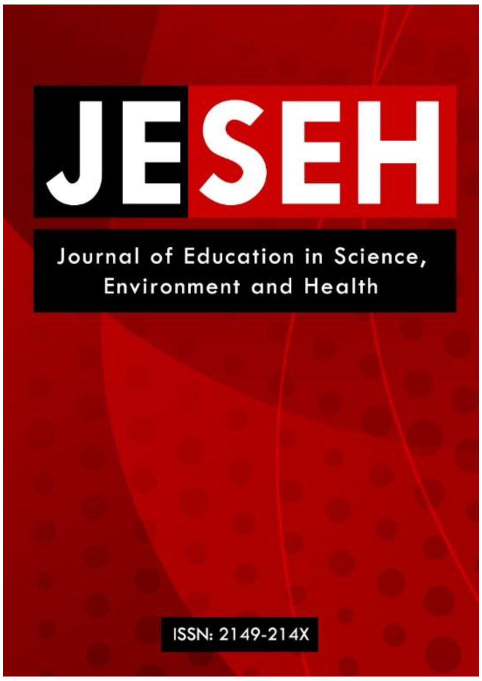

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Artificial Intelligence in Physics Education (2015–2025): Systematic Review of Trends, Applications, and Challenges

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Abstract

The aim of this study is to examine the role of artificial intelligence (AI) in physics teaching and learning between 2015 and 2025 through a systematic literature review. The research process was conducted in accordance with PRISMA 2020 guidelines; a total of 11,208 records were identified through searches in the Web of Science, Scopus, and ERIC databases. After removing duplicate records and applying the inclusion criteria, 40 studies were included in the final analysis. The findings indicate a marked increase in AI-supported physics education research, particularly after 2023. Most of the studies employed a mixed-methods design, with undergraduate students predominantly selected as the sample group. The results of the content analysis reveal that AI applications are most frequently concentrated in mechanics topics, followed by electromagnetism and thermodynamics. A significant proportion of the research focuses on examining the performance of generative AI systems in problem-solving, automated assessment, and personalized feedback processes. However, teacher-focused studies and long-term analyses of pedagogical impact appear to be limited. In conclusion, the field of AI-supported physics education is undergoing rapid development; however, more comprehensive research is needed in terms of methodological diversity, sample balance, and pedagogical depth.

Introduction

Over the past decade, rapid advancements in AI technologies have led to structural transformations in educational systems (Samala et al., 2025). The ability of computer systems to emulate human intelligence by demonstrating learning, reasoning, and decision-making capabilities offers significant opportunities for the personalization of instructional processes, the enhancement of learning efficiency, and the expansion of educational access (Al-Kamzari & Alias, 2025; Fayzullina et al., 2025). This transformation has become particularly evident in science education, where instructional processes have begun to be restructured through data-driven decision-making, adaptive learning environments, and automated assessment systems (He & Krajcik, 2026; Lee et al., 2025).

Due to its inherently abstract concepts, frequent reliance on mathematical modeling, and susceptibility to conceptual misconceptions, physics education has emerged as a distinctive field of inquiry for AI applications (Mahligawati et al., 2023). AI-supported adaptive learning systems, virtual laboratories, and intelligent tutoring tools make physics concepts more accessible and meaningful by delivering content tailored to students' individual learning pace and prior knowledge (Chen et al., 2020; Al-Kamzari & Alias, 2025). While natural language processing–based systems support the analysis of open-ended responses, learning analytics applications contribute to monitoring student performance and developing early intervention strategies. In this respect, AI functions not only as a pedagogical tool in physics instruction but also as an analytical framework that transforms research and assessment processes (Bralin et al., 2024; Heeg & Avraamidou, 2023; Kotsis, 2025).

Since 2015, AI-based approaches have shown a marked increase in physics education research. The systematic review conducted by Bralin et al. (2024) reveals a substantial quantitative growth in AI-focused studies in recent years, particularly in data-driven domains such as the development of assessment instruments, prediction of student achievement, and analysis of learner engagement. This trend indicates that analytical and computational methods are increasingly occupying a central position in physics education research. Similarly, Mahligawati et al. (2023) demonstrated that AI is utilized in physics instruction for concept introduction, personalized learning, social interaction, and assessment processes. Studies focusing on the secondary education level suggest that AI-supported systems have the potential to enhance conceptual understanding and motivation, particularly in abstract topics such as Newtonian mechanics, kinematics, and electromagnetism (Al-Kamzari & Alias, 2025). Broader reviews conducted within the context of science and STEM education further highlight the diversity of AI applications. Kotsis (2025) emphasizes that AI supports personalization and inquiry-based learning in STEM education through intelligent tutoring systems, adaptive platforms, and automated assessment tools, while also raising significant ethical and political concerns such as data privacy, algorithmic bias, and equity. Almasri (2024) demonstrates that between 2014 and 2023, AI assumed functions in science education such as improving learning environments, generating examinations, evaluating student work, and predicting performance. Heeg and Avraamidou (2023) categorized AI applications in science education into nine groups and reported positive effects on learning achievement and argumentation skills. Despite this extensive body of literature, systematic and holistic syntheses specific to physics education remain limited. Most existing reviews provide a general framework within science education or STEM contexts and do not comprehensively map the pedagogical, methodological, and technological trends unique to physics education. Moreover, a substantial portion of existing studies focus on specific contexts, short time frames, or single application types, while large-scale systematic reviews conducted in accordance with standardized guidelines such as PRISMA remain scarce. This situation highlights the need for a comprehensive evaluation of AI applications in physics education in terms of their pedagogical purposes, technological approaches, methodological trends, and impacts on learning outcomes.

Accordingly, systematically examining the pedagogical contributions, methodological orientations, and limitations of AI applications in physics education is important from both theoretical and practical perspectives. In this context, the aim of the present study is to investigate how artificial intelligence has been positioned in physics teaching and learning between 2015 and 2025 through a systematic literature review, and to identify current research trends in the field, the types of AI employed, their strengths and limitations, and future directions. Additionally, the temporal and geographical distribution of the studies, their ethical and pedagogical constraints, and their recommendations for future research are analyzed. By outlining the development of AI in physics education, this review seeks to provide a conceptual and practice-oriented framework for educators, researchers, and policymakers. In line with the purpose of the study, the following research questions are addressed:

RQ1. What are the bibliometric trends in AI-supported physics instruction research?
RQ2. Which research approaches are preferred in AI-supported physics instruction studies?
RQ3. Which participant groups are predominantly examined in the reviewed studies?
RQ4. What types of AI are employed in these studies?
RQ5. For what purposes is AI used in physics instruction?
RQ6. What contributions do AI-supported applications provide to physics instruction?
RQ7. What are the main challenges encountered in AI applications?
RQ8. Based on the reviewed studies, what research gaps and future directions stand out in the field of AI-supported physics instruction?

Method

Research Design

This study was designed as a systematic literature review aimed at comprehensively and systematically examining published scientific studies on AI applications in physics education. The research process was conducted in accordance with the PRISMA 2020 guidelines (Page et al., 2021). A descriptive analysis and thematic synthesis approach was adopted, and both qualitative and quantitative studies were evaluated together. The study began with a systematic search conducted in the Web of Science, Scopus, and ERIC databases using specific keywords related to artificial intelligence and physics education. Inclusion criteria such as publication date range, language, and accessibility were applied. The studies were initially screened based on titles, abstracts, and full texts for eligibility. Subsequently, a detailed data analysis was carried out, incorporating dimensions such as the type of AI application, research design, sample characteristics, main findings, and recommendations. In structuring the review process in line with PRISMA, methodological rigor and transparency were ensured as recommended by Page et al. (2021). In addition, a model including a structured search strategy, clearly defined inclusion and exclusion criteria, and systematic data analysis was employed. This protocol provides clear, step-by-step guidance for searching, screening, and analyzing relevant literature, thereby enabling the replicability of the review process in future studies.

Data Sources and Search Strategy

The literature search was conducted in the Web of Science, Scopus, and ERIC databases. The search was limited to studies published between 2015 and 2025. Boolean operators (AND, OR) were used during the search process. The search strings used for each database are presented in Table 1. In Web of Science and Scopus, searches were performed across all available fields (including title, abstract, and keywords), whereas in ERIC, the search was limited to the title and abstract fields.

Table 1. Search string

Databases	Keywords
Web of science	TS=("physics education" OR "physics teaching" OR "physics learning") AND TS=("artificial intelligence" OR "AI in education" OR "intelligent tutoring system" OR "adaptive learning system" OR "machine learning")
Scopus	("physics education" OR "physics teaching" OR "physics learning") AND ("artificial intelligence" OR "AI in education" OR "intelligent tutoring system" OR "adaptive learning system" OR "machine learning)
ERIC	("physics education" OR "physics teaching" OR "physics learning") AND ("artificial intelligence" OR "AI in education" OR "intelligent tutoring system" OR "adaptive learning system" OR "machine learning)

Study Selection Process (PRISMA)

In accordance with the PRISMA flow diagram, the process was conducted in four stages: identification, screening, eligibility, and inclusion. The total number of records retrieved from the databases, the removal of duplicate studies, title–abstract screening, full-text assessment, and the final number of included studies are presented in detail in the PRISMA diagram (Fig. 1). The reasons for excluding studies at the full-text stage (e.g., irrelevance to the topic, methodological inadequacy, access issues) were documented.

Identification

The literature search was conducted in the Web of Science, Scopus, and ERIC databases due to their broad scope, academic rigor, and reliable indexing of peer-reviewed publications. These databases were preferred because they include high-impact, internationally indexed, peer-reviewed journals in the fields of education and educational technology. In particular, Web of Science and Scopus provide access to current and methodologically robust research through their multidisciplinary structures and extensive citation networks. ERIC, with its specialized focus on education, supported the contextual integrity of the study. The selection of these databases aimed to systematically and comprehensively identify studies on AI applications within the context of physics education. The primary rationale for this choice was to ensure access to the international literature as comprehensively as possible, rather than limiting the review to a specific group of publications. Thus, the scope validity of the study was strengthened, and potential publication bias was minimized.

