Schrödinger:Journal of Physics Education
Vol. 6, No. 4, December 2025, pp. 259~268
ISSN: 2716-1587, DOI: 10.37251/sjpe.v6i4.2263

AI-Powered Tutors as a Catalyst for Conceptual Understanding in Einsteinian Physics Education

[1]Konstantinos T. Kotsis
[1]Lab of Physics Education and Teaching, Department of Primary Education, University of Ioannina, Greece

Article Info

Article history:

Received Oct 27, 2025
Revised Nov 17, 2025
Accepted Nov 29, 2025
Online First Dec 5, 2025

Keywords:

AI-Powered Tutors
Cognitive Scaffolding
Conceptual Change
Einsteinian Physics Education
Spacetime Understanding

ABSTRACT

Purpose of the study: The objective of this study is to investigate the role of AI-powered tutors in assisting students to rectify Newtonian misconceptions and attain a conceptual comprehension of Einsteinian physics concepts, including spacetime curvature, time dilation, and gravity as geometry.

Methodology: A conceptual and narrative literature review was performed utilizing databases such as Scopus, Web of Science, ERIC, SpringerLink, and Google Scholar. The utilized tools and frameworks encompass conceptual change theory, constructivism, cognitive load theory, Bayesian Knowledge Tracing, reinforcement learning, virtual simulations, and natural language processing.

Main Findings: AI-driven tutors proficiently identify misconceptions, deliver tailored feedback, and present multimodal simulations of relativistic phenomena. They augment conceptual comprehension, diminish cognitive load, elevate student engagement and motivation, and facilitate inquiry-based learning. Recently researches indicates enhanced conceptual precision and acceptance of Einsteinian models when artificial intelligence is incorporated with guided instruction.

Novelty/Originality of this study: This study integrates artificial intelligence technologies with conceptual change theory and Einsteinian physics education to propose a systematic pedagogical framework. It enhances understanding by demonstrating how AI operates as a cognitive collaborator, improving conceptual restructuring, metacognition, and accessibility to contemporary physics instead of supplanting educators.

Corresponding Author:
Konstantinos T. Kotsis,
Lab of Physics Education and Teaching, Department of Primary Education, University of Ioannina, Ioannina, 45110, Greece
Email: kkotsis@uoi.gr

1. INTRODUCTION

Einsteinian physics, which includes the theories of special and general relativity, has transformed the understanding of space, time, matter, and gravity in contemporary science. Fundamental concepts like spacetime curvature, time dilation, and the relativity of simultaneity are essential for comprehending phenomena in astrophysics, GPS technology, particle accelerators, and gravitational wave detection [1], [2]. Parallel efforts have also shown that appropriately designed models and analogies can be used successfully to introduce quantum physics concepts at school level, suggesting that both relativity and quantum mechanics can be made pedagogically accessible when modern physics is taught through tangible representations [3].

Notwithstanding its scientific and technological significance, Einsteinian physics is infrequently integrated substantively into primary and secondary education. Educational curricula primarily focus on

Newtonian mechanics, wherein absolute time, Euclidean space, and gravity as a force constitute the default cognitive frameworks of students [4]. Research has shown that while educators and the public are generally positive towards the inclusion of Einsteinian physics, they often express concerns about curriculum overload, teacher preparedness, and student cognitive readiness [5]. Another recent initiatives have demonstrated that models and analogies---such as rubber sheet spacetime, photon clocks, and curved geometry---can make relativity accessible to school students when appropriately scaffolded [2]. This leads to discontinuities when students subsequently engage with relativistic physics, frequently resulting in confusion, resistance, or hybrid misconceptions that amalgamate aspects of classical and contemporary theories [6], [7].

The difficulty of instructing Einsteinian physics is both curricular and profoundly cognitive. Students cultivate intuitive comprehensions of motion, time, and gravity derived from quotidian sensory experiences, which correspond with Newtonian rather than Einsteinian paradigms. Students, upon encountering relativity, strive to integrate new information into their pre-existing schemas, frequently leading to scientifically erroneous or hybrid interpretations, such as perceiving spacetime as a tangible fabric or misconstruing time dilation as a mechanical deceleration of clocks [8]. Conventional teaching methods, characterized by formal mathematics and lecture-centric explanations, frequently do not facilitate conceptual transformation as they inadequately address fundamental cognitive frameworks or offer visual, experiential representations of abstract concepts [4].

Artificial intelligence (AI) has arisen as a crucial educational instrument capable of tackling these challenges. AI-driven tutoring systems establish adaptive learning environments that identify student misconceptions instantaneously, provide customized feedback, and offer multimodal simulations of relativistic concepts such as curved spacetime and time dilation [9], [10]. These systems correspond with constructivist and conceptual change theories by promoting active learning, cognitive conflict, and scaffolded reasoning within the learner's zone of proximal development [11], [12]. Recent research from Greece and Australia indicates that the integration of AI-assisted teaching with inquiry-based learning strategies enhances students' conceptual understanding, increases engagement, and diminishes anxiety regarding modern physics [13], [14].

