successfully apply Newton's principles to calculations but still think in terms of impetus-like thoughts about motion. The well-known misunderstanding "motion implies force" remains in upper secondary and even university education whereby learners always infer a force in the direction of motion even after explicit teaching (Liu & Fang, 2016; Kaniawati et al., 2019; Kotsis & Panagou, 2022). Likewise, students may confuse temperature and heat, think of energy as an active agent rather than a conserved quantity, or think of electric current as something

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which is used up by components in a circuit. Research indicates that training emphasizing procedural correctness and formulas can lead to a fragmented knowledge of concepts, where misconceptions are masked by procedural fluency until students are asked to explain or work on transfer tasks (Docktor & Mestre, 2023).

Domain patterns are well known. Students at all levels in mechanics commonly mix velocity with acceleration, anticipate acceleration to be in the direction of motion, and treat normal forces, friction, and tension as inactive or passive aspects of a system. Students in thermal physics frequently see temperature as a measure of the amount of heat in an object, confuse heat with thermal energy, and ascribe insulating qualities to materials based on their everyday sensory feel rather than thermal conductivity (Stylos et al., 2021; Kotsis et al., 2023). Common misconceptions in electricity and magnetism include the idea that current is "used up" along a circuit, that batteries are sources of constant current, not constant potential difference, and that magnetic and electric fields are physical entities filling space in the same way as a fluid (Maries et al., 2022; Gavrilas & Kotsis, 2024). In energy, students conceptualize energy as a material or fuel that can be stored, consumed and depleted rather than a conserved quantity which changes form in interactions (Kubsch, 2024).

Misconceptions exist at the university level, especially in introductory physics courses, where the instruction is dominated by formalism and mathematical abstraction. Advanced courses tend to develop algorithmic skill without ensuring conceptual restructuring. Diagnostic examinations suggest that university students still possess alternative concepts of the same kind as those detected at earlier stages. These are recurrent misconceptions about force , work , energy and electric fields . Cross-sectional studies suggest that students may express scientifically correct assertions in the course of education but fall back on intuitive explanations when dealing with novel problems, which demonstrates the persistence of their initial frameworks (Duit et al., 2023). Recent findings among honours high-school graduates entering medical school in Greece show that even students with high academic achievement hold significant misconceptions about density and other fundamental concepts, indicating that previous academic achievement is not a good indicator of conceptual understanding (Panagou et al., 2024). Recent research on hydrostatic pressure with Greek junior high school students has documented the everyday experiences of depth, volume, and container shape, and how these lead to predictable yet scientifically false explanations that remain even after standardized instruction, illustrating the disconnect between curricular intent and conceptual outcome (Bessas et al., 2024).

Recently, introductory Einsteinian physics has also been introduced and is gradually being included into the curricula of upper-secondary and even primary education through projects such as Einstein-First. Initial results indicate that learners may work productively with ideas of curved space-time, photons and quantum indeterminacy when presented using analogies, models and thought experiments. The strangeness of relativistic and quantum phenomena is, however, at odds with intuitions built in a Newtonian worldview, giving rise to new types of misconception, for example in the form of viewing spacetime curvature as a gravitational "pull" and quantum superposition as classical ignorance about a definite state (Kaur et al., 2024; Boublil et al., 2024; Vakarou et al., 2024). Such results highlight the more general idea that misconceptions are not about a particular topic but reflect general inclinations of mind: a bias for substance over process, actor over system, visible causation over field-mediated interaction.