The search strategy was structured in line with the research problem and conceptual framework. The key concepts were determined along two main axes: (1) the context of physics education and (2) AI applications. These two axes were combined using Boolean operators (AND, OR). Synonyms and alternative expressions commonly used in the literature were considered to broaden the search scope. Trends in the literature, variations in conceptual usage, and current terminology in educational technology were taken into account when determining the search terms. Consequently, a comprehensive search strategy encompassing both classical AI applications and next-generation systems was developed. The applied search strings and keywords are presented in detail in Table 1 to ensure transparency and replicability. A total of 11,208 records were retrieved from the databases. After removing 158 duplicate records, 11,050 records were transferred to the screening stage.

Screening

Following the removal of duplicate records, the remaining studies were systematically evaluated in line with the purpose of the research. At this stage, 11,050 records were examined at the title and abstract level. The studies were assessed according to predetermined inclusion and exclusion criteria. As a result of the title and abstract screening, 10,117 records were excluded. Studies that were not directly related to the context of physics education, did not involve AI applications, did not meet the language criterion, or were not research articles (e.g., reviews, editorials) were excluded at this stage. After screening, 933 studies were deemed eligible for full-text evaluation and moved to the eligibility stage.

Eligibility

At this stage, the studies were evaluated in detail at the full-text level according to the inclusion and exclusion criteria presented in Table 2. The 933 studies that passed the title and abstract screening were analyzed in terms of their direct relevance to the research questions, methodological adequacy, and the extent to which they addressed AI applications within the context of physics education. Following the full-text assessment, 892 studies were excluded for various reasons. A significant portion of these studies fell outside the context of physics education or did not directly address AI applications. Additionally, studies were excluded if they were published outside the 2015–2025 time range, not published in peer-reviewed international journals, not indexed in Web of Science, Scopus, or ERIC, published in languages other than English, or did not present clearly defined methodologies (e.g., reviews, editorials, or studies lacking methodological clarity). Studies lacking accessible full texts were also excluded. As a result of this process, 40 studies were deemed suitable for final analysis and included in the systematic review (see Figure 1).

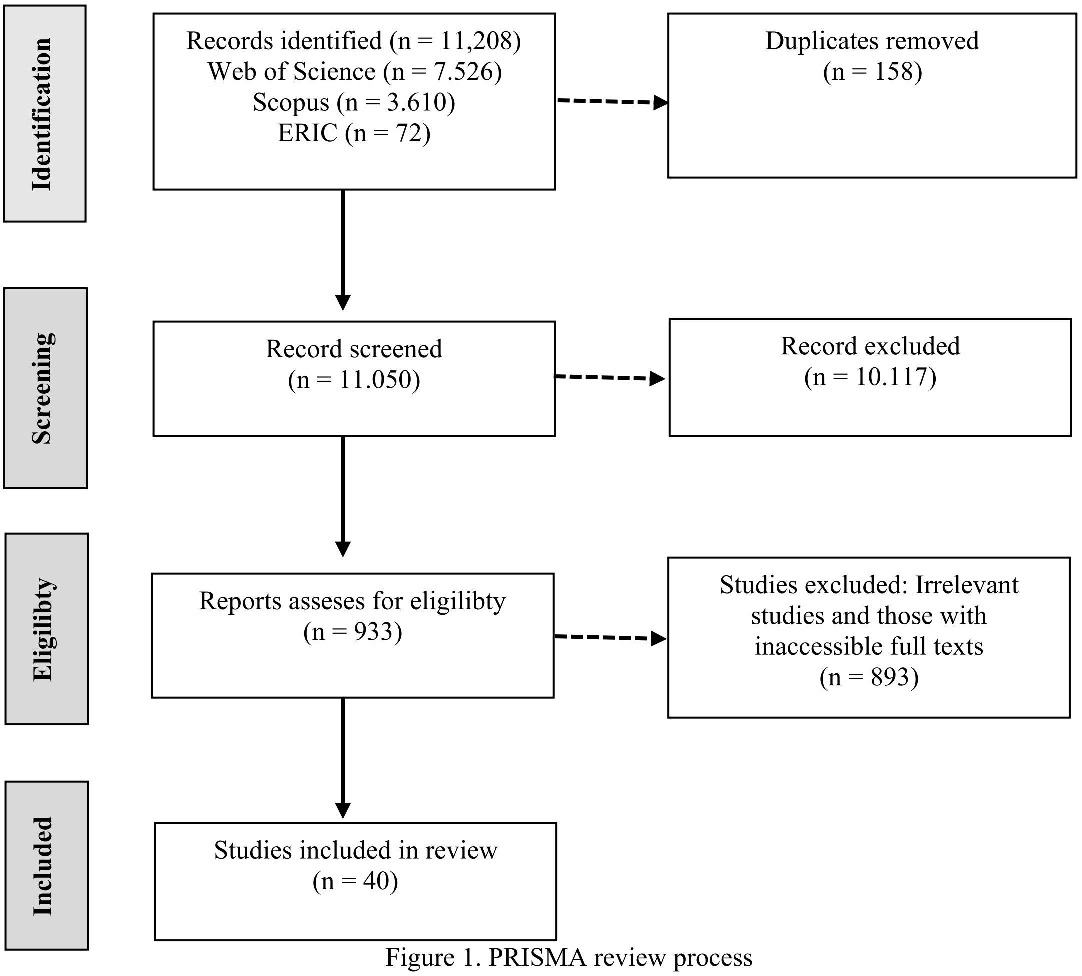

Figure 1. PRISMA review process

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Studies addressing AI applications in physics education	Studies outside the context of physics education
Studies published between 2015–2025	Studies published outside 2015–2025
Articles published in peer-reviewed international journals	Non-scientific publications
Studies indexed in Web of Science, Scopus, or ERIC	Studies outside the specified databases
Studies with accessible full texts	Studies without accessible full texts
Studies published in English	Publications in languages other than English
Research articles with clearly defined methodologies (qualitative, quantitative, mixed, theoretical)	Studies lacking methodological clarity; reviews; editorials

Table 3. Publication details, authors and citations

No	Year of publication	authors names	The APA citation	Country
1	2019	Santos, O. C., & Corbí, A.	(Santos & Corbí, 2019)	Spain
2	2023	Ding, L., Li, T., Jiang, S., & Gapud, A.	(Ding et al., 2023)	USA
3	2023	Bessas, N., Tzanaki, E., Vavougios, D., & Plagianakos, V. P.	(Bessas et al., 2023)	Greece
4	2023	Liang, Y., Zou, D., Xie, H., & Wang, F. L.	(Liang et al., 2023)	China
5	2023	Bitzenbauer, P.	(Bitzenbauer, 2023)	Germany
6	2023	Tong, D., Tao, Y., Zhang, K., Dong, X., Hu, Y., Pan, S., & Liu, Q.	(Tong et al., 2023)	USA & China
7	2023	Kieser, F., Wulff, P., Kuhn, J., & Küchemann, S.	(Kieser et al., 2023)	Germany
8	2023	Tschisgale, P., Wulff, P., & Kubsch, M.	(Tschisgale et al., 2023)	Germany
9	2024	Al-Kamzari, F., & Alias, N.	(Al-Kamzari & Alias, 2024)	Oman
10	2024	Jang, H., & Choi, H.	(Jang & Choi, 2024)	Korea
11	2024	Aldazharova, S., Issayeva, G., Maxutov, S., & Balta, N.	(Aldazharova et al., 2024)	Kazakhstan
12	2024	Singh, C.	(Singh, 2024)	USA
13	2024	Holme, T. A.	(Holme, 2024)	USA
14	2024	Domenichini, D., Bucchiarone, A., Chiarello, F., Schiavo, G., & Fantoni, G.	(Domenichini et al., 2024)	Italy
15	2024	López-Simó, V., & Rezende, M. F., Jr.	(López-Simó & Rezende, Jr., 2024)	Brazil
16	2024	Beltozar-Clemente, S., & Díaz-Vega, E.	(Beltozar-Clemente & Díaz-Vega, 2024)	Peru
17	2024	Monteiro, F. F., Souza, P. V. S., da Silva, M. C., Maia, J. R., da Silva, W. F., & Girard, D.	(Ferreira Monteiro et al., 2024)	Brazil
18	2024	Sirnoorkar, A., Zollman, D., Laverty, J. T., Magana, A. J., Rebello, N. S., & Bryan, L. A.	(Sirnoorkar et al., 2024)	USA
19	2024	Cho, N.	(Cho, 2024)	China
20	2024	Uğraş, H., Uğraş, M., Papadakis, S., & Kalogiannakis, M.	(Uğraş et al., 2024)	Greece
21	2025	Abdulayeva, A., Zhanatbekova, N., Andasbayev, Y., & Boribekova, F.	(Abdulayeva et al., 2025)	Kazakhstan
22	2025	Revalde, G., Zholdakhmet, M., Abola, A., & Murzagaliyeva, A.	(Revalde et al., 2025)	Latvia
23	2025	Kemouss, H., & Khaldi, M.	(Kemouss & Khaldi, 2025)	Morocco
24	2025	Guerrero-Zambrano, M., Sanchez-Alvarado, L., Valarezo-Chamba, B., & Lamilla-Rubio, E.	(Guerrero-Zambrano et al., 2025)	Ecuador
25	2025	Villegas Ch., W., Buenano Fernandez, D., Maldonado Navarro, A., & Mera Navarrete, A.	(Villegas Ch. et al., 2025)	Ecuador
26	2025	Coban, A., Dzsotjan, D., Küchemann, S., Durst, J., Kuhn, J., & Hoye, C.	(Coban et al., 2025)	Germany
27	2025	Wei, Y., Zhang, R., Zhang, J., Qi, D., & Cui, W.	(Wei et al., 2025)	China
28	2025	Bessas, N., Tzanaki, E., Vavougios, D., & Plagianakos, V. P.	(Bessas et al., 2025)	Greece
29	2025	Abdulayeva, A., Zhanatbekova, N., Andasbayev, Y., Khaimuldanov, Y., & Zhiyembayev, Z.	(Abdulayeva et al., 2025)	Kazakhstan
30	2025	Ben-Zion, Y., Einhorn Zarzecki, R., Glazer, J., & Finkelstein, N. D.	(Ben-Zion et al., 2025)	Israel & USA
31	2025	Dhitareka, A. U. P. H., Husna, H. N., & Prima, E. C.	(Dhitareka et al., 2025)	Indonesia
32	2025	Agyare, B., Asare, J., Kraishan, A., Nkrumah, I., & Adjekum, D. K.	(Agyare et al., 2025)	Ghana
33	2025	Avci, H., Lunn, S. J., & Hazari, Z.	(Avci et al., 2025)	USA
34	2025	Jufrida, K., Furqon, A., Falah, R., & Riantoni, R.	(Jufrida et al., 2025)	Indonesia
35	2025	Wattanakasiwich, P., Kaewkhong, K., & Katwibun, D.	(Wattanakasiwich et al., 2025)	Thailand
36	2025	Bravo, B., Inorreta, Y., Jara, Y., & Perez, G	(Bravo et al., 2025)	Argentina