Nonetheless, although AI's potential in science education is encouraging, its capacity to foster a profound conceptual understanding of Einsteinian physics necessitates a thorough examination. Recent work has emphasized that the successful integration of AI in physics classrooms must be understood within a broader framework that combines pedagogy, technological infrastructure, and educational policy, rather than focusing solely on technological innovation [15]. This paper examines how AI-powered tutors serve as cognitive and pedagogical enhancers, rather than substitutes for teachers, aiding students in reorganizing their mental frameworks of space, time, and gravity. It analyzes the alignment of AI technologies with conceptual change theory, cognitive load theory, and socio-constructivist learning, while synthesizing existing empirical research on their efficacy in teaching Einsteinian physics.

While prior research has investigated the use of artificial intelligence in science education, the majority of studies have predominantly focused on technical implementation or overarching STEM learning results, rather than on conceptual reformation in physics. Recent empirical research on AI-driven tutoring systems has concentrated on enhancing problem-solving efficiency, motivation, and assessment precision, although it has seldom investigated how these systems promote profound conceptual transformation from Newtonian to Einsteinian reasoning. Furthermore, current educational programs in Einsteinian physics, especially in Australia and Greece, predominantly depend on analogical models and instructor-led teaching, failing to utilize adaptive AI feedback or multimodal simulations to rectify enduring misconceptions [2], [13], [14]. This indicates a distinct research gap regarding the role of AI as a cognitive collaborator that identifies, contests, and reconstructs learners' intuitive representations of space, time, and gravity.

Notwithstanding these advancements, a deficiency persists in integrative research linking certain AI learning methods, such as Bayesian Knowledge Tracing, reinforcement learning, and natural language feedback, with recognized educational theories. This study bridges the gap by connecting artificial intelligence to educational approaches that elucidate conceptual transformation in contemporary physics education.The necessity of this research stems from the widening gap between the swift advancement of AI technology and its informed pedagogical implementation in physics education.

Students persist in utilizing intuitive Newtonian frameworks that hinder their comprehension of relativity and spacetime geometry, highlighting the necessity for adaptive environments that promote conceptual transformation and metacognitive reflection. This study sets out to weave together the growing body of theoretical and empirical work on AI-driven tutoring systems within Einsteinian physics education. It explores how the underlying mechanisms of these AI tools connect with learning theories known to support deeper conceptual understanding. Building on this analysis, the study proposes a pedagogical framework that illustrates how AI can meaningfully support students as they shift from Newtonian intuitions to Einsteinian modes of reasoning.

2. THEORETICAL FRAMEWORK

Understanding how artificial intelligence can enhance the teaching of Einsteinian physics requires grounding in established learning theories that explain how students develop, revise, and reorganize scientific concepts [6], [7]. Four key perspectives underpin this study, conceptual change, constructivism, cognitive load theory, and metacognition, each illuminating how AI tutors can support the cognitive shift from Newtonian to Einsteinian reasoning.

The theory of conceptual change serves as the principal framework for comprehending this transformation. This framework posits that learners interpret new information via pre-existing mental models, and when new knowledge is perceived as incompatible, they encounter cognitive conflict that must be resolved through either assimilation or accommodation [12]. Within the realm of Einsteinian physics, students frequently integrate relativity into classical paradigms, resulting in hybrid interpretations such as conceptualizing spacetime as a tangible fabric or perceiving time dilation as a defect in clocks rather than an intrinsic characteristic of spacetime [8]. Effective instruction must not only present new concepts but also actively confront deficient mental models and facilitate the reorganization of cognitive schemas. AI-driven tutors are consistent with this theory as they can identify misconceptions instantaneously and produce specific prompts, questions, or visualizations that foster constructive cognitive conflict and support accommodation.

Constructivist and socio-cultural theories underscore the significance of active meaning-making in the comprehension of complex physics. Constructivism posits that learners develop scientific comprehension through interaction, reflection, and conceptual connections rather than through passive information absorption [16]. In Einsteinian physics, where empirical experience offers minimal intuitive backing for abstract concepts like spacetime curvature or time dilation, learners require opportunities to investigate models, analogies, and simulations to collaboratively construct understanding. Socio-cultural theory, specifically Vygotsky's notion of the Zone of Proximal Development (ZPD), asserts that learning occurs when students receive guidance from a more knowledgeable individual, typically a teacher, but increasingly from AI systems that offer adaptive feedback and scaffolded interaction [11], [17]. AI tutors serve as cognitive collaborators, offering personalized assistance that enhances students' reasoning beyond their autonomous abilities.

Einsteinian physics imposes significant demands on working memory due to its intrinsic abstraction and mathematical formalism. Cognitive load theory posits that excessive complexity in instructional materials can overwhelm working memory, thereby impeding learning [18]. Concepts like Lorentz transformations, spacetime geometry, and gravitational time dilation impose significant intrinsic cognitive load. Inadequately designed instruction introduces unnecessary cognitive load, rendering the learning process burdensome. AI can mitigate this by adjusting task complexity to align with learner preparedness, deconstructing problems into manageable components, and providing visualizations that externalize abstract reasoning. AI facilitates dual coding and alleviates extraneous cognitive load by converting symbolic expressions into interactive visual representations of curved spacetime, geodesics, or relativistic motion [19], [20].

