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# Artificial Intelligence and Conceptual Understanding in Physics Education: Opportunities, Risks, and Research Directions

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**Abstract**

Artificial intelligence is swiftly becoming a significant force in physics education, adept at producing explanations, formulating hypotheses, and facilitating in-depth discussions about physical phenomena. This advancement presents novel opportunities for enhancing conceptual comprehension, especially in a field where students' intuitive notions tend to be consistent, coherent, and resistant to alteration. Simultaneously, AI systems often generate assertive yet erroneous reasoning, prompting apprehensions over epistemic trust, excessive dependence, and the perpetuation of fallacies. This Study analyzes artificial intelligence as an epistemic intermediary in physics education, emphasizing its role in conceptual transformation, inquiry-based pedagogy, and educator autonomy. Utilizing developing empirical evidence and theoretical frameworks, the paper contends that AI can enhance conceptual development by stimulating comparison, critique, and evidence-based reasoning, yet can hinder learning when regarded as an authoritative source of answers. The investigation underscores the transformation of teacher professional judgment in AI-enhanced classrooms and explores ethical and pedagogical limits concerning autonomy, equity, assessment integrity, and privacy. The article finishes by delineating essential research trajectories and underscoring that the educational efficacy of artificial intelligence is essentially contingent upon pedagogical design and ethical governance. The function of AI in physics education ought to be to enhance human reasoning rather than supplant it, and to assist learners in cultivating lasting, transferable conceptual comprehension.

**Keywords:** Artificial Intelligence, Conceptual Understanding, Physics Education, Misconceptions, Inquiry-Based Learning

## Introduction

Artificial intelligence has swiftly transitioned from the periphery to the forefront of educational discourse, with big language models and adaptive systems already proficient in generating explanations, solving issues, and engaging in extensive dialogue on intricate scientific subjects. This advancement in physics instruction is significant as conceptual understanding is acknowledged to be both vital and delicate. Students at various educational stages formulate intuitive explanations about force, motion, energy, and fields that, while coherent and based on experience, frequently conflict with established scientific theories, and are shaped by developmental and cognitive factors such as mental age [1]. Extensive research on conceptual change indicates that these frameworks are not readily supplanted by teaching and can survive with formal knowledge, emerging in new situations or under heightened cognitive demands. The emergence of AI systems capable of delivering intricate physics explanations, creating analogies, and responding adaptively to student inquiries introduces a novel epistemic entity into this already intricate educational environment.

Recent investigations indicate that modern AI models can achieve performance at or near expert levels on numerous conceptual physics evaluations, despite their absence of embodied experience or mechanical comprehension of physical processes [2, 3]. Simultaneously, detailed assessments uncover systematic deficiencies, including assured expression of misconceptions, misinterpretation of diagrams, and shortcomings in multi-step causal reasoning, especially in areas like electricity and magnetism [4]. The amalgamation of these capacities renders AI distinctly impactful, serving as both a formidable creator of explanations and a possible catalyst for conceptual distortion. In contrast to conventional educational materials, AI engages interactively in learners' cognitive processes, influencing the formulation of questions, the consideration of alternatives, and the assessment of explanations.

Recent classroom-based study indicates that AI can serve as a facilitator of conceptual comprehension by aiding in reflection, comparison, and hypothesis formulation [5]. Interventions where students formulate experiments or investigate alternative explanations with ChatGPT's assistance demonstrate enhanced articulation of pre-existing concepts and a greater frequency of explanation revisions based on evidence [6, 7]. Simultaneously, research on student views reveals significant faith in AI outputs, despite students' awareness of potential errors, which raises problems regarding epistemic dependency and the delegation of cognitive tasks [8]. These findings underscore a fundamental tension: AI might enhance the mechanisms that facilitate conceptual development, yet it can also subvert them if its outputs are regarded as authoritative rather than subject to challenge.