37	2025	Meyer, A., Bleckmann, T., & Friege, G.	(Meyer et al., 2025)	Germany
38	2025	Daoudi, M.	(Daoudi ,2025)	Morocco
39	2025	Fekets, G.	(Fekets,2025)	Taiwan
40	2025	Xu, Y., Liu, L., Xiong, J., & Zhu, G.	(Xu et al., 2025)	China

Data Extraction Process

A structured data extraction form was developed for the 40 included studies. Each study was systematically analyzed in terms of publication year, country, research design (qualitative, quantitative, mixed, etc.), sample level, type of AI used, research purpose, main findings, and recommendations. The data extraction process was conducted through a database created in spreadsheet format, and all records were processed according to a standardized coding scheme. The coding scheme was developed through a combination of deductive and inductive approaches. Initially, a preliminary set of codes was derived from the research questions and relevant literature and subsequently refined based on patterns emerging from the data during the analysis process. This approach aimed to ensure data integrity and enhance the transparency of the analysis process.

Validity and Reliability

To ensure reporting validity, the review process was conducted in accordance with the PRISMA 2020 guidelines. The PRISMA checklist contributed to the transparent, traceable, and replicable reporting of the systematic review. To evaluate the methodological quality of the included studies, critical appraisal criteria appropriate to each research design were applied. Each study was examined in terms of methodological clarity, sample adequacy, consistency of data collection and analysis processes, and the grounding of findings. Studies with serious methodological deficiencies were excluded from the evaluation. To ensure the reliability of the selection and coding process, the studies were independently evaluated by two researchers. Cohen's Kappa coefficient was calculated to determine inter-rater agreement. Based on observed and chance agreement rates, the Kappa value was calculated as $\kappa = 0.85$. According to the classification of Landis and Koch (1977), this value indicates "almost perfect agreement," thereby supporting the methodological reliability of the study.

Data Analysis

A meta-analysis was not conducted in this study. The included studies were first analyzed using descriptive statistics (frequency and percentage distributions). Subsequently, a thematic content analysis was performed. The studies were classified within thematic categories such as types of AI (e.g., intelligent tutoring systems, machine learning), pedagogical purposes of AI use, benefits and challenges of AI applications, and research methods. The findings were synthesized and interpreted through a systematic and holistic approach.

Results and Discussion

In this section, the bibliometric characteristics and content-related findings of the 40 studies examined within the scope of the research are presented together. The findings were interpreted using a descriptive analysis approach based on the data provided in Table 3, including publication year, author(s), APA citation information, and country distribution. In addition, thematic evaluations were conducted in line with the content-related findings of the articles.

Figure 2 presents the distribution of the articles included in the study by publication year. An examination of the findings indicates that the number of studies has increased markedly in recent years. Considering the overall distribution, 2025 has the highest number of publications ($n = 20$). This is followed by 2024 ($n = 12$) and 2023 ($n = 7$), whereas only one article ($n = 1$) was identified in 2019. These data suggest that AI applications in physics instruction have gained significant momentum, particularly after 2023. Although one study was identified in 2019, a noticeable increase has been observed beginning in 2023. The most striking growth occurred in 2024 and 2025. When the publication trend is examined, there is an approximate 71% increase from 2023 to 2024 and an approximate 67% increase from 2024 to 2025. This pattern indicates that the field is still in a developmental phase and that its research potential is progressively expanding.

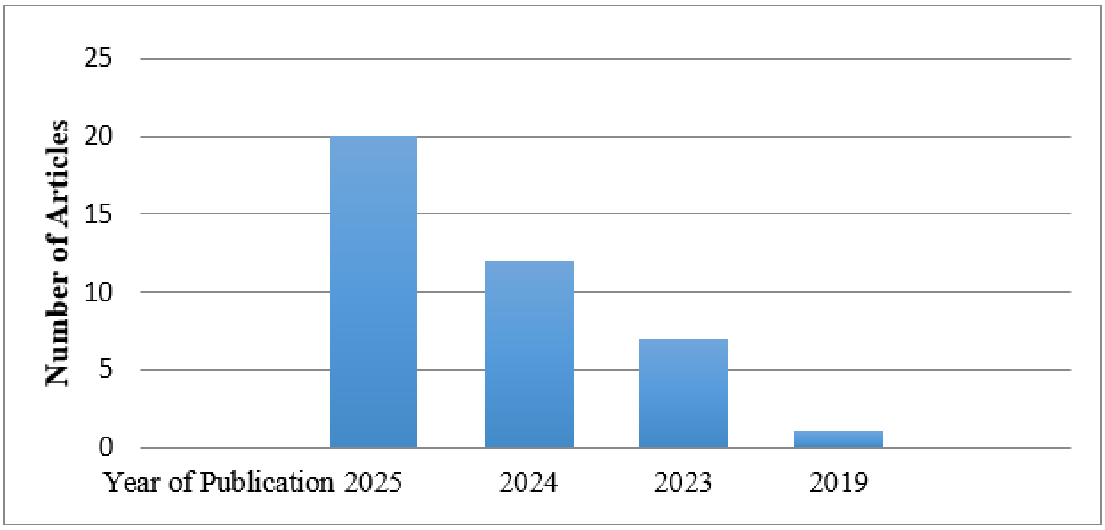

Figure 2. Distribution of articles by year

Based on the data presented in Table 3, the distribution of the 40 articles on AI-supported physics instruction was analyzed by country. The findings indicate that publications are concentrated in specific countries (Table 4). The United States (15%), China (12.5%), and Germany (12.5%) stand out as the countries with the highest publication rates. Together, these three countries account for approximately 40% of the total studies. The notable shares of Kazakhstan and Greece (7.5%) demonstrate that contributions to the literature are not limited to technologically leading countries but also include developing nations. Morocco, Brazil, Ecuador, and Indonesia (5% each) represent emerging contributions from different regions of the world, indicating a geographically diversified but still limited participation. However, a substantial proportion of the studies (25%) consists of single contributions from various other countries. This distribution suggests that while the field is beginning to expand globally, research output remains concentrated in specific centers. In other words, publication production does not exhibit a homogeneous distribution but tends to be more intensive in countries with stronger academic and technological infrastructures. Overall, the findings indicate that AI applications in physics instruction have become a global research topic; however, publication output is still concentrated in certain countries. This pattern suggests that the field is in a developmental phase and that a more balanced geographical distribution may emerge in the coming years.

Table 4. Distribution of publications by country

Country	Number of articles (n)	Percentage (%)
United States	6	15%
China	5	12.5%
Germany	5	12.5%
Kazakhstan	3	7.5%
Greece	3	7.5%
Morocco	2	5%
Brazil	2	5%
Ecuador	2	5%
Indonesia	2	5%
Other countries (each with 1 article)	10	25%

The 40 studies examined in this research were analyzed in terms of research design and participant level. The findings indicate that although methodological diversity exists, mixed methods research designs are clearly dominant (see Table 5). When the distribution presented in Figure 3 is examined, it is observed that 21 studies employed mixed methods, 10 were quantitative, 6 were qualitative, and 3 were theoretical in nature. These results suggest that the field is not limited to measurement- and comparison-based quantitative approaches; rather, qualitative and multidimensional designs aimed at understanding participant experiences, perceptions, and implementation processes have also become widespread. The fact that a significant proportion of the studies published in 2024 and 2025 adopted a mixed methods approach (e.g., Abdulayeva et al., 2025; Ben-Zion et al., 2025; Domenichini et al., 2024) indicates a shift toward a more integrative methodological orientation in the field. Quantitative studies were found to rely primarily on experimental or quasi-experimental designs and focused on measuring learning outcomes, academic achievement, or performance variables (e.g., Ding et al., 2023; Guerrero-

Zambrano et al., 2025; Xu et al., 2025). In contrast, qualitative studies tended to generate in-depth data regarding teacher perspectives, student experiences, and implementation processes (Bessas et al., 2023; Jang & Choi, 2024; Kemouss & Khaldi, 2025).

Overall, the findings demonstrate that mixed methods designs have become predominant in research on AI-supported physics education. This trend suggests that researchers aim not only to measure learning outcomes but also to evaluate implementation processes and participant experiences simultaneously. While early studies in the field primarily focused on quantitative achievement measurements, over time greater attention has been given to pedagogical impact, user experience, and classroom interaction variables.