Metacognition and self-regulated learning theories are essential for comprehending how students achieve mastery in Einsteinian physics. Metacognition encompasses learners' capacity to assess their comprehension, identify discrepancies, and modify strategies as needed [21]. Conventional physics education rarely promotes explicit reflection, prioritizing calculation and procedural precision instead. AI tutors can encourage students to articulate their reasoning, assess alternative explanations, and evaluate their coherence with scientific principles [22]. This metacognitive engagement is crucial for shifting from disjointed Newtonian intuitions to cohesive Einsteinian frameworks.

In summary, instructing on Einsteinian physics necessitates pedagogical strategies that facilitate conceptual transformation, support knowledge development, regulate cognitive load, and enhance metacognitive awareness. AI-driven tutors exhibit traits that closely correspond with these theoretical principles. Through the identification of misconceptions, adaptation to learners' requirements, provision of multimodal representations, and encouragement of reflection, AI can function as an effective pedagogical instrument to enhance profound conceptual comprehension of relativistic physics, contingent upon its foundation in research-informed instructional design and its role as a supplement rather than a substitute for human instruction.

3. RESEARCH METHOD

This study adopts a conceptual and narrative literature review methodology aimed at synthesizing theoretical and empirical insights on the role of artificial intelligence (AI) in facilitating conceptual understanding of Einsteinian physics. The approach was selected to capture the diversity of perspectives at the intersection of physics education, learning sciences, and educational technology, fields in which empirical work is rapidly evolving and theoretical consolidation remains ongoing. Unlike systematic reviews that rely on rigid inclusion protocols, a narrative review provides the flexibility necessary to integrate theoretical, empirical, and technological viewpoints, enabling the construction of a pedagogical model that links AI mechanisms to cognitive transformation in modern physics education [23], [24].

Relevant literature was sourced from five major academic databases: Scopus, Web of Science, ERIC, SpringerLink, and Google Scholar. Search terms included combinations such as “AI tutors and physics education,” “Einsteinian physics conceptual understanding,” “conceptual change and artificial intelligence,” “adaptive learning relativity,” and “misconceptions in spacetime and gravity.” The review focused on peer-reviewed publications between 2024 and 2025, capturing recent advancements in AI-enhanced instructional technologies. Foundational works on conceptual change, constructivism, cognitive load, and metacognition were also incorporated to establish the theoretical foundations of the study [6], [12].

To enhance methodological rigor while maintaining the interpretive flexibility of a narrative review, a structured three-phase process was employed: (a) identification, (b) evaluation, and (c) synthesis of relevant literature. The initial database search yielded 175 records, from which duplicates and non-relevant items were excluded based on title and abstract screening. Studies were included if they explicitly addressed AI-driven mechanisms, such as adaptive feedback, reinforcement learning, Bayesian Knowledge Tracing, or natural language processing, within the context of physics education or conceptual understanding. Publications focusing solely on non-AI multimedia tools, data analytics, or unrelated STEM domains were excluded.

Following detailed evaluation, 24 primary studies met the inclusion criteria and were subjected to in-depth qualitative analysis. Each study was examined for its conceptual focus, research design, educational level, and reported learning outcomes related to Einsteinian physics. Analytical triangulation was employed to cross-compare theoretical, empirical, and design-based findings, ensuring interpretive depth and minimizing researcher bias. This process led to the identification of four recurring pedagogical themes: AI-supported conceptual change, cognitive load management, metacognitive engagement, and motivational scaffolding. These themes provided the foundation for constructing the integrative conceptual framework presented later in Figure 1.

The methodological stance of this review is interpretive rather than positivist, emphasizing the generation of theoretical insight over statistical generalization. This orientation aligns with contemporary physics education research, where conceptual understanding is viewed as a process of cognitive and epistemological reconstruction. Ethical considerations were minimal, as the study relied exclusively on secondary data from published sources; however, care was taken to represent prior research accurately and to acknowledge limitations related to regional focus, sample diversity, and methodological heterogeneity across studies.

Overall, this methodological design ensures both transparency and conceptual coherence. By combining rigorous literature evaluation with theoretical synthesis, the study provides a valid and replicable foundation for exploring how AI can act as a cognitive collaborator, one that supports students’ transition from Newtonian intuition to Einsteinian reasoning within formal and informal learning environments.

4. RESULTS AND DISCUSSION

The synthesis of twenty-four studies demonstrated a consistent pattern of pedagogical mechanisms by which artificial intelligence facilitates conceptual learning in Einsteinian physics. The literature repeatedly indicates that AI tutors not only improve efficiency and engagement but also serve as cognitive catalysts that initiate and maintain conceptual transformation. In many applications, including dialogue-driven teaching systems and adaptive simulations, AI technologies effectively identified and contested students' Newtonian misconceptions, encouraging profound contemplation and conceptual reorganization. These findings strongly correspond with the tenets of conceptual change theory Ryan & Deci [47], indicating that constructive feedback might provoke the dissatisfaction and reorganization processes essential for learners to transition from intuitive to scientific thinking.