In addition to student learning, AI is transforming the teacher's role in physics classes. Educators are progressively required to curate, analyse, and critique AI-generated content while ensuring conceptual coherence and scientific precision. This necessitates novel types of professional discernment, as educators must determine when to employ AI to stimulate critical thinking, when to impose restrictions, and how to elucidate its limitations to learners. Analyses focused on policy highlight that, without meticulous pedagogical framing, AI could undermine teacher autonomy and alter classroom epistemologies, favoring fluency over comprehension [9, 10].

Although there is an expanding corpus of research on AI in education, syntheses relevant to physics are scarce, with the majority of existing studies emphasizing performance or efficiency rather than conceptual advancement. The domain lacks a cohesive framework for comprehending the interplay between AI, misunderstandings, inquiry-based learning, and teacher agency in physics, as well as the delineation of ethical and pedagogical boundaries. Furthermore, the velocity of technology advancement significantly surpasses conventional research cycles, compelling educators to make selections amidst ambiguity.

This Study tackles these difficulties by analyzing artificial intelligence as a facilitator of conceptual comprehension in physics education, situated within broader transformations in curriculum design, pedagogy, and professional practice driven by AI integration [11]. It emphasizes three interconnected dimensions: the interaction of AI with students' misconceptions and conceptual change processes, its transformation of inquiry-based learning, and its reconfiguration of teacher agency and professional judgment. Ethical and pedagogical boundaries are examined, focusing on epistemic trust, equity, and the integrity of assessments. The essay presents an interpretive synthesis of current evidence and delineates necessary research directions to guarantee that AI integration enhances, rather than undermines, the conceptual basis of physics education.

**Artificial Intelligence, Misconceptions, and Conceptual Change in Physics Learning**

Misconceptions in physics are not arbitrary mistakes but rather enduring explanatory frameworks that arise from quotidian experiences and are bolstered by language, perception, education, and embodied interaction with physical systems [12]. Extensive research over several decades has demonstrated that students develop intuitive models of force, motion, energy, and fields that are coherent and functional in everyday circumstances but are incompatible with scientific explanations. These frameworks exhibit resistance to change and frequently coexist with formal knowledge, reemerging when students encounter unfamiliar issues or when cognitive demands intensify, a pattern that has been shown to correlate with students' mental age and cognitive readiness [1]. The integration of artificial intelligence into physics education significantly transforms the dynamics of how misconceptions are identified, contested, and potentially restructured.

Large language models can produce various explanations for the same phenomena, providing parallels, counterexamples, and alternate representations as needed. This capability may facilitate conceptual transformation by rendering competing models explicit and accessible for comparison. Preliminary classroom experiments suggest that student engagement with AI systems for generating forecasts or explanations enhances their ability to express their own thoughts and recognize discrepancies between their reasoning and scientific models [6, 7]. In these instances, AI can serve as a reflection of student cognition, externalizing implicit assumptions for examination and critique, a strategy explicitly operationalised in AI-supported physics lesson designs [13]. This corresponds with established theories of conceptual change that highlight the significance of cognitive conflict and metaconceptual awareness in the reorganization of knowledge. Recent analyses of ChatGPT in physics education further indicate that AI can support these processes by prompting learners to articulate predictions, design testable procedures, and reflect on discrepant outcomes, thereby participating in the scientific process itself [5].

Nonetheless, AI's engagement with misconceptions is profoundly ambiguous. Evaluations of AI performance on conceptual physics assessments indicate that large language models often generate explanations that are linguistically proficient yet conceptually erroneous. In the Force Concept Inventory, AI systems frequently identify the correct answer while articulating reasoning that embodies prevalent student fallacies regarding force as an intrinsic attribute or as a quantity that is "depleted" [3]. In the domains of electricity and magnetism, GPT-4 exhibits proficiency in definitional tasks but encounters difficulties with spatial reasoning and causal relationships, yielding assertive yet erroneous interpretations of field interactions [4]. These errors are especially problematic due to their presentation with rhetorical certainty, rendering them challenging for learners to identify.