The prevalence of misunderstandings among pre-service teachers has significant ramifications. Research has demonstrated repeatedly that future instructors have misconceptions comparable to those of their students and that they prefer to draw on intuitive concepts when preparing instruction or providing explanations in the classroom. These conceptual challenges affect educational decisions, such as how teachers model phenomena and respond to students' queries. Recent research on the conceptual knowledge and self-efficacy of pre-service teachers emphasizes the importance of teacher education programs to systematically promote conceptual development and reflective analysis of intuitive notions (Stylos et al., 2022). Pre-service primary teachers' research shows that even though they have participated in formal physics courses, they have significant misconceptions about energy transformation, thermal equilibrium and electrical phenomena, which are related to lower self-efficacy in teaching the corresponding topics (Stefanou et al., 2023; Kyriazis et al., 2025; Vlachos et al., 2024). Without some targeted intervention there is a possibility that misconceptions will be passed on through generations of learners in a loop whereby teachers transfer their own alternative frameworks to students who then become teachers. But the evidence should, too, be read with caution. The majority of the extant research is based on cross-sectional diagnostic investigations, short-term intervention designs or topic-specific assessments. These studies are significant in their showing repeated patterns in learners' reasoning, but they do not necessarily indicate how misconceptions arise over time, how stable they remain after training, or how they are activated in different circumstances. Furthermore, disparities in diagnostic methods, sample characteristics, educational institutions, and curricular traditions make direct comparison of studies problematic. Thus, the persistence of misconceptions should not be seen as only a failure of instruction, but as a consequence of complex interactions among cognitive development, prior experience, language, curriculum design, assessment processes, and teacher knowledge.

New research also looks at how misconceptions relate to digital and AI learning environments across levels. Simulations, virtual labs, and AI-powered tools can help students explore concepts but can also give ostensibly correct answers that hide underlying errors. Learners may take AI responses passively and reinforce intuitive concepts rather than challenge them (Sailer et al., 2024). But a recent assessment of large language models on traditional physics assessments such as the Force Concept Inventory has demonstrated that these systems can generate answers congruent with expert reasoning, while also making common errors related to friction, frames of reference, and the role of forces in non-inertial frames, emphasizing the fact that AI tools are collaborators in need of critical engagement, not sources of absolute truth (West, 2023; Kortemeyer, 2023). These findings underline the necessity for teaching practices that guarantee the technological tools stimulate conceptual reasoning and not only provide answers.

In sum, the research examined in this section demonstrates that misunderstandings are persistent because they are incorporated in learners' prior experiences, everyday language, perceptual expectations, and instructional histories. Thus, misperception correction is not just about reiterating scientific explanations or offering more worked examples. Instruction has to actively elicit learners' current beliefs, compare intuitive and scientific explanations, and help reconstruct conceptual frameworks through evidence, reflection, and guided reasoning. Thus, in the next section, we will review instructional methods that have been employed to foster conceptual transformation in physics education.

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4. INSTRUCTIONAL APPROACHES TO ADDRESS MISCONCEPTIONS

Effective education that addresses misunderstandings builds on learners' existing concepts, actively engaging them and guiding them through processes of conceptual restructuring. The weight of evidence suggests that no one strategy is sufficient: lasting conceptual change generally results via coordinated combinations of elicitation, cognitive conflict, model development, reflection, and assessment. The following subsections detail the main approaches and the conditions under which they appear to be most effective.

4.1 Hands-on and Virtual Experimentation

Hands-on experimentation is one of the most common ways in physics teaching, however research has shown that its success is design-dependent. Experiments that are confirmatory tasks tend to leave preconceptions unaffected, since learners evaluate outcomes within their existing mental models. Research shows that trials work best when they invite predictions, present learners with surprising results, and give them guided chances to think and explain (Duit et al., 2023). In mechanics and thermal physics, designs like these help destabilise substance-like or anthropocentric understandings and support the building of scientific models. Virtual experiments and simulations are gaining prominence, providing visualizations and manipulations that are not always achievable in real laboratories, such as reducing friction, changing gravitational acceleration, or visualizing electric and magnetic fields. But again these techniques, however helping to achieve a deeper conceptual understanding, are reliant on instructional design. Systematic evaluations show that a mix of real and virtual experiments leads to the strongest learning outcomes as learners are able to combine physical experience with abstract representations (Wörner et al., 2022). Studies at primary school level indicate that virtual labs can reach, or even exceed, real experiments in terms of conceptual outcomes when guided reflection and explanation are incorporated (Evangelou & Kotsis, 2019). Recent work indicates that hybrid sequences where hands-on confirmation follows virtual exploration may be especially effective for abstract topics such as fields and energy transfer (Banda & Nzabahimana, 2025).