Table 1. Summary of Reviewed Studies on AI in Physics and Einsteinian Education

Author(s)	Year	Country	AI Technique / Approach	Physics Topic	Key Outcomes
Vakarou, Stylos & Kotsis [14]	2024	Greece	Didactic interventions with AI tools	Einsteinian physics (interest & motivation)	Increased student interest and positive attitudes toward modern physics
Boublil, Blair & Treagust [25]	2024	Australia	AI-enhanced learning module design	Energy & relativity concepts	Improved conceptual understanding through design-based learning
de Souza, Serrano & Treagust [28]	2024	Australia	AI-supported concept mapping	Special relativity	Improved student mental representations and conceptual coherence
de Souza, Won, Treagust &	2024	Australia	AI-generated visualizations	Relativity	Enhanced visualization and understanding of

Serrano [30]					abstract concepts
Gousopoulos [33]	2024	Greece	Custom GPT-based teaching assistant	Special relativity	Improved engagement and conceptual reasoning using dialogue-based AI
Kaur et al. [34]	2024	Australia	Curriculum design (AI-supported models)	Einsteinian science (Y3–10)	Developed curriculum improving conceptual progression and engagement
Kotsis [36]	2024	Greece	AI-assisted lesson planning	Primary physics	Helped teachers design and implement experimental physics lessons
Kotsis [37]	2024	Greece	ChatGPT-generated experiments	General physics misconceptions	AI-designed activities corrected misconceptions effectively
Mustofa, Bilad & Grendis [41]	2024	Indonesia	Literature review + ChatGPT practice	Physics problem-solving	Highlighted benefits and challenges of AI in analytical reasoning
Vakarou, Stylos & Kotsis [45]	2024	Greece	AI-based lesson plans	School physics	Enhanced inquiry-based and student-centered learning
Vakarou, Stylos & Kotsis [46]	2024	Greece	AI-supported concept assessment	Einsteinian concepts	Identified cognitive progression in students' understanding
Yan, Greiff, Teuber & Gašević [47]	2024	Germany / Canada	Generative AI & cognitive modeling	Human learning in physics	Discussed potentials and challenges of generative AI for education
Kotsis [15]	2025	Greece	Narrative review (pedagogy–technology–policy framework)	General AI–physics integration	Identified theoretical and policy frameworks linking AI and physics pedagogy
Boyzaqova, Ermatova & Egamberdiyeva [26]	2025	Uzbekistan	AI-assisted conceptual learning	Quantum physics introduction	Improved accessibility and comprehension in upper-secondary contexts
Crosthwaite, Smala & Spinelli [27]	2025	Australia	Generative AI prompting in pedagogy	General science / physics	Enhanced teachers' use of AI prompts for lesson planning
de Souza, Serrano & Treagust [29]	2025	Australia	Systematic review of AI mediation tools	General relativity	Identified design features enhancing conceptual accessibility
Fassbender [31]	2025	UK	AI education platforms	General physics pedagogy	Highlighted teacher–AI interaction dynamics ("teachers and centaurs")
Fu [32]	2025	USA	Review of AI for science	Interdisciplinary physics	Overview of opportunities and ethical challenges of AI in science
Kotsis [35]	2025	Greece	Theoretical–pedagogical framework	Higher education physics	Outlined strategies for AI-integrated university physics teaching
Kotsis [38]	2025	Greece	Narrative review (AI–pedagogy–	STEM & physics	Proposed integrated framework for AI–

			policy)		pedagogy alignment
Kotsis [39]	2025	Greece	Comparison of dialogic vs structured AI	Physics learning dialogue	Dialogic AI promotes conceptual reasoning and reflection
Kotsis & Vakarou [40]	2025	Greece	AI-powered teaching models	Newtonian–Einsteinian transition	Enhanced conceptual shift and metacognitive awareness
Shafiq et al. [42]	2025	Pakistan	Review of AI in physics education	All physics levels	Showed AI improves performance and learning personalization
Serio et al. [43]	2025	Italy	School–university collaboration using AI tools	Physics teacher training	Improved teacher preparedness and digital competence

Research from design-based and practical investigations demonstrates that AI systems proficient in natural language interaction are essential for promoting metacognitive reflection. By facilitating explanatory discourse among learners, these systems reveal cognitive problems and offer customized replies that direct thinking towards Einsteinian principles, including the curvature of spacetime, time dilation, and relativistic mass. This adaptive dialogic feedback reinforces the idea that learning transcends mere knowledge collection, involving the reconstruction of conceptual frameworks. The growing trend indicates that AI tutors implement cognitive apprenticeship concepts, enabling learners to externalize their thoughts and obtain quick formative feedback.