Research on student engagement with ChatGPT indicates that several learners exhibit significant epistemic faith in AI-generated responses, despite acknowledging the potential for errors. Ding *et al*. discovered that students often accepted AI answers without scrutiny, particularly when the AI's response was precise and well-organized [8]. This establishes a novel risk profile for conceptual learning: while conventional textbooks or instructor explanations adhere to curricular and professional standards, AI-generated explanations may differ in quality and potentially perpetuate misconceptions. In this regard, AI is not merely a neutral instrument but an epistemic agent that influences the formation of learners' conceptual frameworks.

The influence of AI on conceptual transformation is significantly contingent upon pedagogical framing. The utilization of AI to produce explanations that undergo critique, comparison, and experimental validation might enhance conceptual engagement. Conversely, when AI is regarded as an authoritative source of accurate answers, it might circumvent the challenges and ambiguities crucial for conceptual reformation. This differentiation reflects wider discussions in conceptual transformation research regarding the equilibrium between direction and constructive challenge. AI can reduce cognitive barriers; yet, if it eliminates the necessity for learners to confront contradictory concepts, it may hinder profound comprehension.

Significantly, AI introduces a novel sort of "external cognition" into the educational setting. Students are no longer constrained by their own cognitive frameworks or the explanations provided by educators and textbooks; they can now utilize a generative system that generates ostensibly credible reasoning on demand. This can broaden the array of ideas for contemplation, although it also confuses the epistemological terrain. Learners must now traverse not only intuitive and scientific models but both human and artificial sources of explanation. Enhancing the ability to assess, challenge, and improve AI-generated reasoning is thus integral to conceptual learning.

From a conceptual transformation standpoint, this indicates that AI ought to be intentionally incorporated into educational designs that emphasize evaluation, justification, and evidence. Instead of instructing students to obtain a definitive answer from AI, educators can present AI outputs as hypotheses for examination, explanations for evaluation, or models for comparison. Such applications maintain the primacy of thinking while leveraging AI's generative capabilities. In the absence of this framework, there exists a significant risk that AI will serve as a conceptual shortcut, enabling students to evade the cognitive effort necessary to restructure their comprehension of physics.

**Artificial Intelligence and the Reconfiguration of Inquiry-Based Learning in Physics**

Inquiry-based learning is considered fundamental to good physics education as it engages learners as active architects of knowledge through iterative processes of inquiry, investigation, evidence assessment, and explanation, often mediated through hands-on experimentation with physical systems [12]. In this tradition, conceptual knowledge is anticipated to arise from the constructive conflict between students' intuitive notions and empirical findings. The integration of artificial intelligence into inquiry contexts significantly transforms these dynamics by introducing a novel source of questions, explanations, and feedback that can function in real time and at scale. This reconfiguration prompts critical inquiries regarding whether AI enhances or diminishes the epistemic functions intended by inquiry-based learning.

Recent empirical research indicate that AI can enhance inquiry processes by supporting reasoning that students frequently struggle with. When learners utilize big language models to formulate investigable questions, identify variables, or make predictions, they exhibit enhanced involvement with the framework of scientific inquiry and a more explicit assessment of alternative explanations [14, 15]. In physics, this help is especially beneficial in areas where students find it challenging to manage several variables, such as mechanics or thermal phenomena. AI-generated prompts can highlight causal links, assisting learners in transcending superficial characteristics of phenomena to develop more profound explanatory models. In this regard, AI may serve as a cognitive framework that enhances the visibility and accessibility of epistemic inquiries.

The incorporation of AI into inquiry poses the possibility of diminishing productive struggle. Inquiry-based learning relies on learners encountering uncertainty, contending with conflicting ideas, and constructing meaning via evidence. If AI provides explanations too early or restricts the range of alternative interpretations, it can disrupt these processes. Research on student utilization of ChatGPT in physics problem-solving contexts indicates that learners frequently engage with AI at the first stages of the inquiry process, occasionally prior to fully formulating their own hypotheses or investigating the phenomenon independently [8]. This pattern indicates that AI can unintentionally diminish possibilities for cognitive conflict, a crucial catalyst for conceptual transformation. When explanations are easily accessible, learners may neglect the challenging task of aligning intuition with facts.