4.2 Guided Inquiry and Cognitive Conflict

Inquiry-based learning settings encourage learners to produce explanations, analyse evidence, and build models, which facilitate conceptual change. However, an unguided inquiry can be daunting for students and might promote preconceptions, especially when students lack the conceptual vocabulary to make sense of their discoveries. Recent work suggests that guided inquiry, where teachers scaffold processes of prediction, assessment and justification, results in considerable conceptual improvements, particularly for pre-service teachers who have to acquire subject and pedagogy at the same time (Kyriazis et al., 2025). The ongoing creation of cognitive conflict is central to this scaffolding as a primary process: creating tasks in which the learners' predictions are in conflict with the actual outcomes, the instruction creates dissatisfaction with prior conceptions, which classical conceptual change theory considers a necessary precondition to restructuring. Recent modifications make clear that conflict is not enough; learners need to be presented with an option that is more intelligible, reasonable, and fruitful, and given time to express it (Chi & Ohlsson, 2024).

4.3 Analogies, Multiple Representations, and Language

Analogies and multiple representations have a long tradition in physics education and continue to be among the most powerful methods to bridge intuitive and scientific frameworks. Carefully constructed analogies, such as the analogy of electric current to flow of water in a closed loop or the analogy of curvature of spacetime to stretched fabric, help learners to project familiar relational structure to unknown domains. However, analogies also create new misconceptions if the boundaries are not clearly stated, as in the water comparison that leads learners to think of current as something stored in or used by components (Amin et al., 2023). Effective use of analogies consequently needs explicit mapping of features that do and do not transfer, as well as numerous representations, diagrams, graphs, equations, and vocal explanations that allow learners to triangulate the underlying notion. Studies of multimodal education have demonstrated that conceptual coherence is improved by the coordination of representations, as long as learners are assisted in translating between representations and are not only exposed to isolated representations (Treagust et al., 2022).

4.4 Diagnostic Assessment as Pedagogical Tool

All methods generally emphasize diagnostic assessment to discover misconceptions and monitor conceptual change. Recent validation studies highlight the necessity of credible concept inventories and open-ended evaluation tools to interpret educational outcomes (Treagust et al., 2022). Multi-tier diagnostic instruments have been developed at an increasing rate in recent years, and two-tier, three-tier and four-tier tests have been employed in an increasing variety of areas from mechanics to optics to thermodynamics. Instruments that combine answer tiers with reasoning tiers and confidence tiers discriminate scientific conception, lack of understanding, false positives, false negatives, and real misconception (Kaltakci-Gurel et al., 2017; Istiyono et al., 2023). In addition to their research role, such instruments can serve as formative tools, providing teachers with practical information on students' reasoning and prompting reflective practice. Thus, diagnostic evaluation not only informs instruction, but also increases teachers' awareness of students' reasoning, and therefore is fundamental to physics teaching and teacher preparation.

4.5 Digital and AI-Supported Learning

Digital and AI-supported learning tools offer new opportunities for conceptual development in physics education, especially if they are intended to foster explanation, comparison and reflection. Learners can be prompted by AI-powered feedback systems to defend their responses, to uncover flaws in their thinking, and to obtain adaptive support in navigating problem-solving. Recent work suggests generative AI tutors can produce explanations that learners consider clear and useful , and initial quasi-experimental evidence suggests the potential for improved conceptual outcomes for ChatGPT-supported instruction in some STEM contexts (Banda & Nzabahimana, 2025; Kestin et al., 2025).

