

Deep Learning in Physics Education: Exploring the Potential of Mindful, Meaningful, and Joyful for a Better Learning Experience

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Abstract

This article explores the synergistic potential of integrating the Deep Learning approach with the Mindful, Meaningful, and Joyful learning paradigm to enhance physics education. Traditional physics instruction often faces "fundamental barriers" in human learning, leading to a lack of student engagement and a decline in expert-like confidence. Despite efforts to improve teaching methods, significant progress in student learning outcomes remains difficult to achieve. We argue that Deep Learning, with Intelligent Tutoring System (ITS) capabilities in personalization, adaptation, and interactive simulation, can act as a powerful driver to foster mindful, meaningful, and joyful learning experiences in physics. Mindful learning enhances cognitive and emotional well-being, meaningful learning promotes deep understanding and relevance, and joyful learning nurtures intrinsic motivation and creativity. A comprehensive review of the latest literature (2015-2025) reveals that intelligent Deep Learning-powered tutoring systems, adaptive learning environments, virtual laboratories, personalized feedback mechanisms, and gamification strategies can collectively transform physics pedagogy. This integration encourages increased student engagement, better conceptual understanding, critical thinking, problem-solving skills, and more positive emotional involvement, thereby creating a more effective and sustainable learning journey. It is concluded that the holistic framework integrating Deep Learning with this pedagogical philosophy offers a promising path to address long-standing challenges in physics education.

Keywords: Deep Learning; Physics Learning; Literature Review, Intelligent Tutoring System (ITS)

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1. INTRODUCTION

Physics, as a fundamental science, plays a crucial role in technological advancement and societal development. However, the teaching and learning of physics have historically faced significant challenges, with the presence of a persistent fundamental barrier in human learning (Shafiq, et.al., 2020). Although various pedagogical interventions have been implemented to enhance student motivation, simplify content, or develop engaging materials, there has been no significant improvement in student test scores (Davis & Price, 2017). This struggle is often linked to "the wide variety of student learning and preparation types. This indicates that a one-size-f Intelligent Tutoring System (ITS)-all approach in physics education often fails to accommodate the cognitive diversity and learning styles of students.

Moreover, typical physics courses often lead to a decline in students' confidence in physics, making them view it as irrelevant or merely rote memorization, rather than fostering an appreciation for physics as a coherent and logical method for understanding the world. These findings are particularly concerning as they indicate a profound pedagogical failure; students may leave physics courses with a perspective contrary to the faculty's expectations, namely that physics is a coherent and logical method for understanding the world (Madsen, et al., 2015). This indicates a critical gap in fostering a deep and expert-like understanding and engagement.

In facing this challenge, the rapid advancements in Artificial Intelligence (AI), particularly Deep Learning, are fundamentally transforming the landscape of various scientific disciplines and hold great potential for transforming education. Deep Learning's ability to analyze complex data, recognize patterns, and adapt to individual needs positions it as a powerful tool to overcome long-standing educational barriers, offering personalized learning, adaptive assessments, and increased efficiency. This potential goes beyond mere efficiency improvements; Deep Learning can fundamentally change how and to whom physics is taught, potentially overcoming "fundamental barriers" by adapting to diverse learners. This shift can lead to significant improvements in STEM literacy and participation, as physics becomes more accessible to a broader demographic. This positions Deep Learning as a tool for educational equity, addressing historical limitations in physics teaching that inadvertently selected only certain types of learners.

To maximize this potential, it is important to integrate Deep Learning with pedagogical philosophies that have been proven to enhance the quality of the learning experience holistically. This article focuses on three main learning concepts: 1) Mindful Learning: Defined as a flexible state of mind characterized by active engagement, contextual awareness, sensitivity to novelty, and the continuous creation of differences and new categories (Langerian mindfulness). This is associated with improved well-being, creativity, and critical thinking (Feriyanto & Anjariyah, 2024). It indicates that mindful learning is not just about reducing stress, but also about enhancing cognitive capacity for higher-order thinking. 2) Meaningful Learning: Involves connecting new knowledge with prior understanding, fostering deep comprehension through cooperative, active, authentic, constructive, and intentional learning experiences. This goes beyond mere memorization towards true understanding and application. 3) Joyful Learning: Emphasizes the creation of a fun and motivating learning environment that fosters happiness and intrinsic motivation (Ghazali, et al., 2020). These things promote emotional engagement, creativity, imagination, and long-term retention.