The influence of AI on inquiry is hence extremely contingent upon pedagogical design, with classroom studies showing that carefully sequenced AI-supported activities can promote hypothesis testing, evidence evaluation, and reflective discussion, whereas unstructured use tends to reduce inquiry to answer-seeking [13]. When educators present AI as a mechanism for generating alternative hypotheses or for prompting students to substantiate their assertions, AI can enhance inquiry by broadening the spectrum of ideas being examined. Conversely, when AI functions as an answer engine, inquiry devolves into verification instead of exploration. Research in educational settings demonstrates that students exhibit greater engagement in evidentiary reasoning when AI-generated outputs are regarded as tentative and open to verification, rather than as definitive answers [6]. This method maintains the epistemic integrity of investigation while utilizing AI's generative capabilities.

AI also transforms the temporal framework of investigation. Conventional inquiry sequences typically continue across prolonged durations, allowing time for planning, experimenting, and reflection. Artificial intelligence facilitates swift iteration, permitting students to formulate several ideas and obtain instantaneous feedback. This acceleration may enhance efficiency but could also shorten reflecting moments crucial for conceptual integration. The issue for educators is to leverage AI's rapidity without compromising depth. This necessitates intentional pace and organized opportunities for reflection, comparison, and synthesis of comprehension.

A different aspect pertains to the allocation of agency within the inquiry process. Inquiry-based learning historically prioritizes student autonomy in formulating questions and designing investigations. When AI significantly influences these processes, agency may transfer from the learner to the system. Studies indicate that pupils occasionally rely on AI-generated inquiries or methods, presuming that the system possesses superior knowledge [16]. This respect may undermine learners' sense of ownership within the inquiry process and diminish their inclination to suggest or defend their own ideas. Preserving learner agency is therefore a primary design consideration in AI-enhanced inquiry settings.

From a theoretical standpoint, AI contests fundamental assumptions regarding inquiry as a human-centered epistemic endeavor, contributing to a reconfiguration of how scientific knowledge is generated, mediated, and validated in physics education [5]. It presents a non-human entity capable of offering explanations devoid of experiences, intents, or epistemic commitments. This prompts inquiries regarding how learners perceive the validity of AI-generated knowledge and how they assimilate it with empirical data. If AI is regarded as a source of authoritative knowledge instead of a tool for investigation, the essence of inquiry is transformed. It is imperative to build pedagogies that explicitly consider the epistemic status of AI to maintain inquiry as a domain for authentic conceptual advancement.

AI has the capacity to enhance inquiry-based learning in physics by facilitating reasoning, broadening the range of concepts, and aiding iterative investigation. These advantages depend on meticulous educational structuring that fosters constructive struggle, learner autonomy, and epistemic openness. In the absence of such framing, AI may reduce inquiry to a mere exercise in answer validation, jeopardizing the fundamental processes that foster conceptual comprehension.

**Artificial Intelligence, Teacher Agency, and Professional Judgment in Physics Education**

The swift incorporation of artificial intelligence into physics education is not only altering student learning methodologies but also radically reshaping the professional responsibilities of educators, marking a transition from traditional instructional roles to technologically mediated pedagogical design [5]. Historically, physics educators have functioned as the principal epistemic authority in the classroom, tasked with choosing representations, identifying misconceptions, facilitating inquiry, and directing students towards scientifically coherent explanations. AI now integrates into this ecosystem as a formidable creator of information, explanations, and feedback, prompting essential inquiries regarding the preservation, transformation, or possible erosion of teacher agency in AI-mediated learning environments.