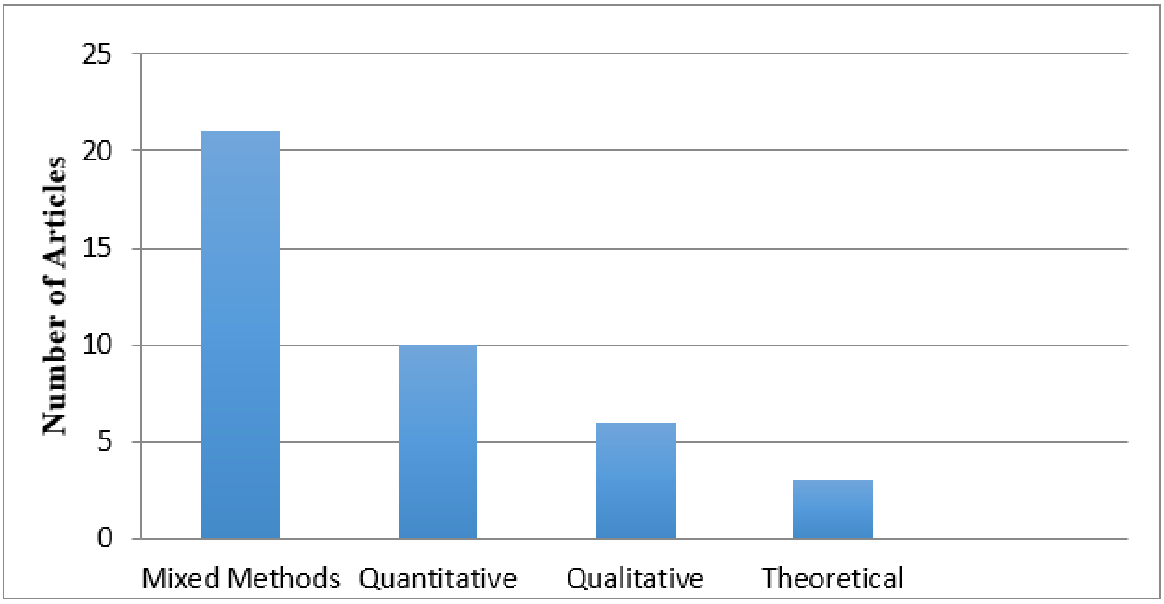

Figure 3. Distribution of publications by research type

The analyses conducted in terms of participant type indicate that research in this field is largely concentrated at the higher education level. Of the 40 studies examined, 13 were conducted exclusively with undergraduate students (e.g., Abdulayeva et al., 2025; Domenichini et al., 2024; Sirnoorkar et al., 2024). This finding suggests that the field has been predominantly shaped within the university context and that research designs have been developed primarily in higher education settings. At the high school level, 6 studies were found to involve only high school students (e.g., Abdulayeva et al., 2025; Kemouss & Khaldi, 2025; López-Simó & Rezende, 2024). In addition, 5 studies included both high school and undergraduate students (e.g., Revalde et al., 2025; Xu et al., 2025). When these two categories are considered together, a total of 11 studies involve the high school level. This indicates that secondary education also holds a significant representation within the field. Therefore, while research on AI-supported physics education is not limited to the university level, higher education remains the dominant context.

Studies involving the middle school level are more limited. Only 2 studies include middle school students, and in these studies middle school participants were examined either together with teachers (Wattanakasiwich et al., 2025) or with high school students (Bessas et al., 2025). This limited representation suggests that AI-supported physics applications for younger age groups are still in the early stages of dissemination. The relatively limited scope of physics content at the middle school level, along with the need for more pedagogically sensitive planning of implementation processes, may be among the possible reasons for this situation. The total number of studies involving teachers is 5 (e.g., Avci et al., 2025; Bravo et al., 2025; Uğraş et al., 2024). Some of these studies focus directly on teachers' perspectives, while others examine teachers alongside student groups. Representing approximately 12.5% of the total sample, this group indicates a limited distribution in terms of teacher representation. However, the sustainable and pedagogically meaningful implementation of AI systems in classroom settings is directly related to teachers' integration skills, pedagogical alignment processes, and levels of professional development. In this respect, the existing body of research appears to be structured primarily around student outcomes (e.g., achievement, performance, conceptual learning), whereas the teacher dimension has not yet been examined in sufficient depth.

Table 5. Characteristics of the studies: research design and participant type

No	Study of type	Participant type
1	Quantitative	High school students
2	Quantitative	Undergraduate students
3	Theoretical	-
4	Theoretical	-
5	Quantitative	High school students
6	Quantitative	Mixed students
7	Quantitative	Undergraduate students
8	Mixed Methods	High school and undergraduate students
9	Mixed Methods	High school students
10	Qualitative	Teachers and academics
11	Mixed Methods	High school and undergraduate students
12	Qualitative	Graduate students
13	Theoretical	-
14	Mixed Methods	Undergraduate students
15	Mixed Methods	High school students
16	Mixed Methods	Undergraduate students
17	Quantitative	K–12 Teachers
18	Mixed Methods	Undergraduate students
19	Mixed Methods	High school and undergraduate students
20	Qualitative	High School Teachers
21	Mixed Methods	Undergraduate students
22	Mixed Methods	High school and undergraduate students
23	Mixed Methods	High school students
24	Quantitative	Undergraduate students
25	Mixed Methods	Undergraduate students
26	Mixed Methods	Undergraduate students
27	Mixed Methods	Undergraduate students
28	Quantitative	Middle school students and teachers
29	Mixed Methods	High school students
30	Mixed Methods	Undergraduate students
31	Qualitative	-
32	Mixed Methods	Undergraduate students
33	Qualitative	Secondary school STEM teachers
34	Mixed Methods	Undergraduate students
35	Mixed Methods	Middle and high school students
36	Quantitative	Teachers
37	Mixed Methods	High School students
38	Qualitative	High School teachers
39	Mixed Methods	High School students
40	Quantitative	High school and undergraduate students

When the overall distribution is considered, it becomes evident that the field has not yet achieved a fully balanced structure in terms of sample diversity. The stronger technological infrastructure in higher education institutions, easier access to AI applications, and the conceptual intensity of university-level physics courses may help explain the concentration at the undergraduate level. In contrast, the limited number of studies conducted with younger age groups may be associated with the need for more careful pedagogical and ethical planning of AI-based implementations at these levels. In conclusion, the findings related to participant level indicate that research on AI-supported physics education has begun to diversify methodologically; however, there remains a need for more inclusive and balanced sample distributions. Increasing practice-based studies at the secondary education level and research focusing on teacher education may strengthen the pedagogical depth of the field and contribute to a more effective integration of technological innovations into classroom transformation.

When the 40 studies examined in this research are analyzed in terms of physics content areas, it becomes evident that the literature is concentrated around specific thematic domains (see Table 6). The findings indicate that AI-supported applications have been most frequently tested in mechanics-related topics. Studies focusing on mechanics (e.g., force, motion, energy, acceleration, centripetal force, statics, kinematics) constitute a substantial portion of the literature (e.g., Aldazharova et al., 2024; Kieser et al., 2023; López-Simó & Rezende, 2024; Xu et al., 2025). This concentration may be associated with the fact that mechanics forms the foundation of physics instruction at both secondary and tertiary levels and, due to its problem-solving-oriented structure, provides an appropriate domain for evaluating the performance of AI applications. As one of the core pillars of physics education, mechanics encompasses concepts such as force, motion, and energy, which are frequently associated with conceptual misconceptions while also allowing for the assessment of problem-solving skills. Therefore, it may offer a suitable testing ground for evaluating the accuracy, reasoning processes, and solution steps of AI systems. Electromagnetism and electricity also exhibit a notable concentration (e.g., Cho, 2024; Revalde et al., 2025). In particular, AI performance has been tested in these domains within the context of conceptual inventories and problem-solving tasks. Studies focusing on thermodynamics and heat are also present in the literature (e.g., Jufrida et al., 2025; Putra Habib Dhitareka et al., 2025), although this domain does not appear to be represented as extensively as mechanics. Quantum physics and advanced-level topics, by contrast, are represented to a relatively more limited extent compared to mechanics and foundational areas (e.g., Bitzenbauer et al., 2023; Singh, 2024). Nevertheless, the emergence of AI- and augmented reality (AR)-supported personalized feedback applications within quantum contexts suggests that the field is gradually expanding toward more abstract and mathematically intensive content areas. This development indicates that AI systems may hold potential not only for foundational problem-solving tasks but also for the instruction of conceptually complex and abstract topics.

Studies addressing general physics or physics within a broader STEM context also occupy a significant place in the literature (e.g., Avci et al., 2025; Bessas et al., 2025; Uğraş et al., 2024). Another notable finding is that a considerable proportion of studies focus directly on testing the problem-solving, assessment, or feedback capabilities of ChatGPT or other generative AI systems (e.g., Bitzenbauer et al., 2023; Wei et al., 2025; Xu et al., 2025). This trend suggests that the field has largely concentrated on analyzing the performance of large language models in solving physics problems. While many of these studies primarily address the question, “Can AI solve physics problems?” (e.g., Aldazharova et al., 2024; Tong et al., 2023; Xu et al., 2025), issues related to pedagogical design, long-term learning effects, and conceptual change processes have been addressed to a comparatively limited extent. In conclusion, the distribution of topics indicates that the literature on AI-supported physics education is largely concentrated around fundamental concepts and problem-solving contexts, whereas advanced, interdisciplinary, and conceptually deep domains remain comparatively less explored.

Table 6. Physics topic and study title

No	Physics topics	Article title
1	Mechanics: force, torque, angular momentum, linear & circular motion	Can Aikido Help With the Comprehension of Physics? A First Step Towards the Design of Intelligent Psychomotor Systems for STEAM Kinesthetic Learning Scenarios
2	Optics	Students’ perceptions of using ChatGPT in a physics class as a virtual tutor
3	Hydrostatics, fractals	Implementing AI in Physics lessons in the High School
4	Problem-solving, vectors, quantitative analysis	Exploring the potential of using ChatGPT in physics education.
5	Quantum physics: wave–particle duality, photon	ChatGPT in physics education: A pilot study on easy-toimplement activitie
6	Physics problems	Investigating ChatGPT-4’s performance in solving physics problems and its potential implications for education
7	Newtonian mechanics: force, motion, acceleration	Educational data augmentation in physics education research using ChatGPT
8	Mechanics: loop-the-loop, energy, centripetal force	Integrating artificial intelligence-based methods into qualitative research in physics education research: A case for computational grounded theory
9	High school physics: mechanics, thermodynamics	The Essential Technology Implementations for Developing a Hybrid Module for High School Physics in the Sultanate of Oman
10	General physics	A Double-Edged Sword: Physics Educators’ Perspectives on Utilizing ChatGPT and Its Future in Classrooms
11	Newtonian mechanics: force, motion, friction, inertia	Assessing AI’s problem solving in physics: Analyzing reasoning, false positives and negatives through the force concept inventory
12	Graduate physics: quantum, electromagnetism, thermal, computational	2024 Jackson Award for Excellence in Graduate Physics Education lecture: Physics graduate education for the 21st century
13	Physical foundations, scientific discovery	Education Implications of Artificial Intelligence-Based Chemistry and Physics Nobel Prizes
14	Classical mechanics	An AI-Driven Approach for Enhancing Engagement and Conceptual Understanding in Physics Education