Students' struggles in physics, often marked by "frustration" and "conflict" in traditional settings, as well as a decline in their confidence about the subject, indicate that issues in physics education are not only cognitive but also highly affective. Emotional engagement is crucial for Deep Learning; therefore, the current negative emotional experiences in physics become a significant barrier that prevents meaningful and enjoyable learning. The potential of Deep Learning to foster positive emotions (through gamification, personalized success, stress reduction) becomes a critical intervention to unlock cognitive potential (Guo & Depaynos, 2023). This indicates that future physics education supported by Deep Learning should be designed with the component of "emotional intelligence," actively fostering a positive emotional environment to ensure students remain engaged, resilient, and motivated.

This study aims to explore the synergistic potential of integrating Deep Learning approaches with the Mindful, Meaningful, and Joyful learning paradigm to create more effective, engaging, and enriching experiences in physics education. Specifically, we will review how Deep Learning technology can facilitate and enhance the core principles of mindful, meaningful, and joyful learning, and discuss Intelligent Tutoring System (ITS) implications for transforming physics pedagogy to foster deeper conceptual understanding, critical thinking, problem-solving skills, and positive emotional engagement.

2. METHODS

This research adopts a systematic literature review approach, in line with the library research method. This method involves comprehensive collection, critical reading, meticulous note-taking, and thematic analysis of existing scientific publications. A systematic literature review is a strategic methodological choice for rapidly evolving fields such as Deep Learning in physics education. This allows for mapping emerging interdisciplinary fields, identifying new trends, existing evidence, and critical gaps. This method is very valuable when direct empirical studies about specific integration is likely still rare, thus requiring a synthesis of evidence from related but different domains (for example, Deep Learning in general education, mindfulness in general STEM, gamification in science). Thus, this review can build a strong theoretical framework and identify promising paths for future empirical research.

Research Process Sequence

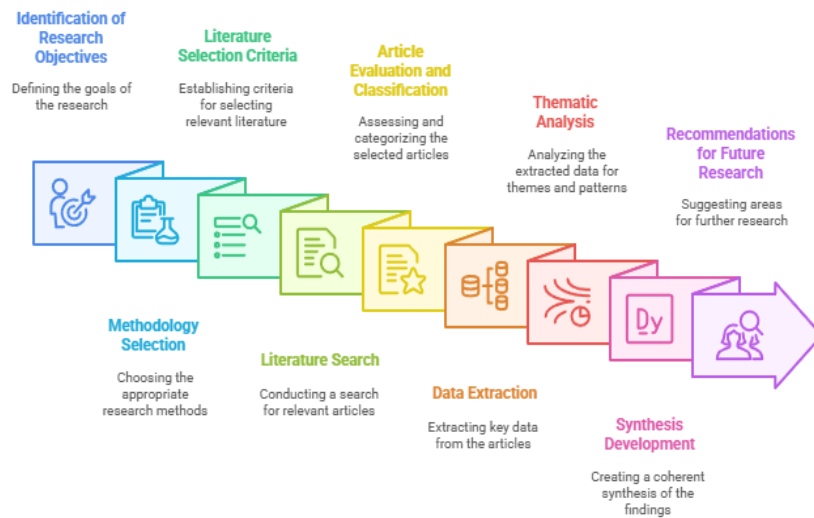


Figure 1. Research Process Sequence

The literature search focused on peer-reviewed journal articles published in the last decade (2015-2025) to ensure currency and relevance, as required by the template. The restriction on this recent literature implicitly acknowledges the rapid pace of change in AI and educational technology. This review serves as an overview of the current state of the art at this intersection, highlighting that continuous updates and further research will be necessary given the dynamic nature of this field.

The keywords used for the search include Deep Learning physics education, AI in physics education, mindful learning physics, meaningful learning physics, joyful learning physics, adaptive learning physics, intelligent tutoring systems physics, personalized feedback physics, gamification physics, and virtual reality physics education. A total of 20 journal articles and research reports were selected for in-depth analysis, ensuring that at least 80% consisted of research articles. Attention was given to prioritizing comprehensive and reliable sources, especially those with explicit citation details and summaries.