But the utility of AI for education rests heavily on how it's integrated into instruction. AI-generated explanations can sound coherent and authoritative even when learners do not understand the underlying mechanics, fostering passive acceptance rather than conceptual reorganization. This risk is particularly pertinent in misunderstanding research, where the primary goal is not simply to get at a correct response, but to alter the reasoning that leads to an answer (West, 2023). Comparisons of AI systems such as DeepSeek and ChatGPT on physics misinterpretation tasks show that their performance varies across themes, with mistakes occurring in areas such as friction, reference frames, and the application of

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conservation principles (Kotsis, 2025). These findings show that AI tools should not be considered as neutral explanative sources but as instructional resources whose outputs require interpretation, critique and mediation by teachers.

Recent work also suggests that AI-supported discourse may help students grapple with difficult conceptual shifts, including the leap from Newtonian to Einsteinian thinking. Carefully designed AI interactions could help learners shift between paradigms, especially in settings where teachers themselves may not feel confident in current physics concepts (Kotsis & Vakarou, 2025). To tap this potential, AI-based exercises should force students to compare accounts, identify inconsistencies, evaluate assumptions and explain their rationale. Effective use of AI in physics education thus demands pedagogical frameworks that highlight reasoning and critique rather than answer acquisition, placing AI as a dialogic partner whose responses become subjects of scrutiny rather than final authorities.

5. CROSS-CUTTING THEMES AND RESEARCH GAPS

There are some cross-cutting themes throughout the literature. Cognitive economy is fundamental: misunderstandings survive because they offer straightforward, functional explanations, formed by ordinary experience and confirmed by perceptual data. Language and representation are particularly relevant, since students and teachers tend to carry commonplace connotations of words such as “force,” “energy,” “heat” or “weight” into scientific contexts, thus generating systematic errors (Amin et al., 2023). The ontological status of central physics constructs is itself a source of difficulty: learners who apply substance-schemas to phenomena that require process-schemas do so when they treat energy as a substance, force as a property of objects, or fields as material entities, and instruction that does not address this ontological shift tends to produce surface-level rather than deep change (Chi & Ohlsson, 2024). Assessment techniques that promote procedural accuracy over explanation further obfuscate mistakes, promoting notions that conceptual knowledge is secondary to formula manipulation (Docktor & Mestre, 2023).

Another cross-cutting theme is that of the instructor as mediator. What counts as a genuine explanation in the classroom and how student ideas are taken up are shaped by teachers’ own conceptual frameworks, their pedagogical topic expertise, and their attitudes toward experimentation and inquiry (Vlachos et al., 2024). Curricula that are conceptually consistent on paper can be applied in ways that revert to formulaic teaching when teachers lack confidence in the underlying physics, especially in areas such as energy, electromagnetism, and contemporary physics where teachers’ own preparation is often uneven.

There are still major research gaps, and these gaps lead to numerous priorities for future effort. First, longitudinal studies are needed to follow the development of misunderstandings, their stabilization, weakening or re-emergence as learners progress from primary to secondary, university and teacher education environments. Such research would elucidate whether misunderstandings remain, are rearranged into more sophisticated hybrid frameworks, or are only reactivated in specific problem scenarios (Kapon et al., 2023; Vosniadou et al., 2023). Second, the transfer and persistence of conceptual change need further evidence. Much intervention research indicate immediate post-test benefits but very few investigate whether learners maintain scientific notions months or years later or whether they use them successfully in novel contexts. Future research should therefore feature delayed evaluations, transfer tasks, and qualitative examinations of reasoning outside of typical problem formats (Duit et al., 2023; Docktor & Mestre, 2023). Third, teacher education should be seen as a primary research site rather than a secondary application of student misperception research. Studies should study how the alternative perspectives of pre-service teachers interact with their pedagogical topic knowledge, self-efficacy, lesson planning and answers to pupils’ explanations (Stylos et al., 2022; Stefanou et al., 2023; Kyriazis et al., 2025). Fourth, the rapid development of digital and AI-supported learning environments demands thorough empirical examination. Future research should investigate not only if AI tools increase performance but also how they alter the quality of explanations, epistemic trust, critical assessment, and conceptual reorganization (Sailer et al., 2024; Banda & Nzabahimana, 2025; Kotsis, 2025). Finally, emerging domains like introductory Einsteinian physics require developmental learning progressions to illustrate how students transition from every day and Newtonian intuitions to relativistic and quantum models, without merely substituting one set of misconceptions for another (Kaur et al., 2024; Vakarou et al., 2024).