15	Mechanics: Newton's laws, acceleration, energy	Challenging ChatGPT with Different Types of Physics Education Questions
16	Statics, kinematics	Physics XP: Integration of ChatGPT and Gamification to Improve Academic Performance and Motivation in Physics 1 Course.
17	General physics	ChatGPT in Brazilian K-12 science education.
18	Mechanics: centripetal force, motion	Student and AI responses to physics problems examined through the lenses of sensemaking and mechanistic reasoning.
19	Force, electricity & magnetism, resistive circuits	An investigation of using Spark generative AI in solving physics concept inventories in English and Chinese: performance and issues.
20	General physics (STEM context)	Innovative Early Childhood STEM Education with ChatGPT: Teacher Perspectives
21	Thermodynamics, electromagnetism	Fostering AI literacy in pre-service physics teachers: inputs from training and co-variables
22	Mechanics, waves, electromagnetism	Can ChatGPT Pass a Physics Test?
23	Waves, electricity, mechanics, nuclear	Physics Teaching with Artificial Intelligence (AI): A Personalized Approach for Accommodator-Style Learners According to Kolb.
24	Mechanics, thermodynamics, waves, EM, quantum, energy, relativity	Transforming Physics Teacher Training Through ChatGPT: A Study on Usability and Impact.
25	Mechanics & electromagnetism: conceptual understanding, problem-solving	Adaptive intelligent tutoring systems for STEM education: analysis of the learning impact and efectiveness of personalized feedback.
26	Quantum cryptography	AI support meets AR visualization for Alice and Bob: personalized learning based on individual ChatGPT feedback in an AR quantum cryptography experiment for physics lab courses
27	Computational physics, quantitative problems	Research on Intelligent Grading of Physics Problems Based on Large Language Models
28	General physics	The role of ChatGPT in junior high school physics education: Insights from teachers and students and guidelines for optimal use
29	Advanced physics	The Role Of Artificial Intelligence (Ai) In Personalised Physics Education
30	Ballistics, electric fields, quantum wells	Leveraging AI for Rapid Generation of Physics Simulations in Education: Building Your Own Virtual Lab
31	Heat and temperature	An exploratory study of ChatGPT in STEM teaching on heat and temperature topic
32	University-level physics education	A cross-national assessment of artificial intelligence (AI) Chatbot user perceptions in collegiate physics education.
33	Physics & STEM: general, not topic-specific	Exploring STEM educators' perspectives on the integration of AI-enabled technologies in teaching and learning.
34	Thermodynamics, heat transfer, structural equilibrium, rotational dynamics	Ai-Driven Ethnoscience Learning: Enhancing Physics Education Through Malay Cultural Insights.
35	Nuclear, fluids, EM, force & motion	Physics instructors' acceptance and implementation of generative AI.
36	Electromagnetic induction	Use of Generative Artificial Intelligence to Solve Physics Problems in Engineering.
37	Mechanics and thermodynamics	Automatic feedback on physics tasks using open-source generative artificial intelligence
38	Classical to quantum mechanics	Moroccan Teachers' Perceptions About Integrating Historical Contexts and AI in the Seamless Transition from Classical to Quantum Mechanics.
39	Physics & STEM, general, not topic-specific	Development Of An Artificial Intelligence supported Chatbot As An Interactive Learning Platform In Stem Education: Exploring Usability And Student Experience
40	Mechanics: energy, friction, elastic–plastic deformation	Graders Of The Future: Comparing The Consistency And Accuracy Of Gpt4 And Pre-Service Teachers In Physics Essay Question Assessments

Table 7 presents the publication details of the analyzed studies, categorizing each article according to journal title, volume, issue, page range, and DOI information. The reviewed studies were published in a range of internationally recognized journals in the fields of educational technology and physics education. Notable outlets include *Computers and Education* (Avci et al., 2025), *Physical Review Physics Education Research* (Kieser et al., 2023; Tschisgale et al., 2023; Wattanakasiwich et al., 2025), *Computers and Education: Artificial Intelligence* (Agyare et al., 2025; Sirnoorkar et al., 2024), and *American Journal of Physics* (Singh, 2024). This distribution indicates that research on AI-supported physics education is positioned at the intersection of educational technology and discipline-based physics education research, gaining visibility in both domains.

Table 7. Publication details of articles by journal and DOI.

No	Name of Journal	Volume	Issues	Pages	DOI
1	IEEE Access	7	-----	176458	https://doi.org/10.1109/ACCESS.2019.2957947
2	International Journal of Educational Technology in Higher Education	20	63	5-18	https://doi.org/10.1186/s41239-023-00434-1
3	International Conference on Computational Science and Computational Intelligence	....	---	-1775 1779	https:// 10.1109/CSCI62032.2023.00293
4	Smart Learning Environments	10		2-19	https://doi.org/10.1186/s40561-023-00273-7
5	Contemporary Educational Technology	15	3	2-10	https://doi.org/10.30935/cedtech/13176
6	Asia Pacific Education Review	25	-----	1379–1389	https://doi.org/10.1007/s12564-023-09913-6
7	Physical Review Physics Education Research	19	-----	020150-13	https://doi.org/10.1103/PhysRevPhysEducRes.19.020150
8	Physical Review Physics Education Research	19	2	020123-24	https://doi.org/10.1103/PhysRevPhysEducRes.19.020123
9	International Journal of Instruction	17	3	617-634	https://doi.org/10.29333/iji.2024.17334a
10	Journal of Science Education and Technology	34	----	267–283	https://doi.org/10.1007/s10956-024-10173-1
11	Contemporary Educational Technology	16	4	1-16	(http://creativecommons.org/licenses/by/4.0/)
12	American Journal of Physics	92	12	918–923	https://doi.org/10.1119/5.0242316
13	Journal of Chemical Education	101	---	4533−4534	https://doi.org/10.1021/acs.jchemed.4c01275
14	IEEE Global Engineering Education Conference	....	---	1-3	https://doi.org/10.1109/EDUCON60312.2024.10578670
15	The Physics Teacher	62	----	290–294	https://doi.org/10.1119/5.0160160
16	International Journal of Engineering Pedagogy	14	6	82-92	https://doi.org/10.3991/ijep.v14i6.47127
17	Frontiers in Education	9	1321547	1-8	https://doi.org/10.3389/feduc.2024.1321547
18	Computers and Education: Artificial Intelligence	7	100318	1-15	https://doi.org/10.1016/j.caeai.2024.100318
19	Discover Artificial Intelligence	4	108	1-16	https://doi.org/10.1007/s44163-024-00215-3
20	Technology, Knowledge and Learning	30	----	809–831	https://doi.org/10.1007/s10758-024-09804-8
21	Technology, Knowledge and Learning	10	1505420	1-13	https://doi.org/10.3389/feduc.2025.1505420
22	Technology, Knowledge and Learning	30	---	1-20	https://doi.org/10.1007/s10758-025-09814-0
23	International Journal of Instruction	18	3	39-58	https://doi.org/10.29333/iji.2025.1833a

24	Education Sciences	15	887	1-26	https://doi.org/10.3390/educsci15070887
25	Smart Learning Environments	12	41	1-31	https://doi.org/10.1186/s40561-025-00389-y
26	Smart Learning Environments	12	15	1-28	https://doi.org/10.1140/epjqt/s40507-025-00310-z
27	Education Sciences	15	116	1-15	https://doi.org/10.3390/educsci15020116
28	Social Sciences & Humanities	11	101610	1-13	https://doi.org/10.1016/j.ssaho.2025.101610
29	Jurnal Pendidikan IPA Indonesia	14	3	599-615	https://journal.unnes.ac.id/journals/jpii
30	Jurnal Pendidikan IPA Indonesia	63	----	424-427	https://doi.org/10.1119/5.0252343
31	Discover Education	4	309	1-25	https://doi.org/10.1007/s44217-025-00751-9
32	Computers and Education: Artificial Intelligence	8	100365	1-15	https://doi.org/10.1016/j.caeai.2025.100365
33	Computers and Education	9	100304	1-12	https://doi.org/10.1016/j.caeo.2025.100304
34	Computers and Education Open	24	----	1-27	https://doi.org/10.28945/5520
35	Physıcal Revıew Physıcs Educatıon Research	21	010155	010155-24	https://doi.org/10.1103/r2fn-kdy4
36	Physical Review Physics Education Research	43	3	73–91	https://orcid.org/0000-0002-3941-0547
37	International Journal of Science Education	….	0693	1464-5289	https://doi.org/10.1080/09500693.2025.2499220
38	Mechanics, African Journal of Research in Mathematics, Science and Technology Education	29	2	171-190	https://doi.org/10.1080/18117295.2025.2460911
39	Journal of Baltic Science Education	24	5	878–893	https://doi.org/10.33225/jbse/25.24.878
40	Journal of Baltic Science Education	24	1	187–207	https://doi.org/10.33225/jbse/25.24.187

The types of artificial intelligence employed in the 40 reviewed studies were analyzed, and the findings are presented in Table 8. Overall, the results indicate a clear dominance of generative AI–based chatbots and advanced large language models (LLMs), particularly GPT-4–based systems. ChatGPT and GPT-4 were the most frequently utilized AI tools across the studies. Research directly employing ChatGPT or GPT-4 (n = 24) accounts for more than half of the total sample, highlighting the central role of generative AI in physics education research, particularly in the post-2023 period. In contrast, classical AI-based Intelligent Tutoring Systems (ITS) were represented in only a limited number of studies. Similarly, AI-supported sensor-based systems appeared in only one study. This pattern suggests a notable shift from earlier adaptive instructional systems toward generative language models in recent research trends. In several studies, the type of AI was described using general terms without specifying the exact model or technological framework. This lack of technical detail indicates that systematic model-level comparisons remain limited in the literature. Additionally, some studies adopted a multi-tool approach. For example, one study combined ChatGPT, Google AI, and PhET simulations, demonstrating that AI tools are increasingly being integrated with existing digital learning environments rather than being used in isolation.