Data Analysis: Synthesis and Thematic Analysis of Results. The selected articles are systematically analyzed to extract information related to 1) The application and impact of Deep Learning /AI in various aspects of physics education (for example, intelligent tutoring, adaptive learning, virtual laboratories, personalized feedback, gamification). 2) Definition, characteristics, and benefits of Intelligent Tutoring System (ITS) of Mindful Learning, Meaningful Learning, and Enjoyable Learning, particularly in the context of STEM. 3) Explicit or implicit connections, synergy, and potential integration between Deep Learning technology and these three learning paradigms. 4) Challenges and limitations associated with the implementation of AI/ Deep Learning in education. Thematic analysis is then used to synthesize the extracted data, identify recurring patterns, emerging themes, and causal relationships, ultimately building a comprehensive argument for the synergistic potential of the integrated approach.

3. RESULT AND DISCUSSION

Deep Learning in Physics Education: Current Landscape and Innovations
Deep Learning and Artificial Intelligence (AI) are rapidly transforming the landscape of physics education, shifting from traditional pedagogical models to more interactive and student-centered approaches (Suresh, et al, 2024). This shift is driven by Deep Learning's ability to enable scalable personalization, which has historically been limited by the teacher-student ratio. Deep Learning addresses this limitation, making customized and high-quality support accessible to a much larger population of students. This directly addresses the wide variety of learning types and student

preparations that are difficult to handle with traditional methods, democratizing access to effective learning strategies.

Intelligent Tutoring System (ITS) and Adaptive Learning AI-based Intelligent Tutoring System (ITS) provides personalized instruction, real-time feedback, and adaptive learning paths, significantly enhancing student performance and fostering deeper understanding (Rus, et al., 2016). This system analyzes students' knowledge, learning speed, and preferred styles to adjust the difficulty and focus of the content. Deep Tutor, an Intelligent Tutoring System (ITS) focused on high school physics, uses deep language and discourse processing to address the illusion of knowing (false assumptions about students' understanding), leading to more accurate assessments and better communication. These advanced feedback mechanisms are crucial for targeted interventions. Adaptive learning systems, supported by machine learning algorithms, dynamically identify knowledge gaps and adjust educational materials to individual needs, keeping students engaged without feeling overwhelmed (Strielkowski, et al., 2025).

The ability to provide personalized support on a large scale can significantly reduce achievement gaps by offering targeted assistance to struggling students while challenging advanced learners, thereby promoting fairer and more efficient learning outcomes across the student body in physics (Nurulwati, et al., 2020). Virtual Laboratory and Interactive Simulation AI based virtual laboratories and interactive simulations (PhET Interactive Simulations combined with ChatGPT) allow students to experiment with concepts and receive detailed explanations, making abstract physics knowledge easier to understand. These platforms provide hands-on experiments without the need for a physical laboratory, which is essential for visualizing complex and high-risk physical phenomena. The integration of AI with Augmented Reality (AR) and Virtual Reality (VR) creates immersive and adaptive experiences, enhancing knowledge retention and enabling safe practice in scenarios such as nuclear reactions or high-voltage circuits. Intelligent Tutoring System (ITS). These Deep Learning - powered tools do not just convey information; they create rich and interactive learning experiences. This shifts physics education from passive fact reception to active exploration, experimentation, and problem-solving in a dynamic environment. The focus shifts from "what information is conveyed" to "what experiences are provided to facilitate understanding," directly supporting the principles of constructivist learning.

This experiential learning, facilitated by Deep Learning, can foster deeper conceptual understanding and critical thinking skills that are difficult to achieve through traditional methods. Personalized Feedback and Assessment Deep Learning, particularly Large Language Models (LLMs) like GPT-3.5 and GPT-4, are revolutionizing personalized and timely feedback on students' written responses to conceptual questions (Davis & Price, 2017). Studies show that AI-generated feedback is rated as equally accurate and often more useful to students compared to human feedback, overcoming critical barriers in courses with a large number of students. The ability of AI to generate feedback that is not only accurate but also pedagogically effective perhaps due to Intelligent Tutoring System (ITS) consistency, detail, or non-evaluative nature directly enhances meaningful learning by clarifying misunderstandings and mindful learning by encouraging reflection on one's understanding. Deep Learning techniques also enable adaptive assessment, providing customized exams based on previous performance and analyzing behavioral data for personalized responses. This implies a future where personalized and high-quality feedback is no longer a luxury constrained by instructor time but a standard feature of physics education, enabled by Deep Learning.