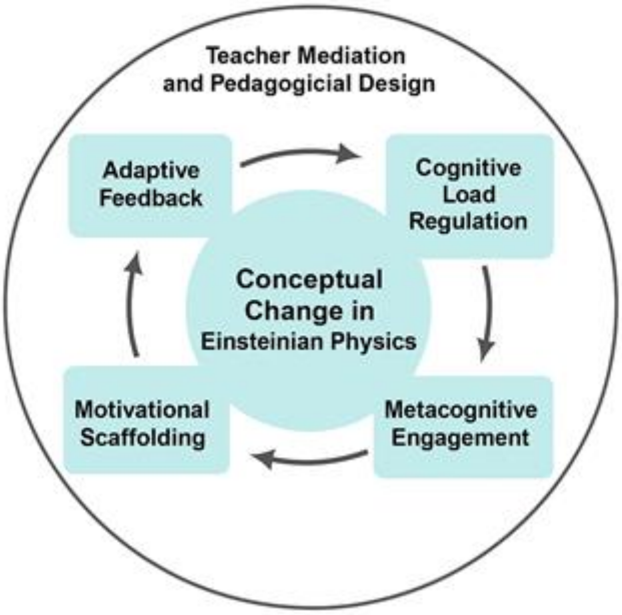

Figure 1. AI-Powered Conceptual Learning Framework in Einsteinian Physics

A key finding in the examined literature pertains to the administration of cognitive load. AI-driven settings utilizing dynamic visualization, augmented reality, or multimodal input shown a reduction in superfluous cognitive load while maintaining the cognitive effort necessary for conceptual elaboration. Numerous research shown that reinforcement-learning algorithms adaptively modified task complexity and visual intricacy according to learner performance, enabling students to concentrate cognitive resources on comprehension rather than interpreting abstract representations. This approach aligns with Sweller's cognitive load hypothesis [18], illustrating that effective visualization along with real-time adaptivity can alter the perception and mental modeling of complicated events, such as geodesic motion or gravitational curvature.

The analyzed research consistently highlight the importance of metacognitive activity and self-regulation as mediating elements in conceptual comprehension. AI tutors, featuring reflective prompts and progress dashboards, facilitated students in tracking their understanding, establishing learning objectives, and assessing their cognitive advancement during the educational process. These aspects promote the cultivation of self-regulated learning practices, consistent with the metacognitive control paradigm [48], and reframe AI as a means of enhancing epistemic awareness rather than merely providing instruction. Students that engaged with metacognitively structured AI systems expressed increased confidence in differentiating between intuitive and scientific models of gravity and relativity.

Motivational and emotional factors also surfaced as essential elements of effective AI-enhanced learning environments. Numerous research highlighted the motivational influence of gamified feedback, empathic conversational bots, and affect-sensitive systems that identify and react to emotional signals. Students demonstrated increased engagement and persistence when AI tutors effectively matched cognitive challenges with autonomy support, in accordance with Self-Determination Theory [49]. These findings suggest that motivation and conceptual knowledge are interconnected processes that mutually support each other through enduring interest and enjoyment.

Figure 1 depicts the AI-Powered Conceptual Learning Framework in Einsteinian Physics, demonstrating how four interrelated mechanisms adaptive feedback, cognitive-load regulation, metacognitive involvement, and motivational scaffolding concurrently promote conceptual transformation. Adaptive feedback induces cognitive conflict that triggers restructuring; optimal imagery regulates mental load; reflective dialogue reinforces conceptual change; and motivational scaffolding maintains perseverance in engaging with paradoxical concepts. At the core of the framework is conceptual change, arising from the dynamic interplay of various processes, while the encompassing layer signifies teacher mediation and pedagogical design, guaranteeing coherence, ethical supervision, and theoretical congruence between AI tools and educational practice. Instead of supplanting instructors, AI functions as a cognitive collaborator that enhances educators' capacity to deliver personalized, conceptually revolutionary physics teaching.

While the synthesis provides an extensive examination of the educational potential of AI-driven tutoring in Einsteinian physics, certain empirical constraints must be recognized. A major issue is the geographical concentration of research, with a substantial amount of empirical studies emerging from Australia and Greece, regions where initiatives in Einsteinian physics education have been notably prevalent in the last ten years. This localized emphasis limits the generalizability of results and prompts inquiries on the cultural, linguistic, and curricular transferability to alternative educational systems. Subsequent study should consequently extend beyond these areas to encompass many socio-cultural contexts, especially those with restricted access to modern technologies or unique educational practices.

A second constraint is to the limited scale and design-oriented character of the majority of current studies. Numerous projects depend on pilot implementations that encompass a limited number of classes or brief intervention cycles, frequently without long-term follow-up or control groups. Although these designs are useful for assessing feasibility and engagement, they offer insufficient data concerning enduring conceptual transformation, scalability, or teacher professional growth. More rigorous quasi-experimental or longitudinal investigations are required to assess the sustainability of AI-enhanced conceptual advancements and their incorporation into mainstream curricula.

Moreover, a clear disparity exists between technological advancement and theoretical expression. Certain studies emphasize algorithmic complexity or interface aesthetics, offering minimal examination of the foundational learning processes. This disparity underscores the necessity for enhanced integration between AI development and established educational ideas, including conceptual transformation, cognitive load, and motivation. Ultimately, ethical and privacy issues are little examined: limited research addresses data protection, algorithmic bias, or the consequences of learner modeling for fairness and inclusion. Acknowledging these limits highlights that although AI-driven tutoring holds transformative promise for physics education, its pedagogical efficacy must be assessed within the confines of current empirical evidence and developing ethical standards.

The ramifications of this synthesis transcend classroom practice and extend into the realms of educational policy and ethical governance. The implementation of AI-driven tutoring in Einsteinian physics necessitates a reevaluation of curriculum design, educator professional development, and data governance structures. Policy initiatives must prioritize the use of AI technologies inside cohesive curricular frameworks, ensuring that technological advancements match with national educational objectives and evaluation standards, rather than operating as standalone experiments. Integrating AI applications into contemporary physics education strategies enables ministries and educational authorities to provide fair access to advanced learning opportunities and mitigate regional discrepancies in exposure to new scientific concepts.