A broader trend analysis reveals that earlier studies primarily emphasized ITS and adaptive learning systems, whereas recent research has been largely dominated by generative AI applications. The strong presence of ChatGPT and GPT-4 suggests that the field is increasingly leveraging LLMs for problem solving, feedback generation, and conceptual explanation tasks. This trend may be associated with accessibility factors, as systems such as ChatGPT are widely available and can be readily implemented in classroom settings. In contrast, the development of ITS platforms requires extensive software design and technical infrastructure, which may explain their reduced presence in recent studies. However, the concentration of research around a single platform (ChatGPT/GPT-4) may introduce a technology-dependent orientation within the field. Moreover, given the known limitations of generative AI systems—including accuracy concerns, hallucination risks, and issues related to pedagogical appropriateness—future studies should adopt more rigorous and comprehensive evaluation frameworks. Although data-driven modeling, simulation-based learning, and experimental practices are central to physics education, the limited representation of ITS and sensor-based AI systems points to a potential research gap. Studies employing multiple AI tools suggest that integrating generative chatbots with simulations, augmented reality, and virtual laboratory environments may offer more robust learning experiences, particularly for teaching abstract physics concepts.

Table 8. AI type used in the studies.

No	AI type used
1	AI-supported sensor-based feedback systems
2	ChatGPT
3	GPT-3.5 / GPT-4
4	ChatGPT
5	ChatGPT
6	ChatGPT-4
7	ChatGPT / GPT-4
8	ChatGPT
9	Artificial Intelligence (AI)
10	ChatGPT / GPT-4
11	GPT-4
12	Not specified
13	Artificial Intelligence (AI)
14	Artificial Intelligence (AI)
15	ChatGPT-3.5
16	ChatGPT
17	ChatGPT
18	ChatGPT-3.5 / GPT-4
19	ChatGPT-3.5 / GPT-4
20	Artificial Intelligence (AI)
21	Generative AI (GenAI) – ChatGPT
22	ChatGPT-3.5
23	Artificial Intelligence (AI)
24	Generative AI (AI-based)
25	Intelligent Tutoring System (ITS)
26	ChatGPT / GPT-4
27	Large Language Model (LLM) – GPT-4
28	ChatGPT
29	Artificial Intelligence (AI)
30	GPT-4
31	ChatGPT / GPT-4
32	ChatGPT (Generative AI Chatbot)
33	AI-supported educational technologies
34	Artificial Intelligence (AI)
35	Generative AI (GenAI)
36	ChatGPT
37	GPT-4
38	ChatGPT, Google AI, PhET Interactive Simulations
39	GPT-4
40	ChatGPT-4

Table 9 presents the applications of artificial intelligence in physics education research. The analysis of 40 studies indicates that AI has been utilized in a multidimensional manner across physics education and physics education research, including instructional support, virtual tutoring, personalized and adaptive learning systems, assessment and automated feedback, conceptual analysis, research-oriented applications, and professional development. Studies focusing on instructional use (e.g., Bessas et al., 2025; Bitzenbauer et al., 2023; Bravo & Pérez, 2025; Zou et al., 2023) demonstrate that AI systems can provide immediate feedback, guide problem-solving processes, explain concepts, and address misconceptions.

Table 9. Application of AI in physics research

No	Application of AI in studies
1	Design of psychomotor systems training through AI and sensory perception modeling and acrobatic movements (STEAM) to support the learning of physical concepts.
2	AI (ChatGPT) was used as a virtual tutor in university-level physics courses to answer physics questions on light and radioactivity and to examine students' incorrect responses.
3	AI-based ChatGPT was applied in high school physics courses to create lesson plans, answer student questions, correct misconceptions, and relate concepts to real life, especially for hydrostatic pressure and fractals topics.
4	AI-based ChatGPT was used to explain concepts, guide problem-solving, and provide immediate feedback to students in physics classes.
5	ChatGPT was used in secondary-level physics (quantum physics) courses to develop critical thinking skills.
6	ChatGPT-4 was used at middle and high school levels to solve physics problems, assess conceptual understanding, and evaluate physics reasoning performance in comparison with students.
7	ChatGPT (GPT-4 based large language model) was employed in physics education research to generate synthetic data for Force Concept Inventory (FCI) and analyze conceptual understanding and physics reasoning performance.
8	AI (NLP and machine learning) was used in physics education research to analyze large-scale qualitative text data and identify patterns.
9	AI was considered as one of the technological applications evaluated for hybrid physics modules, but ranked last in priority according to Fuzzy Delphi Method (FDM) results.
10	ChatGPT can support problem-solving and personalized learning; however, risks include dependency, educational inequality, and teachers' digital competency needs.
11	GPT-4 was tested on Force Concept Inventory (FCI) in physics education; it showed high accuracy in topics like Newton's third law but struggled with diagram interpretation and spatial reasoning, exhibiting conceptual errors.
12	Highlights the pedagogical necessity of using digital and online technologies, including large language models (LLMs), in physics education.
13	For the Physics prize, the role of physics in developing the foundations of artificial neural networks has been acknowledged.
14	Automatically generate physics learning activities in a gamified environment using Generative AI, design adaptive learning paths, and personalize the teaching of classical mechanics concepts.
15	AI is successful in definitions and simple calculations in physics; it is limited in complex and interpretive problems, thus serving as a supportive tool.
16	The combined use of ChatGPT and gamification significantly increased academic achievement and motivation in Physics 1 students (188 students, experimental–control group).
17	Most K-12 science teachers in Brazil are cautious and uncertain about whether ChatGPT can enhance educational quality or whether its use counts as plagiarism.
18	Examined "meaning-making" and "mechanical reasoning" in solving physics problems by comparing student responses with ChatGPT (versions 3.5 and 4.0); results indicate AI responses reflect a "physics definition" approach, while student responses reflect a "physics application" approach.
19	Examines the use of generative AI in physics education research and analyzes its performance in conceptual physics tests in mechanics and electromagnetism; no application for pure physics or physical simulations was considered.
20	Investigates ChatGPT's integration into early STEM education based on teacher perspectives; highlights advantages such as instant feedback, personalized content, motivation, and faster instruction while addressing technical issues and security concerns.
21	Examines the effect of a pre-service physics teacher training program to improve AI literacy and investigates the role of perceived usefulness of AI on future teaching intentions.
22	Evaluates ChatGPT's performance on multiple-choice questions and problem-solving tasks in physics education across four languages; relatively successful in theoretical questions, limited in problem-solving, with language significantly affecting performance.
23	Examines AI-supported personalized physics instruction for high school students with Kolb's accommodator learning style; AI improves learning experiences and performance via interactive simulations, immediate feedback, and adaptive activities.
24	Investigates ChatGPT's usability and impact in pre-service physics teacher training; shows AI improves educational activity design, teacher satisfaction, and effectiveness in developing adaptive, game-based physics activities.

25	AI-based intelligent tutoring systems provide real-time, adaptive, and personalized learning in mathematics, physics, and programming; significantly improved academic achievement and student satisfaction with adaptive feedback in the experimental group.
26	ChatGPT-based feedback integrated into an AR-supported quantum cryptography lab improved university students' learning outcomes and cognitive processes; AI feedback directed visual attention to task-relevant elements, enhancing learning performance.
27	Examines automated physics problem assessment based on large language models; the tree-of-thought prompt approach can score complex computational problems with high accuracy and offers strong potential for intelligent assessment in physics education.
28	AI is used in physics research, especially via language models like ChatGPT, to support conceptual explanations and investigate problem-solving processes; considered a complementary tool requiring teacher guidance for accuracy and conceptual consistency.
29	AI-based personalized learning systems adapt content based on student performance in physics education, showing significant improvements in academic achievement, problem-solving skills, and critical thinking.
30	Generative AI models (e.g., ChatGPT, Claude) enable rapid creation of interactive simulations in physics education without programming knowledge, enhancing conceptual understanding, exploratory learning, and student engagement.
31	ChatGPT's responses to STEM pedagogy questions align conceptually with existing academic literature but have limited reliability for academic and instructional purposes due to lack of sources and multiple perspectives.
32	Examines physics students' perceptions of ChatGPT using the Technology Acceptance Model (TAM); perceived ease of use and subjective norms influenced usage intention and actual use, while ethical concerns negatively affected ChatGPT use.
33	STEM teachers adopt AI as a supportive instructional tool but face institutional support and professional development challenges in classroom implementation.
34	Aims to deliver culturally sensitive and personalized STEM education in project-based learning in Indonesia's Jambi region using machine learning and educational data mining, based on Malay ethno science.
35	Investigates physics teachers' adoption and use of generative AI, highlighting knowledge gaps, language limitations, and pedagogical concerns as major barriers in the adoption process.
36	Use of ChatGPT in solving electromagnetic induction problems.
37	Automatic assessment of student responses and feedback generation in physics problem-solving tasks.
38	Supporting historical narratives, interactive learning, and facilitating conceptual transition in physics teaching.
39	AI-generated storytelling (Newton's Laws)
40	Evaluation of student responses according to cognitive levels.

However, several studies report that AI remains limited in handling complex, interpretive, and higher-order reasoning problems (López-Simó & Rezende, Jr., 2024; Sirnoorkar et al., 2024). Within the domain of personalized and adaptive learning, AI-supported systems have been shown to adapt instructional content based on student performance and contribute to improvements in academic achievement (Abdulayeva et al., 2025; Kemouss & Khaldi, 2025; Villegas Ch. et al., 2025). Adaptive feedback systems (Villegas Ch. et al., 2025), AR + ChatGPT integration (Coban et al., 2025), and gamified learning environments (Beltozar-Clemente & Díaz-Vega, 2024; Domenichini et al., 2024) have demonstrated positive effects on learning performance and student motivation.