6. IMPLICATIONS FOR PHYSICS EDUCATION AND TEACHER PREPARATION

The formative character of misconceptions necessitates physics training that systematically considers learners’ pre-existing notions. Good curricula should include conceptual hurdles into the design of education, rather than treating them as separate faults to be remedied by providing more examples. Rather than repetitious coverage that does not build conceptual depth, there needs to be a coherent conceptual progression across grade levels, and rather returning to key ideas, force, energy, field, system, with increasing precision and abstraction (Kapon et al., 2023). Curriculum planners should analyze how the language used at each stage supports or undermines the eventual scientific concept, as well as how representations introduced early can be usefully extended rather than discarded later.

The training of teachers is especially important because the conceptual frameworks of pre-service teachers influence the explanations they provide and the judgments they make regarding education. Teacher education programmes should therefore systematically provide future teachers with the opportunity to detect, confront and reconstruct their own misunderstandings before they are asked to diagnose and tackle misconceptions in learners. Such possibilities may involve organized reflection on everyday explanations, concept mapping, prediction-observation-explanation exercises, analysis of pupils’ written replies, and microteaching sessions and subsequent peer and instructor feedback (Stylos et al., 2022; Stefanou et al., 2023).

These activities should be part of the curriculum of physics techniques courses, not separate topic remediation. Where conceptual understanding is directly linked to pedagogy, pre-service teachers are able to learn both the scientific explanation of a phenomenon and why that explanation is often difficult for learners, what alternative conceptions are likely to emerge and how instructional tasks can be designed to promote conceptual change. Recent inquiry-based laboratory activity studies in teacher education reveal measurable gains in both conceptual understanding of heat and self-efficacy for teaching heat, demonstrating that conceptual and affective elements can be addressed jointly (Kyriazis et al., 2025). In this perspective, teacher preparation should see misconceptions not as isolated student errors, but as important objects of educational topic knowledge.

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With the increasing prevalence of digital and AI tools, teachers need to understand how to use these tools to promote conceptual thinking rather than surface correctness. This includes designing tasks where learners assess AI-generated explanations, recognizing typical mistakes in AI outputs and utilizing AI to uncover students' alternative concepts rather than bypass them (Sailer et al., 2024; Kotsis, 2025). Professional development that considers AI as an object of pedagogical reasoning rather than a turnkey solution is likely to be more sustainable than approaches that focus on tool adoption alone.

At the system level, conceptual goals take root only when there is congruence among curriculum standards, assessment techniques, and teacher evaluation. As long as high-stakes evaluations reward procedural fluency, instruction will always follow suit, and conceptual goals will stay rhetorical. Thus, reform of evaluation in order to incorporate factors that demand explanation, justification and transfer is a requirement for continued advancement (Docktor & Mestre, 2023).

7. CONCLUSIONS

Rather than viewing physics misconceptions as isolated errors, they should be viewed as stable explanatory resources that the learners are using to make sense of physical facts. These resources are to be activated, probed, challenged and recreated, not presumed to wither away with direct instruction. There is evidence at all levels of schooling that misconceptions remain because they are based on ordinary experience, language, intuitive reasoning and the cognitive economy of substance-like explanations. Thus, training that aims to develop conceptual understanding must involve explanation, reflection, cognitive conflict and guided comparison of intuitive and scientific models. Hands-on experimentation, virtual laboratories, analogies, diagnostic evaluation, and AI-supported technologies may each play a role in conceptual development, but the effectiveness of each is dependent on instructional design that foregrounds reasoning over response production.