Recent evidence indicates that AI can enhance teachers' teaching capabilities by facilitating differentiation, offering alternative explanations, and aiding in the swift diagnosis of student reasoning. In physics classrooms, educators have started employing AI systems to produce numerous representations of identical concepts, generate variations of conceptual inquiries, and suggest experimental designs that can be tailored for diverse learner groups [7, 17]. In this context, AI serves as a professional resource that enhances instructors' educational repertoire instead of supplanting it. Educators indicate that AI-generated explanations can provoke classroom dialogue and offer avenues for confronting misconceptions that students may be hesitant or incapable of expressing independently. This corresponds with overarching assertions in the AI-in-education discourse that highlight AI's capacity to function as a "pedagogical amplifier" when integrated into reflective teaching methodologies [15].

The introduction of AI concurrently creates new vulnerabilities for teacher autonomy. Research on student behavior reveals that learners frequently ascribe significant epistemic authority to AI-generated solutions, occasionally favoring them over teacher explanations, particularly when AI answers are articulate and assertively presented [8]. This dynamic might gradually undermine the teacher's position as the principal mediator of knowledge, transferring authority to the machine. This transition might be especially unsettling for educators who already perceive a lack of confidence in their physics topic expertise. There exists a risk that educators may rely on AI explanations instead of critically assessing them, particularly in areas where AI demonstrates robust performance. This respect may result in the unthinking propagation of AI-generated fallacies or oversimplifications.

Consequently, professional judgment assumes greater significance in classrooms enriched with AI. Educators must determine when AI contributions are pedagogically beneficial, when they warrant scrutiny, and when they should be entirely disregarded. This necessitates a profound comprehension of both physics concepts and the inherent failure mechanisms of AI. Investigations into AI efficacy in conceptual physics tasks indicate that models can yield accurate numerical results despite flawed reasoning or may misinterpret diagrams and spatial relationships in subtle ways [3, 4]. Educators who are oblivious to these constraints may unintentionally validate erroneous explanations by integrating them into their teaching. In contrast, educators who comprehend the limitations of AI can leverage them constructively, encouraging students to identify and rectify mistakes, thus enhancing conceptual awareness and epistemic humility.

The incorporation of AI redefines educators' roles in overseeing classroom epistemologies. Educators are now responsible for exemplifying critical engagement with AI, illustrating that AI outputs represent hypotheses rather than certainties, and that scientific knowledge is constructed through evidence, argument, and consensus rather than algorithmic production. This approach is especially significant in physics, where students frequently pursue definitive solutions and may feel uneasy with ambiguity. By presenting AI as an imperfect collaborator, educators can maintain the principle that explanations must be substantiated by empirical and theoretical consistency.

Professional development serves as a vital mechanism in this process. Preliminary research and policy evaluations consistently indicate that educators require organized chances to understand AI's capabilities, limitations, and ethical considerations, along with methods for incorporating AI into inquiry-based teaching [9, 10]. Professional learning must extend beyond technical training to encompass epistemological thinking and pedagogical design. Educators require assistance in cultivating what might be referred to as "AI pedagogical literacy": the ability to analyze AI-generated outputs, predict student reactions, and create learning experiences that utilize AI while maintaining pedagogical authority.

AI fundamentally undermines conventional conceptions of teacher expertise. Expertise is now characterized not only by content knowledge but also by the capacity to maneuver through a complicated informational landscape where authoritative-sounding explanations can be produced instantaneously. In this sense, teacher agency pertains to the ability to curate, evaluate, and contextualize knowledge. Physics educators serve as both disseminators of scientific knowledge and custodians of epistemic integrity, facilitating learners' abilities to assess sources, evaluate evidence, and formulate conceptually coherent explanations.

The impact of AI on teacher agency in physics education will ultimately hinge on institutional decisions, professional development frameworks, and classroom methodologies. The adoption of AI as a substitute for teacher reasoning jeopardizes the integrity of professional judgment. If utilized as a means to enhance educational outreach and enrich conceptual discourse, it can strengthen the teacher's position as a primary architect of learning. The task is thus not technological but pedagogical: to devise AI integration that honors and amplifies the professional autonomy crucial for substantive physics instruction.