Significant findings also emerge regarding the use of AI in assessment processes. AI systems have been employed for automated problem grading (Meyer et al., 2025; Wei et al., 2025), conceptual test performance analysis (Aldazharova et al., 2024; Cho, 2024; Revalde et al., 2025), and evaluation of student responses according to cognitive levels (Xu et al., 2025). These applications indicate the growing potential of AI-driven intelligent assessment frameworks in physics education. In addition to instructional applications, some studies have employed AI as a methodological tool in physics education research. Applications such as synthetic data generation (Kieser et al., 2023), qualitative data analysis (Tschisgale et al., 2023), and comparative analyses of student and AI-generated responses (Sirnoorkar et al., 2024) suggest that AI can contribute to research design and analytical processes. Studies focusing on teacher perspectives (Ferreira Monteiro et al., 2024; Kemouss & Khaldi, 2025; Uğraş et al., 2024) reveal both opportunities and concerns regarding AI integration. Teachers acknowledge advantages such as instant feedback and personalization (Uğraş et al., 2024). However, ethical concerns, limited digital competencies, and insufficient institutional support are identified as significant barriers (Avci et al., 2025;

Ferreira Monteiro et al., 2024; Wattanakasiwich et al., 2025). Overall, the literature positions AI as a tool with transformative pedagogical potential in physics education. Nevertheless, it also emphasizes the necessity of strengthening theoretical and pedagogical frameworks to ensure sustainable, ethical, and educationally grounded integration.

Table 10. AI benefits in studies

No	AI benefits in studies
1	Aikido movements enhanced understanding of the “moment of inertia” concept.
2	AI literacy supported students in using AI effectively in education.
3	ChatGPT sped up teachers’ lesson planning and boosted students’ motivation.
4	ChatGPT solved physics problems, explained solutions, and generated new exercises.
5	Intervention improved students’ perceptions of ChatGPT and daily life integration.
6	Students strengthened reasoning and scientific method skills.
7	ChatGPT produced accurate conceptual answers and modeled students’ prior knowledge.
8	CGT method enhanced problem-solving and explanation quality through human–AI collaboration.
9	Mobile and digital learning technologies increased student usage.
10	ChatGPT supported personalized, inquiry-based learning; curriculum and infrastructure issues remain.
11	GPT-4 provided high accuracy on Newtonian mechanics questions; some conceptual errors observed.
12	Growth mindset instructors created inclusive and motivating learning environments.
13	AI has potential to enhance instruction through data-driven strategies.
14	Gamified learning and generative AI contributed positively to physics learning.
15	ChatGPT excelled at simple calculation questions; insufficient for complex problems.
16	AI and gamification increased students’ interest, self-efficacy, and engagement.
17	Teachers observed learning benefits but highlighted accuracy and ethical considerations.
18	AI responses were structured with clear assumptions; students showed richer epistemic practices.
19	ChatGPT’s language performance varied; some issues in understanding physics concepts detected.
20	Teachers agreed ChatGPT is beneficial in early childhood STEM education.
21	Intervention increased students’ AI literacy and intent to integrate AI.
22	ChatGPT’s problem-solving success varied across languages.
23	AI-supported learning tools improved student achievement and conceptual understanding.
24	Participants found ChatGPT useful for adapting activities and reducing preparation time.
25	Intervention group showed improvements in feedback accuracy, progress, and student satisfaction.
26	AI improves learning of abstract quantum physics concepts through personalized feedback.
27	Tree-of-Thought method solved complex problems with highest accuracy.
28	Teachers used ChatGPT for lesson planning; students for rapid answers.
29	Intervention group improved in advanced problem-solving, research skills, and motivation.
30	Students experienced active learning with simulations and enjoyed the activity.
31	ChatGPT responses conceptually aligned with literature; reliability limited by missing academic references.
32	Ethical use positively guided students’ ChatGPT usage.
33	Teachers used AI as cognitive and socio-emotional support; reduced routine tasks.
34	AI increased student engagement and conceptual understanding; prediction accuracy reached 85%.
35	Teachers adopted ChatGPT at different levels; used most for content creation.
36	Improved understanding of electromagnetic induction, self-regulated learning, and metacognitive awareness.
37	Student responses classified with high accuracy; feedback deemed appropriate.
38	Producing historical context enhanced critical thinking and student engagement.
39	Students generally satisfied; multilingual interaction received limited support.
40	AI (LLMs) can enhance grading consistency, support personalized learning, and assist teachers in creating and evaluating educational content.

The findings regarding the benefits of artificial intelligence (AI) in physics education are presented in Table 10. Overall, the results indicate that AI provides significant contributions across cognitive, pedagogical, motivational, and assessment dimensions. Strong evidence is particularly observed in areas such as personalization, immediate feedback, and adaptive learning (Coban et al., 2025; Kemouss & Khaldi, 2025; Villegas Ch. et al., 2025). A substantial portion of the studies report that AI directly supports the understanding of physics concepts (Abdulayeva et al., 2025; Kemouss & Khaldi, 2025; Santos & Corbí, 2019). For instance, Bravo and Pérez (2025) reported significant improvements in the understanding of electromagnetic induction topics. Some studies further indicate that AI-supported tools enhance student performance and conceptual comprehension (Abdulayeva et al., 2025; Jufrida et al., 2025; Kemouss & Khaldi, 2025).

However, limitations have been noted in solving complex problems and tasks that require deep conceptual reasoning (Cho, 2024; López-Simó & Rezende, Jr., 2024; Revalde et al., 2025). Some studies emphasize AI's positive impact on problem-solving and scientific reasoning skills (Tschisgale et al., 2023; Tong et al., 2023; Zou et al., 2023). In Zou et al. (2023), ChatGPT was found effective in problem-solving and generating new questions. Similarly, Tschisgale et al. (2023) highlighted that human–AI collaboration improved the quality of problem-solving.

Several studies also highlight the motivational effects of AI-supported learning environments (Ben-Zion et al., 2025; Domenichini et al., 2024; Fekets, 2025). In particular, gamification and generative AI have been reported to increase students' engagement and self-efficacy (Beltozar-Clemente & Díaz-Vega, 2024; Domenichini et al., 2024). Overall student satisfaction with AI use was generally high, and teachers reported perceiving AI as beneficial in STEM education (Fekets, 2025; Uğraş et al., 2024). One of AI's strongest contributions is its support for personalized learning and feedback (Meyer et al., 2025; Villegas Ch. et al., 2025; Xu et al., 2025). According to Coban et al. (2025), personalized feedback facilitated the learning of abstract concepts. Xu et al. (2025) reported that large language models (LLMs) improved grading consistency and content creation. Villegas Ch. et al. (2025) found that adaptive feedback enhanced student satisfaction and learning progress. These findings suggest that AI can function as a supportive tool in assessment and evaluation processes.

AI's benefits for teachers are also noteworthy. Reports indicate that AI reduces lesson planning time (Bessas et al., 2023; Bessas et al., 2025; Guerrero-Zambrano et al., 2025), supports content creation (Wattanakasiwich et al., 2025), and provides cognitive and socio-emotional support by alleviating some routine tasks (Avci et al., 2025). Nonetheless, teachers highlighted limitations related to accuracy, ethical use, and technical infrastructure (Ferreira Monteiro et al., 2024; Jang & Choi, 2024; Revalde et al., 2025). Overall, literature positions AI as a transformative tool in physics education while emphasizing the need to strengthen pedagogical frameworks to ensure sustainable and ethical integration.

The challenges encountered in physics education research that incorporates AI are summarized in Table 11. These findings indicate that while AI offers significant opportunities in physics education, it also presents various limitations at pedagogical, technical, cognitive, and ethical levels. A substantial portion of the studies report that AI can make errors in understanding physical concepts and performing mathematical operations. Reported difficulties include weak performance in numerical calculations and errors in vector directions (Zou et al., 2023), high error rates in arithmetic and trigonometric calculations (López-Simó & Rezende, Jr., 2024), increased errors in multi-step problems (Revalde et al., 2025), mistakes in physics terminology and low-quality feedback in open-ended questions (Meyer et al., 2025), and lower scoring accuracy of ChatGPT-4 compared to human evaluators (Xu et al., 2025). Additionally, AI responses were found to be persuasive but not always correct (Bessas et al., 2025; Sirnoorkar et al., 2024). Some studies also highlight limitations in AI's pedagogical content knowledge (Ben-Zion et al., 2025; Putra Habib Dhitareka et al., 2025; Fekets, 2025).

Contextual limitations of LLM-based systems are frequently reported, including difficulties in converting visual questions to text (Kieser et al., 2023), hallucinations and out-of-context outputs (Ben-Zion et al., 2025; Bravo & Pérez, 2025; Kieser et al., 2023), overly simplified or biased outputs (Avci et al., 2025; Bravo & Pérez, 2025), and multilingual performance issues (Cho, 2024; Fekets, 2025; Revalde et al., 2025). Ethical concerns regarding AI use are strongly emphasized in the literature. These include the production of inaccurate or misleading information (Bessas et al., 2023; Ferreira Monteiro et al., 2024; Wattanakasiwich et al., 2025), risks of over-reliance and excessive trust (Ferreira Monteiro et al., 2024), academic integrity and privacy issues (Holme, 2024; Wattanakasiwich et al., 2025), and challenges in ethical and pedagogical integration (Abdulayeva et al., 2025).

The uncertainty surrounding AI's accuracy and reliability requires careful use in educational settings (Holme, 2024; Jang & Choi, 2024). Examined studies also highlight structural and technological barriers, such as limited digital infrastructure in public schools (Jufrida et al., 2025), lack of institutional support and cost issues (Avci et al., 2025), and participants' unfamiliarity with AI technologies (Guerrero-Zambrano et al., 2025). These findings suggest that AI integration requires not only pedagogical but also structural transformation. Some studies indicate that short-term interventions do not produce lasting effects (Bitzenbauer et al., 2023) and sample biases exist (Santos & Corbí, 2019). In conclusion, literature identifies three essential requirements for AI use in physics education: 1) Development of pedagogical frameworks (domain-specific adaptation), 2) Strengthening ethical and critical AI literacy, and 3) Improvement of infrastructure and institutional support mechanisms.