An important addition of this review is to argue for the developmental consideration of misunderstandings spanning childhood, school science, university learning, and teacher training. Teacher education programs are particularly significant because the conceptual frameworks of prospective instructors determine how physics topics are communicated, how pupils' reasoning is perceived, and how classroom activities are created. Thus, one of the most essential interventions available to the sector is to strengthen pre-service teachers' content knowledge as well as their pedagogical content knowledge, with explicit attention to common misconceptions and diagnostic tools. Physics education can advance towards more coherent, enduring, and meaningful learning experiences through the adoption of conceptually deliberate pedagogies, alignment of assessment with conceptual goals, and critical integration of digital and AI resources. Future research needs to take up longitudinal studies of conceptual development, rigorous studies of transfer and durability, and continuous examination of teacher education as a location for authentic conceptual change. Misconceptions handed down from generation to generation are not an unavoidable fact of life; they are a tractable problem that responds to coherent, conceptually informed design at all levels of the educational system.

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REFERENCES

1) Amin, T. G., Smith, C. L., & Wiser, M. (2023). Student conceptions and the role of language in science learning. Journal of the Learning Sciences, 32(2), 203–240. https://doi.org/10.1080/10508406.2022.2136769
2) Banda, H. J., & Nzabahimana, J. (2025). Integrating generative AI into STEM education: Enhancing conceptual understanding, addressing misconceptions, and assessing student acceptance. Disciplinary and Interdisciplinary Science Education Research, 7, Article 5. https://doi.org/10.1186/s43031-025-00125-z
3) Bessas, N., Tzanaki, E., Vavougios, D., & Plagianakos, V. P. (2024). Diagnosing students' misconception in hydrostatic pressure through a 4-tier test. Heliyon, 10(23), e40425. https://doi.org/10.1016/j.heliyon.2024.e40425
4) Boublil, S., Blair, D., & Treagust, D. F. (2024). Design and implementation of an Einsteinian energy learning module. International Journal of Science and Mathematics Education, 22(1), 49–72. https://doi.org/10.1007/s10763-022-10348-5
5) Chi, M. T. H., & Ohlsson, S. (2024). Complex learning and conceptual change: Revisiting mechanisms and implications for instruction. Educational Psychologist, 59(2), 67–82. https://doi.org/10.1080/00461520.2024.2301152
6) Docktor, J. L., & Mestre, J. P. (2023). Synthesis of discipline-based education research in physics. Physical Review Physics Education Research, 19(2), 020101. https://doi.org/10.1103/PhysRevPhysEducRes.19.020101
7) Duit, R., Treagust, D. F., & Widodo, A. (2023). Teaching science for conceptual change: Progress and challenges. International Journal of Science Education, 45(6), 889–907. https://doi.org/10.1080/09500693.2022.2153846
8) Evangelou, F., & Kotsis, K. T. (2019). Real vs. virtual physics experiments: Comparison of learning outcomes among fifth-grade primary school students: A case on the concept of frictional force. International Journal of Science Education, 41(3), 330–348. https://doi.org/10.1080/09500693.2018.1549760
9) Gavrilas, L., & Kotsis, K. T. (2024). Electromagnetic radiation: A comprehensive review of misconceptions. Eurasian Journal of Science and Environmental Education, 4(2), 19–38. https://doi.org/10.30935/ejsee/15719
10) Greenhalgh, T., Thorne, S., & Malterud, K. (2018). Time to challenge the spurious hierarchy of systematic over narrative reviews? European Journal of Clinical Investigation, 48(6), e12931. https://doi.org/10.1111/eci.12931
11) Istiyono, E., Dwandaru, W. S. B., Fenditasari, K., Ayub, M. R. S. S. N., & Saepuzaman, D. (2023). The development of a four-tier diagnostic test based on modern test theory in physics education. European Journal of Educational Research, 12(1), 371–385. https://doi.org/10.12973/eu-jer.12.1.371