From a teacher education standpoint, governments ought to prioritize the enhancement of both pedagogical and technical literacy. Educators must be proficient in utilizing AI platforms, analyzing the data produced by these systems, critically evaluating their feedback mechanisms, and modifying instruction as necessary. Continuous professional development programs should incorporate modules on AI ethics, algorithmic transparency, and bias detection to help educators remain informed participants in technology-mediated learning environments.

The ethical implications of the growing dependence on AI in educational settings include issues related to data privacy, informed consent, and algorithmic prejudice. The use of learner analytics, behavioral modeling, and adaptive algorithms must adhere to transparent data management standards that safeguard student identities and avert discriminatory profiling. The establishment of ethical supervision frameworks at the institutional level is equally crucial, incorporating educational technologists, ethicists, and educators in collaborative review processes. Artificial intelligence should enhance, rather than supplant, the relational and humanistic aspects of physics instruction, maintaining the dialogical nature of science education while improving its inclusion and adaptability.

This paradigm indicates that national initiatives for digital education ought to embrace evidence-based and morally sound methodologies for AI integration. Collaboration among educational institutions, policymakers, and research communities will be crucial to ensure that the implementation of AI tutors in physics education honors both cognitive and ethical aspects of learning. By seeing AI as a pedagogical partner instead of an independent authority, governments may protect human-centered educational principles while harnessing the transformational capabilities of intelligent technologies for conceptual comprehension in contemporary physics.

5. CONCLUSION

This synthesis creates a cohesive educational framework elucidating how artificial intelligence might facilitate profound conceptual transformation in Einsteinian physics. The study illustrates that AI-powered tutors, by integrating the principles of conceptual change, cognitive load theory, metacognition, and motivation, can transcend mere content delivery to function as cognitive collaborators addressing misconceptions, facilitating reflection, and fostering curiosity through adaptive feedback and multimodal engagement. From a policy and practice standpoint, the integration of AI must be firmly rooted in pedagogy and governed by ethical principles. Educational authorities ought to integrate AI applications into cohesive curricular frameworks that correspond with inquiry-based learning and evidence-based teaching goals. Professional development for educators is crucial; they must be proficient in interpreting AI analytics, assessing algorithmic feedback, and maintaining ethical standards in deployment. Collaboration across disciplines, including physicists, educators, and computer scientists, can guarantee that AI systems are both intellectually robust and centered on human needs. Ethical governance must accompany innovation. Transparent data management standards, algorithmic impartiality, and accountability frameworks are essential to safeguard learner privacy and guarantee equity. The formation of interdisciplinary ethics committees, comprising educators, technologists, and researchers, can oversee the implementation of AI in educational settings. Future research should conduct longitudinal and cross-cultural studies to validate the proposed paradigm, investigating the impact of AI-supported training on conceptual understanding, epistemological views, and motivation in various circumstances. The incorporation of explainable AI signifies a prospective avenue for improving transparency and interpretability, aiding educators and learners in comprehending adaptive decision processes. The judicious application of AI in physics education should enhance, rather than supplant, the human aspects of teaching and learning. When rooted in robust pedagogy and ethical consciousness, AI can enhance contemplation, creativity, and scientific inquiry acting as a genuine collaborator in furthering conceptual comprehension of the world.

REFERENCES

[1] J. Horvath, “Should we teach general relativity in high school? Why and how,” *Int. J. Astron. Educ.*, vol. 8, pp. 30–46, 2021, doi: 10.32374/AEJ.2021.1.1.008.
[2] T. Kaur, D. Blair, J. Moschilla, W. Stannard, and M. Zadnik, “Teaching Einsteinian physics at schools: Part 1, models and analogies for relativity,” *Phys. Educ.*, vol. 52, no. 5, art. no. 055008, 2017, doi: 10.1088/1361-6552/aa83e4.
[3] T. Kaur, D. Blair, J. Moschilla, and M. Zadnik, “Teaching Einsteinian physics at schools: Part 2, models and analogies for quantum physics,” *Phys. Educ.*, vol. 52, no. 6, art. no. 065013, 2017, doi: 10.1088/1361-6552/aa83e1.
[4] I. M. Greca and M. A. Moreira, “Mental models, conceptual models, and modeling ability: Clarification and measurement,” *Int. J. Sci. Educ.*, vol. 24, no. 1, pp. 61–79, 2002, doi: 10.1080/09500690110098819.
[5] A. Foppoli, R. Choudhary, D. Blair, T. Kaur, J. Moschilla, and M. Zadnik, “Public and teacher response to Einsteinian physics in schools,” *Phys. Educ.*, vol. 54, no. 1, art. no. 015001, 2018, doi: 10.1088/1361-6552/aae4a4.
[6] S. Vosniadou, “The development of students’ understanding of science,” *Front. Educ.*, vol. 4, art. no. 32, 2019, doi: 10.3389/feduc.2019.00032.
[7] R. Duit and D. F. Treagust, “Conceptual change: A powerful framework for improving science teaching and learning,” *Int. J. Sci. Educ.*, vol. 25, no. 6, pp. 671–688, 2003, doi: 10.1080/09500690305016.
[8] A. M. Leonardi, S. Mobilio, and C. Fazio, “An analysis of students’ misconceptions on special relativity,” in *J. Phys.: Conf. Ser.*, vol. 2750, no. 1, art. no. 012018, 2024, doi: 10.1088/1742-6596/2750/1/012018.
[9] R. Luckin and M. Cukurova, “Designing educational technologies in the age of AI: A learning-sciences-driven approach,” *Br. J. Educ. Technol.*, vol. 50, no. 6, pp. 2824–2838, 2019, doi: 10.1111/bjet.12861.
[10] W. Holmes, M. Bialik, and C. Fadel, *Artificial Intelligence in Education: Promises and Implications for Teaching and Learning*. Boston, MA, USA: Center for Curriculum Redesign, 2019.
[11] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA, USA: Harvard Univ. Press, 1978.
[12] M. T. H. Chi and R. Wylie, “The ICAP framework: Linking cognitive engagement to active learning outcomes,” *Educ. Psychol.*, vol. 49, no. 4, pp. 219–243, 2014, doi: 10.1080/00461520.2014.965823.