AI-based gamification significantly enhances student engagement, motivation, and learning outcomes in physics education. Games like "Basketball Physics Challenge" show increased time on task, higher trial frequency, and a positive correlation between game scores and quiz performance, fostering a deeper understanding and retention of complex scientific concepts (Richter & Kickmeier, 2025). The increase in "time on task" and "trial frequency" are direct indicators of intrinsic motivation and perseverance, which are crucial for mastering challenging subjects like physics. Gamification, especially AI-driven, can provide adaptive challenges and instant feedback in a satisfying context, transforming potentially frustrating struggles into engaging challenges.

Although the potential of Deep Learning is immense, AI integration faces obstacles such as equity issues, cost burdens, human resistance to adaptation, and concerns related to data privacy and

algorithmic discrimination. There is a need for ML models that can be interpreted in physics, prioritizing explanation over pure accuracy, especially considering the "black box" nature of some Deep Learning models. Bridging the gap between ML specialists and physics specialists is also crucial for effective implementation. This highlights the need for a new generation of "physics-based" and "interpretable" physics educational tools.

Mindful learning, rooted in Langer's definition, is a cognitive state characterized by active engagement, contextual awareness, sensitivity to novelty, and the continuous creation of differences and new categories (Prince, 2023). This is different from meditation-based mindfulness, which emphasizes a flexible state of mind during learning. Physics is often considered challenging and can cause frustration. The ability of mindful learning to build emotional resilience and metacognitive flexibility directly addresses this issue, equipping students to handle Deep Learning and the inherent difficulties of physics, preventing the "frustration" noted in traditional instruction. This makes students more persistent and adaptable learners.

Mindful learning is positively related to generating new thoughts, fostering intelligence, and developing meta-cognitive awareness of the learning process. This enhances 21st-century skills such as creativity, collaboration, communication, and critical thinking by encouraging students to notice differences, consider various perspectives, and explore diverse solutions. The core of Langerian mindfulness activities making distinctions, noticing new things, and recategorizing is fundamental to the scientific process Intelligent Tutoring System (ITS), especially in physics. By explicitly cultivating these mindful cognitive Intelligent Tutoring System (ITS), physics education can go beyond rote memorization of formulas to foster genuine scientific inquiry and conceptual development, aligning the learning process with the epistemology of physics.

Mindful learning is significantly correlated with Subjective Well-Being (SWB) and Psychological Well-Being (PWB). Mindfulness-based interventions have been proven to reduce negative emotions such as anxiety and stress, especially in high-stakes math test situations. This is particularly important considering the stress often associated with physics. This acts as a "protective factor" for student well-being, helping students manage emotional challenges in learning. Integrating mindful learning into physics education, potentially through Deep Learning tools that encourage reflection or provide soothing feedback, can transform the learning experience from a source of stress into an opportunity for growth.

Mindfulness positively affects self-efficacy, helping students gain a better understanding of their abilities and reducing problem-solving barriers such as sticking to familiar methods or obsessing over unsolved problems (Shelach & Tarrasch, 2025). In science education, integrating mindfulness can result in significantly higher levels of mindfulness, motivation, and achievement. Meaningful Learning: Fostering Deep Understanding and Relevance in Physics Meaningful learning goes beyond memorization, focusing on students' ability to connect new information with existing knowledge and apply it in various contexts. It stimulates intellectual curiosity and engagement in dynamic instructional activities. Meaningful learning is defined as the opposite of "rote learning." The contrast between meaningful learning and the negative outcomes of traditional physics instruction is striking. If students leave a physics course believing it is about memorization, then the core goals of science education fostering conceptual understanding and critical thinking are being undermined. Deep Learning, by enabling adaptive content, authentic simulations, and personalized feedback, can directly counter this trend by facilitating active, constructive, and intentional learning experiences that make physics concepts relevant and deeply understood, thereby transforming negative beliefs into expert-like beliefs.