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12) Kaltakci-Gurel, D., Eryilmaz, A., & McDermott, L. C. (2017). Development and application of a four-tier test to assess pre-service physics teachers' misconceptions about geometrical optics. Research in Science & Technological Education, 35(2), 238–260. https://doi.org/10.1080/02635143.2017.1310094
13) Kaniawati, I., Fratiwi, N. J., Danawan, A., Suyana, I., Samsudin, A., & Suhendi, E. (2019). Analyzing students' misconceptions about Newton's laws through Four-Tier Newtonian Test (FTNT). Journal of Turkish Science Education, 16(1), 110–122. https://doi.org/10.12973/tused.10269a
14) Kapon, S., Laherto, A., & Levrini, O. (2023). Conceptual progression and coherence in physics education: Bridging learning across age and context. Physical Review Physics Education Research, 19(2), 020102. https://doi.org/10.1103/PhysRevPhysEducRes.19.020102
15) Kaur, T., Kersting, M., Blair, D., Adams, K., Treagust, D., Santoso, J., Lonshakova, A., Boublil, S., Zadnik, M., Ju, L., Wood, D., Horne, E., & McGoran, D. (2024). Developing and implementing an Einsteinian science curriculum from years 3–10: A. Concepts, rationale and learning outcomes. Physics Education, 59(6), 065014. https://doi.org/10.1088/1361-6552/ad66a7
16) Kestin, G., Miller, K., Klales, A., Milbourne, T., & Ponti, G. (2025). AI tutoring outperforms in-class active learning: An RCT introducing a novel research-based design in an authentic educational setting. Scientific Reports, 15(1), 1–10. https://doi.org/10.1038/s41598-025-97652-6
17) Kortemeyer, G. (2023). Could an artificial-intelligence agent pass an introductory physics course? Physical Review Physics Education Research, 19(1), 010132. https://doi.org/10.1103/PhysRevPhysEducRes.19.010132
18) Kotsis, K. T. (2024). Correcting students' misconceptions in physics using experiments designed by ChatGPT. European Journal of Contemporary Education and E-Learning, 2(2), 83–100. https://doi.org/10.59324/ejceel.2024.2(2).07
19) Kotsis, K. T. (2025). Comparing ChatGPT and DeepSeek in addressing misconceptions about physics concepts. European Journal of Contemporary Education and E-Learning, 3(2), 191–206. https://doi.org/10.59324/ejceel.2025.3(2).17
20) Kotsis, K. T., & Panagou, D. (2022). Using alternative ideas for determining the learning curve on the concept of force. European Journal of Science and Mathematics Education, 10(4), 495–506. https://doi.org/10.30935/scimath/12251
21) Kotsis, K. T., & Vakarou, G. (2025). Bridging the gap between Newtonian and Einsteinian thinking: The impact of AI-powered teachers on physics education. European Journal of Contemporary Education and E-Learning, 3(4), 32–45. https://doi.org/10.59324/ejceel.2025.3(4).03
22) Kotsis, K. T., Stylos, G., Houssou, P., & Kamaratos, M. (2023). Students' perceptions of the heat and temperature concepts: A comparative study between primary, secondary, and university levels. European Journal of Education and Pedagogy, 4(1), 136–144. https://doi.org/10.24018/ejedu.2023.4.1.577
23) Kubsch, M. (2024). What affects the continued learning about energy? Evidence from a 4-year longitudinal study. Journal of Research in Science Teaching, 61(5), 975–997. https://doi.org/10.1002/tea.21931
24) Kyriazis, N., Stylos, G., & Kotsis, K. T. (2025). Impact of inquiry-based laboratory activities on understanding heat concepts and self-efficacy in pre-service teachers. Journal of Pedagogical Research, 9(1), 161–181. https://doi.org/10.33902/JPR.202530426