[13] P. Alstein, K. Krijtenburg-Lewerissa, and W. R. van Joolingen, "Teaching and learning special relativity theory in secondary and lower undergraduate education: A literature review," *Phys. Rev. Phys. Educ. Res.*, vol. 17, no. 2, art. no. 023101, 2021, doi: 10.1103/PhysRevPhysEducRes.17.023101.
[14] G. Vakarou, G. Stylos, and K. T. Kotsis, "Effect of didactic interventions in Einsteinian physics on students' interest in physics," *Eur. J. Sci. Math. Educ.*, vol. 12, no. 2, pp. 200–210, 2024, doi: 10.30935/scimath/14303.
[15] K. T. Kotsis, "Artificial intelligence for physics education in STEM classrooms: A narrative review within a pedagogy–technology–policy framework," *Schrödinger: J. Phys. Educ.*, vol. 6, no. 3, pp. 204–211, 2025, doi: 10.37251/sjpe.v6i3.2148.
[16] R. Driver, H. Asoko, J. Leach, P. Scott, and E. Mortimer, "Constructing scientific knowledge in the classroom," *Educ. Res.*, vol. 23, no. 7, pp. 5–12, 1994, doi: 10.3102/0013189X023007005.
[17] N. Mercer and C. Howe, "Explaining the dialogic processes of teaching and learning," *Learn., Cult. Soc. Interact.*, vol. 1, no. 1, pp. 12–21, 2012, doi: 10.1016/j.lcsi.2012.03.001.
[18] J. Sweller, P. Ayres, and S. Kalyuga, *Cognitive Load Theory*. New York, NY, USA: Springer, 2011, doi: 10.1007/978-1-4419-8126-4.
[19] R. E. Mayer, *Multimedia Learning*, 3rd ed. Cambridge, U.K.: Cambridge Univ. Press, 2021.
[20] M. G. de Souza, M. Won, D. Treagust, and A. Serrano, "Visualising relativity: Assessing high school students' understanding of complex physics concepts through AI-generated images," *Phys. Educ.*, vol. 59, no. 2, art. no. 025018, 2024, doi: 10.1088/1361-6552/ad1e71.
[21] B. J. Zimmerman, "Becoming a self-regulated learner: An overview," *Theory Pract.*, vol. 41, no. 2, pp. 64–70, 2002, doi: 10.1207/s15430421tip4102_2.
[22] R. Azevedo and D. Gašević, "Analyzing multimodal multichannel data about self-regulated learning with advanced learning technologies: Issues and challenges," *Comput. Hum. Behav.*, vol. 96, pp. 207–210, 2019, doi: 10.1016/j.chb.2019.03.025.
[23] H. Snyder, "Literature review as a research methodology: An overview and guidelines," *J. Bus. Res.*, vol. 104, pp. 333–339, 2019, doi: 10.1016/j.jbusres.2019.07.039.
[24] T. Greenhalgh, J. R. Malterud, and J. Gruer, "The nature of evidence in qualitative research," *Qual. Health Res.*, vol. 28, no. 8, pp. 1203–1206, 2018, doi: 10.1177/1049732318780198.
[25] S. Boublil, D. Blair, and D. F. Treagust, "Design and implementation of an Einsteinian energy learning module," *Int. J. Sci. Math. Educ.*, vol. 22, no. 1, pp. 49–72, 2024, doi: 10.1007/s10763-022-10348-5.
[26] S. Boyzaqova, S. Ermatova, and K. Egamberdiyeva, "Integrating elements of quantum physics into physics education in academic lyceums," *Int. J. Artif. Intell.*, vol. 1, no. 4, pp. 723–730, 2025. [Online]. Available: https://inlibrary.uz/index.php/ijai/article/view/98943
[27] P. Crosthwaite, S. Smala, and F. Spinelli, "Prompting for pedagogy? Australian F–10 teachers' generative AI prompting use cases," *Aust. Educ. Res.*, vol. 52, pp. 1795–1825, 2025, doi: 10.1007/s13384-024-00787-0.
[28] M. G. de Souza, A. Serrano, and D. Treagust, "Exploring the relationship between mental representations and conceptual understanding of special relativity by high school students," *Res. Sci. Technol. Educ.*, pp. 1–26, 2024, doi: 10.1080/02635143.2024.2446801.
[29] M. G. de Souza, A. Serrano, and D. Treagust, "External mediation educational resources for teaching general relativity: A systematic review," *J. Turk. Sci. Educ.*, vol. 22, no. 3, pp. 561–583, 2025, doi: 10.36681/tused.2025.029.
[30] W. J. Fassbender, "Of teachers and centaurs: Exploring the interactions and intra-actions of educators on AI education platforms," *Learn. Media Technol.*, vol. 50, no. 3, pp. 352–364, 2025, doi: 10.1080/17439884.2024.2447946.
[31] V. Fu, "AI for science: Opportunities, challenges, and future directions," *TechRxiv*, Feb. 2025, doi: 10.36227/techrxiv.173949768.84003950/v1.
[32] D. Gousopoulos, "Educational approach of special relativity using a custom GPT as a teaching assistant," *EIKI J. Eff. Teach. Methods*, vol. 2, no. 4, 2024, doi: 10.59652/jetm.v2i4.328.
[33] T. Kaur *et al.*, "Developing and implementing an Einsteinian science curriculum from years 3–10: Concepts, rationale and learning outcomes," *Phys. Educ.*, vol. 59, no. 6, art. no. 065008, 2024, doi: 10.1088/1361-6552/ad66a7.
[34] K. Kotsis, "Integrating artificial intelligence into the higher education of physics: Theoretical frameworks and pedagogical strategies," *Gabaldon Int. J. Educ. Methodol.*, vol. 1, no. 1, pp. 1–9, 2025, doi: 10.5281/zenodo.17114953.
[35] K. T. Kotsis, "Artificial intelligence helps primary school teachers to plan and execute physics classroom experiments," *EIKI J. Eff. Teach. Methods*, vol. 2, no. 2, 2024, doi: 10.59652/jetm.v2i2.158.
[36] K. T. Kotsis, "Correcting students' misconceptions in physics using experiments designed by ChatGPT," *Eur. J. Contemp. Educ. E-Learn.*, vol. 2, no. 2, pp. 83–100, 2024, doi: 10.59324/ejceel.2024.2(2).07.
[37] K. T. Kotsis, "Dialogic vs. structured AI in physics education: Theoretical frameworks and pedagogical implications," *Eur. J. Contemp. Educ. E-Learn.*, vol. 3, no. 5, pp. 18–31, 2025, doi: 10.59324/ejceel.2025.3(5).02.
[38] K. T. Kotsis and G. Vakarou, "Bridging the gap between Newtonian and Einsteinian thinking: The impact of AI-powered teachers on physics education," *Eur. J. Contemp. Educ. E-Learn.*, vol. 3, no. 4, pp. 32–45, 2025, doi: 10.59324/ejceel.2025.3(4).03.
[39] H. A. Mustofa, M. R. Bilad, and N. W. B. Grendis, "Utilizing AI for physics problem solving: A literature review and ChatGPT experience," *Lensa: J. Kependidikan Fisika*, vol. 12, no. 1, pp. 78–97, 2024, doi: 10.33394/j-lkf.v12i1.11748.
[40] M. Shafiq, M. A. Sami, N. Bano, R. Bano, and M. Rashid, "Artificial intelligence in physics education: Transforming learning from primary to university level," *Indus J. Soc. Sci.*, vol. 3, no. 1, pp. 717–733, 2025, doi: 10.59075/ijss.v3i1.807.
[41] M. Serio *et al.*, "School–university collaboration to train teachers on new topics and new tools in physics education," *J. Phys.: Conf. Ser.*, vol. 2950, no. 1, art. no. 012048, 2025, doi: 10.1088/1742-6596/2950/1/012048.
[42] G. Vakarou, G. Stylos, and K. T. Kotsis, "AI for enhancing physics education: Practical tools and lesson plans," *Int. J. Sci. Math. Technol. Learn.*, vol. 31, no. 2, pp. 159–176, 2024, doi: 10.18848/2327-7971/CGP/v31i02/159-176.