- Dimensions of Meaningful Learning:
- Cooperative learning: Willingness to interact and collaborate with instructors and peers.
 - Active learning: Participation in learning activities and exploration of new information.
 - Authentic learning: The ability to connect learned concepts with everyday experiences and real-world phenomena.
 - Constructive learning: Creating new understanding by integrating previous knowledge and new knowledge, articulating what has been learned, and reflecting on the process.

- Intentional learning: Setting personal learning goals, organizing learning, and identifying/closing understanding gaps.

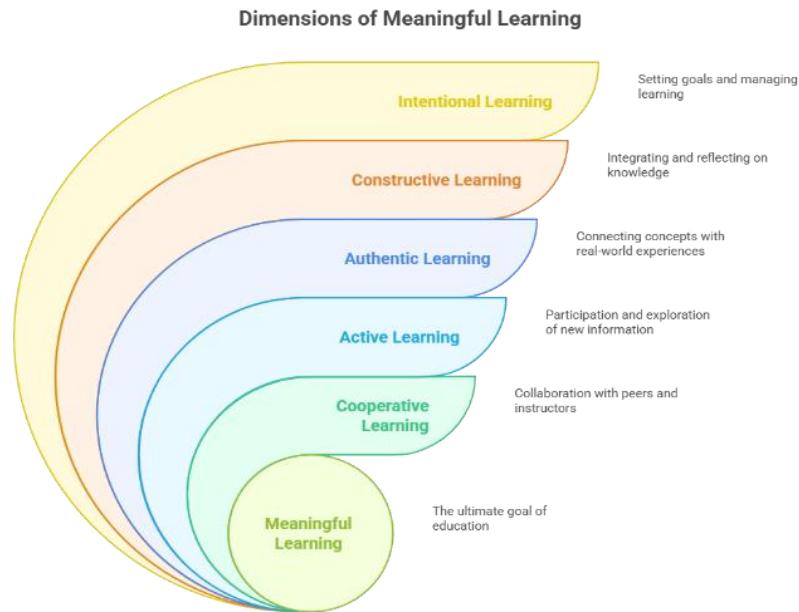


Figure 2. Dimensions of Meaningful Learning

Challenges in Traditional Physics Education Typical physics courses often fail to support students in developing expert-like confidence, and in many cases, students' confidence in physics actually declines, causing them to view physics as rote memorization and irrelevant. This directly contradicts the goals of meaningful learning. The Role of Technology in Facilitating Meaningful Learning The efficacy of MOOCs for students is positively related to meaningful learning, indicating that technology-enhanced environments can support deeper engagement. Project-based learning and gamified educational methods facilitate critical thinking and problem-solving, promoting meaningful learning. Immersive technologies (AR/VR, 3D models) provide interactive and direct experiences that enhance visualization and problem-solving, making abstract concepts more tangible and relevant. This aligns with constructivist teachings. Computer-based interventions, even without explicit Deep Learning, have shown significant improvements in conceptual understanding in Newtonian dynamics.

Physics is often considered abstract and detached from reality. Deep Learning, particularly through AI-powered virtual laboratories and immersive simulations, can bridge this gap by providing authentic real-world contexts for learning. This allows students to actively engage with physical phenomena as they occur in the real world, test theoretical models against simulation data, and see the practical implications of abstract concepts. This fosters a much deeper, more intuitive, and meaningful understanding.

Enjoyable Learning: Enhancing Motivation and Emotional Engagement in Physics Fun learning focuses on creating a positive and intrinsically motivating learning environment where students feel comfortable, motivated, and enthusiastic. These aim to foster happiness and intrinsic motivation, which have been proven to significantly improve learning outcomes. Strategies for Fostering a Positive Learning Environment Integration of Art and Game-Based Activities: This strategy is effective in fostering emotional engagement and retention. Game-based learning, in particular, has been proven to improve average test scores and enhance conceptual understanding. Gamification, especially those driven by AI, can provide adaptive challenges and instant feedback in a satisfying context, turning potentially frustrating struggles into engaging challenges. Scaffolded Learning: Providing adaptive support that gradually decreases as students' proficiency increases, ensuring a smooth transition from easier to more difficult concepts, improving overall outcomes and reducing frustration. Positive Emotional Experiences: Research shows that positive emotions enhance motivation and enrich the learning environment, while negative emotions

reduce engagement. Fun learning can develop students' open-mindedness, imagination, and creativity, which are important for scientific inquiry.