25) Liu, G., & Fang, N. (2016). Student misconceptions about force and acceleration in physics and engineering mechanics education. International Journal of Engineering Education, 32(1A), 19–29.
26) Maries, A., Brundage, M., & Singh, C. (2022). Using the Conceptual Survey of Electricity and Magnetism to investigate progression in student understanding from introductory to advanced levels. Physical Review Physics Education Research, 18(2), 020114. https://doi.org/10.1103/PhysRevPhysEducRes.18.020114
27) Panagou, D., Kostara, C. E., Stylos, G., & Kotsis, K. T. (2024). Medical school students' misconceptions regarding concept of density. Journal of Pedagogical Research, 8(4), 1–15. https://doi.org/10.33902/JPR.202426211
28) Sailer, M., Schultz-Pernice, F., & Fischer, F. (2024). Digital learning environments and conceptual understanding: A systematic perspective on mechanisms and outcomes. Educational Psychologist, 59(1), 1–18. https://doi.org/10.1080/00461520.2023.2263915
29) Stefanou, M., Stylos, G., Georgopoulos, K., & Kotsis, K. T. (2023). Primary preservice teachers' misconceptions and reasoning of thermal concepts in everyday contexts. The International Journal of Learning in Higher Education, 31(1), 127–157. https://doi.org/10.18848/2327-7955/CGP/v31i01/127-157
30) Stylos, G., & Kotsis, K. T. (2023). Correlation of primary school students' misconceptions about concepts of mechanics from their mental age. European Journal of Education Studies, 10(1), 77–90. https://doi.org/10.46827/ejes.v10i1.4619
31) Stylos, G., Kamtsios, S., & Kotsis, K. T. (2022). Assessment of Greek pre-service primary teachers' efficacy beliefs in physics teaching. Journal of Science Teacher Education, 34(1), 44–62. https://doi.org/10.1080/1046560X.2021.2023959
32) Stylos, G., Sargioti, A., Mavridis, D., & Kotsis, K. T. (2021). Validation of the thermal concept evaluation test for Greek university students' misconceptions of thermal concepts. International Journal of Science Education, 43(2), 247–273. https://doi.org/10.1080/09500693.2020.1865587
33) Treagust, D. F., Duit, R., & Fischer, H. E. (2022). Multiple representations and diagnostic assessment in science education: Methodological considerations. International Journal of Science Education, 44(12), 1821–1840. https://doi.org/10.1080/09500693.2022.2063721
34) Vakarou, G., Stylos, G., & Kotsis, K. T. (2024). Probing students' understanding of Einsteinian physics concepts: A study in primary and secondary Greek schools. Physics Education, 59(2), 025004. https://doi.org/10.1088/1361-6552/ad1768
35) Vlachos, I., Stylos, G., & Kotsis, K. T. (2024). Primary school teachers' attitudes towards experimentation in physics teaching. European Journal of Science and Mathematics Education, 12(1), 60–70. https://doi.org/10.30935/scimath/13830
36) Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2023). Reconsidering the development of scientific understanding: The role of naïve frameworks. Human Development, 67(1), 1–21. https://doi.org/10.1159/000528948

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37) West, C. G. (2023). Advances in apparent conceptual physics reasoning in GPT-4. Physical Review Physics Education Research, 19(1), 010132. https://doi.org/10.1103/PhysRevPhysEducRes.19.010132

38) Wörner, S., Kuhn, J., & Scheiter, K. (2022). The best of two worlds: A systematic review on combining real and virtual experiments in science education. Review of Educational Research, 92(6), 911–952. https://doi.org/10.3102/00346543221079417

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