[43] G. Vakarou, G. Stylos, and K. T. Kotsis, “Probing students’ understanding of Einsteinian physics concepts: A study in primary and secondary Greek schools,” *Phys. Educ.*, vol. 59, no. 2, art. no. 025004, 2024, doi: 10.1088/1361-6552/ad1768.

[44] L. Yan, S. Greiff, Z. Teuber, and D. Gašević, “Promises and challenges of generative artificial intelligence for human learning,” *Nat. Hum. Behav.*, vol. 8, no. 10, pp. 1839–1850, 2024, doi: 10.1038/s41562-024-02004-5.

[45] G. J. Posner, K. A. Strike, P. W. Hewson, and W. A. Gertzog, “Accommodation of a scientific conception: Toward a theory of conceptual change,” *Sci. Educ.*, vol. 66, no. 2, pp. 211–227, 1982, doi: 10.1002/sce.3730660207.

[46] J. H. Flavell, “Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry,” *Am. Psychol.*, vol. 34, no. 10, pp. 906–911, 1979, doi: 10.1037/0003-066X.34.10.906.

[47] R. M. Ryan and E. L. Deci, “Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being,” *Am. Psychol.*, vol. 55, no. 1, pp. 68–78, 2000, doi: 10.1037/0003-066X.55.1.68.