This fosters emotional engagement and retention through various activities. AI-supported data analysis has been proven to enhance student motivation and reduce stress in physics education, leading to increased emotional engagement and a more supportive learning environment. Students find AI methods more engaging, easier to use, and more helpful, which intrinsically motivates them. Reducing stress and negative emotions through AI-supported tools and mindful practices is a prerequisite for truly enjoyable learning. Deep Learning, by providing adaptive scaffolding, personalized support, and instant feedback, can reduce these negative emotions, creating a psychologically safe space where excitement can thrive.

Synergistic Potential: Integrating Deep Learning with Mindful, Meaningful, and Joyful Approaches for a Better Physics Learning Experience. The true transformative power lies in the synergistic integration of Deep Learning with Mindful, Meaningful, and Joyful learning, forming a holistic framework to enhance the quality of education and student engagement. Deep Learning acts as the backbone of integrative technology that enables Mindful, Meaningful, and Joyful learning to be effectively and widely implemented in physics education. This provides adaptive intelligence, personalized pathways, and interactive environments that are essential for this pedagogical philosophy to thrive in complex subjects like physics.

Intelligent Tutoring Systems powered by Deep Learning and adaptive platforms can provide personalized learning pathways that adjust speed and difficulty, allowing students to focus and engage actively in the present without feeling overwhelmed (Dai, et al. 2024). This directly supports the aspect of "active engagement" in mindful learning. AI-assisted personalization can tailor content and feedback to individual needs, enhancing cognitive abilities and focus. By reducing stress and anxiety, Deep Learning supported environments create a calmer mental state conducive to mindful awareness and reflection. This enables students to "notice new things" and "create new differences" (Langerian mindfulness) more effectively.

Deep Learning enables the delivery of adaptive content that connects new knowledge with prior understanding, facilitating critical thinking and problem-solving skills through project-based education methods and gamification. Physics-Informed Neural Networks (PINN) integrate data with governing physical laws, allowing students to explore complex systems where empirical data and theoretical principles are crucial, fostering a deeper and physically consistent understanding. This directly supports "constructive" and "authentic" learning by bridging theory and real-world applications. AI-powered virtual laboratories and immersive simulations provide "live" and "authentic" experiences, making abstract physics concepts tangible and relevant to everyday life (Tuyboyov, et al., 2025). Personalized feedback generated by LLM can clarify misunderstandings and guide students in articulating their understanding, fostering "intentional" and "constructive" learning (Lara, 2024). A common challenge in physics education is the perceived disconnect between abstract theory and real-world applications. Deep Learning, through Intelligent Tutoring System (ITS) ability to drive highly realistic simulations (virtual labs) and integrate physical laws into Intelligent Tutoring System (ITS) models (PINN), directly addresses this gap. This allows students to actively engage with physical phenomena as they occur in the real world, test theoretical models against simulation data, and see the practical implications of abstract concepts. This fosters a much deeper, more intuitive understanding, and meaningful.

How Deep Learning Enhances Enjoyable Experiences: AI-based gamification, through adaptive challenges and instant feedback, intrinsically motivates learners, increases engagement, and promotes positive emotional connections with physics. This aligns with the core principles of enjoyable learning. Interactive simulations and virtual laboratories, enhanced by Deep Learning, provide enjoyable and motivating learning activities, fostering emotional engagement and retention. Reducing stress and frustration through adaptive support and personalized assistance creates a more conducive learning environment. Table 1 presents a visual summary of this synergistic potential, outlining how Deep Learning can facilitate each learning paradigm and Intelligent Tutoring System (ITS) impact on the physics learning experience.