**Discussion**

The investigations in this Study converge on a key insight: artificial intelligence is not merely an instructional tool in physics education but an epistemic agent that transforms the construction, evaluation, and legitimization of conceptual understanding. The ability to produce coherent explanations, formulate hypotheses, and adaptively reply to learners' inquiries presents new possibilities for facilitating conceptual transformation, but also introducing potential concerns of epistemic dependency and conceptual distortion. The ramifications of this dual role are significant for a discipline where learners' intuitive frameworks are strong and resistant to alteration, and where comprehension relies on the integration of various representations, causal models, and abstract principles.

The instructional efficacy of AI is demonstrated to rely more on the pedagogical environments in which it is integrated than on its technical complexity. When AI is presented as an imperfect collaborator whose results can be evaluated, tested, and improved, it can broaden the range of ideas accessible to learners and enhance engagement with explanatory reasoning [6, 14]. In these systems, AI facilitates the epistemic transitions essential to inquiry-based learning by rendering alternative explanations apparent and encouraging metacognitive reflection. On the contrary, when AI is regarded as an authoritative source of information, it jeopardizes constructive struggle and undermines the cognitive effort necessary for conceptual restructuring [8]. This tension indicates that AI's educational influence is shaped by instructional standards and classroom knowledge frameworks, rather than solely by algorithmic efficacy.

A secondary principal subject is to the redefinition of teacher agency. The existence of AI amplifies the significance of professional discernment in the selection, interpretation, and challenge of AI-generated content. The epistemic posture of teachers---whether they demonstrate critical engagement with AI or yield to it---affects pupils' trust and learning practices. The examined research suggests that educators who treat AI outputs as subjects for exploration instead of definitive answers promote deeper conceptual discussions and maintain the importance of evidence-based reasoning [15, 17]. This recontextualization emphasizes that AI does not undermine the teacher's position; instead, it necessitates new types of expertise focused on epistemic mediation, ethical discernment, and pedagogical design. Professional development must transcend mere tool training to foster AI pedagogical literacy, encompassing an understanding of model limitations, common failure mechanisms, and methods for maintaining learner agency [9, 10].

Ethical constraints further constrain the parameters of permissible AI utilization. The dangers of excessive dependence, unequal access, privacy violations, and distorted evaluations are fundamental to the core objectives of physics education. If the employment of AI displaces learners' sense-making or prioritizes fluency over comprehension, it contradicts the epistemic objectives of the profession. The ethical border is both pedagogical and legal or technical: AI should be utilized to stimulate, not substitute, thinking; to support, not undermine, inquiry; and to enhance, not diminish, learner autonomy. The cautious principle is justified due to the rapid advancement of AI and the delay in empirical study. Institutional adoption should be guided by iterative, evidence-based implementation coupled with transparent evaluation.

This synthesis leads to multiple study avenues. Initially, longitudinal research are essential to investigate how prolonged engagement with AI influences the growth and retention of physics concepts, encompassing the stability of misconception rectification and the transfer of comprehension across various contexts. Secondly, design-based research ought to delineate and evaluate educational frameworks that regard AI as a source of hypotheses, counterexamples, and representations, rather than merely as a solution provider. Third, investigations must elucidate how learners perceive the epistemic status of AI-generated knowledge and how this perception influences their interaction with evidence and authority. Fourth, research on teacher learning should investigate how various types of professional development affect teachers' ability to facilitate AI-mediated inquiry and uphold conceptual rigor. Ultimately, equity-centered research is crucial to prevent AI-enhanced physics education from worsening existing inequalities in access, representation, and opportunity.

In summary, artificial intelligence possesses the capacity to serve as a significant facilitator of conceptual comprehension in physics education, contingent upon its integration being directed by pedagogical intent, ethical oversight, and ongoing research. The future of AI in physics education will be dictated not by the capabilities of algorithms, but by how educators construct learning environments that maintain inquiry, critical assessment, and the paramount importance of human judgment. Considering AI as a collaborator in scientific reasoning, rather than a substitute, presents a progressive approach that harmonizes technology advancement with the fundamental objectives of physics education.

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