Table 1. The Role of Deep Learning in Fostering Mindful, Meaningful, and Joyful Learning in Physics

Learning Paradigm	Main Characteristics	Deep Learning Facilitator/Application	Impact on Physics Learning Experience	Main Source
Mindful Learning	Active engagement, contextual awareness, sensitivity to the new, creation of new differences, meta-awareness, cognitive flexibility, reduction of stress and anxiety.	Intelligent Tutoring System (ITS) powered by Deep Learning and an adaptive platform (adjusting speed and difficulty), AI-assisted personalization, stress-reducing feedback, DeepTutor (addressing the illusion of guidance).	Improving focus and attention, reducing anxiety in learning physics, enhancing emotional resilience to difficulties, encouraging non-linear thinking and creativity, fostering self-awareness about the learning process.	Wen, et al., 2021
Meaningful Learning	Connecting new knowledge with prior understanding, cooperative, active, authentic, constructive, and intentional learning; deep understanding, real-world relevance, problem-solving.	Adaptive content based on Deep Learning (connecting knowledge), PINN (integrating data & physical laws), AI-powered virtual labs, immersive simulations (AR/VR), personal LLM feedback.	Building a strong conceptual understanding, bridging theory and practice, enhancing problem-solving skills in authentic contexts, encouraging reflection and knowledge construction, transforming students' beliefs to be like experts.	Maftuh, et.al., 2023
Joyfull Learning	A positive learning environment, intrinsic motivation, happiness, emotional engagement, creativity, imagination, long-term retention.	AI-based gamification (adaptive challenges, instant feedback), interactive simulations powered by Deep Learning, adaptive tiered learning, AI-supported data analysis (reducing stress).	Increasing motivation and perseverance, transforming the perception of physics into an interesting subject, encouraging enjoyable exploration, enhancing emotional engagement and information retention, fostering creativity and imagination in problem-solving.	Prabowo, 2025

4. CONCLUSION

Deep Learning offers a transformative framework to address long-standing challenges in physics education, which have historically been marked by "fundamental barriers" in learning and the decline of student confidence. Through intelligent tutoring systems, adaptive environments, virtual laboratories, personalized feedback, and gamification, Deep Learning not only enhances efficiency but also fundamentally transforms the nature of the learning experience.

Specifically, Deep Learning effectively facilitates Mindful Learning by fostering focus, reducing anxiety, and promoting meta-cognitive awareness, allowing students to engage more deeply with the material. This supports Meaningful Learning by enabling authentic, constructive, and intentional engagement, bridging abstract theory with real-world applications and fostering deep understanding. Finally, Deep Learning enhances Enjoyable Learning by increasing intrinsic motivation, emotional engagement, creativity, and perseverance through interactive and engaging experiences. The synergistic integration of these approaches, supported by Deep Learning, offers holistic and transformative solutions for physics education.

This transformation is not only technological; it also depends on balanced and ethical implementation. Although the potential of Deep Learning is immense, Intelligent Tutoring System (ITS) transformative power relies on responsible and ethical implementation. Ignoring issues of equity,

cost, and bias can exacerbate existing gaps and undermine the goal of a "better learning experience. Therefore, technological innovation must be combined with wise policies, teacher training, and ongoing ethical reviews to ensure that Intelligent Tutoring System (ITS) benefits are widely accessible and do not inadvertently create new barriers or disadvantages. This positions this report not just as a review of potential but as a call to action for the physics education community.

Furthermore, the role of educators in AI-enhanced classrooms is evolving. Deep Learning tools do not replace educators but redefine their roles. By shifting routine tasks (assessment, basic instruction), AI frees teachers to engage in higher-level pedagogical activities: fostering emotional relationships, guiding complex investigations, addressing individual student needs through "meaningful interactions," and ensuring a positive classroom environment. 13 These human-AI collaboration models are crucial for realizing the full potential of Deep Learning in physics education.



Recommendation for educators Encourage the adoption of Deep Learning-powered tools (Intelligent Tutoring System (ITS), simulations, gamification platforms) to personalize learning, provide timely feedback, and create an engaging environment. Emphasizing the importance of fostering a mindful and joyful state alongside cognitive engagement. For Curriculum Developers Advocate for the design of a physics curriculum that explicitly integrates Deep Learning technology to promote authentic, inquiry-based project learning experiences. Prioritizing content that leverages Deep Learning capabilities to connect theory with real-world phenomena. For Researchers Calling for more empirical studies on the long-term impact and scalability of the integrated Deep Learning framework in various physics education settings. Addressing ethical considerations of AI in education, including data privacy, algorithmic bias, and equitable access. Further research on interpretable Deep Learning models for specific physics applications is very important.

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