Table 11. Challenges faced by AI in studies

No	Challenges faced by AI in research
1	Differences in participants' prior knowledge and sampling bias
2	Varied perceptions of ChatGPT usage across different groups
3	Incorrect or misleading answers may cause conceptual misunderstandings
4	Weak performance in numerical calculations; errors in vector directions
5	Limitations in accuracy of AI outputs; short-term interventions reduce lasting impact
6	Errors in methodological and mathematical representations
7	Challenges converting visual questions to text; risk of bias and hallucinations
8	Issues with verifiability, reproducibility, and scalability in traditional qualitative analyses
9	Effective integration of technology in hybrid learning limited by infrastructure
10	Reliability issues, algorithmic and language constraints
11	Low success in spatial reasoning tasks; conceptual errors in physics concepts
12	Historical inequalities; negative impact of fixed-mindset instructors
13	Accuracy and reliability concerns; ethical issues in AI use
14	Lack of conceptual understanding, low motivation, insufficient personalization
15	Arithmetic and trigonometric errors; high error rates in multi-step problems
16	Gaps in mathematical knowledge and conceptual analysis at university level
17	Misinformation, ethical concerns, over-reliance on AI, low digital literacy
18	AI solutions may be convincing but not always correct; student solutions may be incomplete
19	Difficulty understanding physics concepts; language inequities
20	Technical challenges in ChatGPT integration; student-related issues
21	Difficulties in ethical, pedagogical, and behavioral AI integration
22	Low problem-solving success; language errors; inconsistent answers
23	Students struggle with abstract concepts; teacher-centered instruction; content overload
24	Limited familiarity of participants with AI technologies; technical and access limitations
25	Challenges in Intelligent Tutoring Systems (ITS)
26	the abstract and complex nature of quantum physics makes the topic difficult to understand.
27	Automatic grading of complex physics computation problems is difficult
28	Confusing AI explanations; concerns about scientific and contextual accuracy
29	AI in physics education faces limited frameworks and poor subject-specific adaptation.
30	AI hallucinations; missing pedagogical content knowledge; inconsistent outputs
31	Lack of proper academic citations; single-perspective responses; misalignment with pedagogy
32	AI research challenges: biased or oversimplified outputs, limited context, ethical concerns, and reliance on users' critical skills
33	Lack of institutional support; cost and accessibility issues; excessive AI tools
34	Limited digital infrastructure in public schools; varied teacher competency
35	Insufficient technical knowledge; AI may generate incorrect physics information; ethical and privacy concerns
36	AI challenges: biased/oversimplified answers, need for critical thinking, and context limits
37	Errors in physics terminology; low feedback quality in open-ended tasks
38	Limited analytical depth; AI cannot fully replace teacher expertise
39	Language barriers; AI cannot replace teacher; technical and system limitations
40	ChatGPT-4 scoring accuracy lower than human evaluators

The recommendations presented in Table 12 from the reviewed studies were coded using a qualitative content analysis approach, and the resulting codes were thematically classified in Table 13. The recommendations are grouped into ten main themes. One of the most prominent areas is *Pedagogical Integration and Instructional Design* (Bessas et al., 2023; Kieser et al., 2023; Singh, 2024; Sirnoorkar et al., 2024). The studies include design-oriented recommendations such as personalized learning, adaptive systems, hybrid modules, and AR–LLM integration. These studies suggest that AI should be considered not only as a content generator but also as a tool that transforms instructional design. The second dominant theme is *Teacher Education and Professional Development* (Avci et al., 2025; Bessas et al., 2025; Sirnoorkar et al., 2024; Uğraş et al., 2024). The studies emphasize that generative AI tools should be used under teacher guidance within a pedagogical framework rather than being directly provided to students. Additionally, the development of in-service training programs and discipline-specific AI professional development models is highlighted as essential. The third dominant theme is *AI Literacy and Ethical Use* (Abdulayeva et al., 2025; Ding et al., 2023; Cho, 2024; Revalde et al., 2025). Specifically, misconceptions about GenAI among students should be addressed, usage guidelines should be clearly defined, and ethical boundaries must be established. This finding indicates that technological integration requires not only pedagogical but also ethical transformation. *Technical Development and Model Improvement* recommendations (Cho, 2024; Coban et al., 2025; Meyer et al., 2025) point to the need for enhancing LLMs' visual processing, technical language accuracy, and multilingual capabilities. This suggests that current models still lack full proficiency in physics and related disciplines. The *Critical Thinking and Scientific Reasoning* theme (Bitzenbauer et al., 2023; Sirnoorkar et al., 2024) emphasizes that students should not be passive consumers of AI outputs; instead, they should be positioned as active learners who question and evaluate AI-generated responses. The *Assessment and Evaluation* theme (Wei et al., 2025; Xu et al., 2025) focuses on the accuracy of LLM grading and human-AI collaborative assessment models. This finding highlights that hybrid models take precedence over fully automated evaluation processes. *Long-Term and Longitudinal Research* (Abdulayeva et al., 2025; Bravo et al., 2025; Guerrero-Zambrano et al., 2025) indicates a significant gap in the literature.

Table 12. Recommendation in studies

No	Research recommendation
1	The use of AI- and sensor-supported intelligent psychomotor systems in STEAM education
2	Making AI literacy a mandatory component in STEM courses (especially in physics)
3	Using ChatGPT by students with critical thinking and by teachers for planning and personalized instruction
4	Developing effective prompting strategies for LLM use in physics education and integrating them with cognitive load–reducing instructional designs
5	Using ChatGPT under teacher guidance to support critical thinking
6	Supporting scientific thinking and collaborative learning through the ethical use of AI
7	Using ChatGPT as a data augmentation tool with human expert supervision
8	Using AI as a supportive tool working alongside human analysts in qualitative research
9	Implementing hybrid physics modules across different educational levels
10	Evaluating the impact of ChatGPT in education to improve instructional practices
11	Enhancing AI models' conceptual reasoning abilities and utilizing them to improve assessment tools
12	Creating inclusive learning environments and integrating digital tools into physics education
13	Using AI tools in innovative, creative, and data-driven ways in education
14	Integrating generative AI with gamification and personalized learning approaches
15	Expanding research to other physics topics and comparing advanced models
16	Using ChatGPT and gamification to deepen learning in university-level physics education
17	Developing AI literacy and integration strategies in teacher education
18	Designing hybrid learning activities that compare AI outputs with student responses and promote critical thinking
19	Ensuring high-quality prompts, appropriate parameters, and response verification in GenAI use
20	Providing teacher support, infrastructure development, and stakeholder awareness for ChatGPT integration
21	Including AI literacy in teacher education curricula
22	Establishing AI usage policies, promoting critical evaluation, and improving multilingual performance
23	Supporting teachers in developing AI-based instructional activities
24	Investigating the long-term effects of ChatGPT on teacher education
25	Testing systems with diverse student groups and developing more adaptive designs
26	Examining the effects of AR and LLM integration with larger samples
27	Using advanced prompting strategies to improve grading accuracy in LLMs
28	Using ChatGPT as a supportive tool in teaching within an ethical and critical framework
29	Conducting longitudinal studies on the long-term effects of AI-supported learning
30	Applying AI simulations in different course contexts and examining their effects
31	Using ChatGPT as a supportive tool rather than a direct instructional material
32	Conducting more research on the role of ChatGPT in higher education
33	Developing structured AI-based professional development programs for teachers
34	Designing culturally responsive and personalized project-based learning using data mining tools
35	Developing GenAI training, infrastructure, and prompt guidelines for physics education
36	Investigating the long-term academic effects of AI tools as cognitive support systems
37	Improving LLMs through domain-specific fine-tuning in physics
38	Examining the sustainability and long-term impact of AI integration
39	Replicating studies with larger and more diverse samples
40	Developing hybrid assessment models combining AI and human evaluation

Table 13. Thematic classification of recommendations in studies

Theme	Related recommendation article numbers
Pedagogical Integration and Instructional Design	3, 7, 12, 14, 18, 28
Teacher Education and Professional Development	17, 18, 20, 28, 33
AI Literacy and Ethical Use	2, 19, 21, 22
Technical Development and Model Improvement	19, 26, 37
Critical Thinking and Scientific Reasoning	5, 18, 28
Long-Term and Longitudinal Research	24, 29, 36
Assessment and Evaluation	27, 40
K–12 and Early STEM Integration	14, 17
Cognitive and Affective Dimensions	16, 25
Infrastructure and Support Mechanisms	20, 35

Most studies are based on short-term interventions, and evidence of sustainable effects is lacking. The absence of long-term and longitudinal studies suggests that the field is still in an early developmental stage. Future research should be supported by larger samples, diverse educational levels, and sustainable impact analyses. The *K–12 and Early STEM Integration* theme (Domenichini et al., 2024; Ferreira Monteiro et al., 2024) underscores the importance of careful and guided AI use at early ages. *Cognitive and Affective Dimensions* (Beltozar-Clemente & Díaz-Vega, 2024; Villegas Ch. et al., 2025) highlight the role of AI tools as "cognitive prostheses" and the need to investigate their impact on students' motivation, engagement, and emotional experiences. Finally, the *Infrastructure and Support Mechanisms* theme (Uğraş et al., 2024; Wattanakasiwich et al., 2025) emphasizes the necessity of developing prompt-writing guidelines, technical infrastructure, and user support systems.

Conclusion

This study analyzed research on AI-supported physics instruction, revealing a notable shift in the field's trajectory. Early studies predominantly focused on Intelligent Tutoring Systems (ITS) and adaptive learning platforms, whereas recent years have seen the dominance of generative AI systems, particularly large language models based on ChatGPT and GPT-4. This shift is directly related to the accessibility of these tools and their ease of implementation in classroom settings.

The findings indicate that generative AI systems serve as significant supportive tools in problem solving, feedback generation, and conceptual explanation processes. Increased student motivation, expanded opportunities for personalized learning, and accelerated teacher preparation were among the key contributions highlighted in the literature. However, issues such as accuracy concerns, hallucination generation, limitations in spatial reasoning, pedagogical misalignment, and ethical considerations remain notable constraints. These findings suggest that generative AI should be positioned not as a replacement for teachers, but as a complementary tool supporting the instructional process. Furthermore, the relatively limited representation of simulation-based, data-driven, and experimental AI applications indicates that the field has recently gravitated toward language-based systems. Given the nature of physics education, there is significant potential in developing hybrid AI ecosystems that support modeling, experimentation, and conceptual structuring processes.

In conclusion, although generative AI systems have become a dominant component in physics education research, ensuring sustainable and pedagogically balanced development of the field requires increasing comparative studies, implementing long-term experimental designs, and developing theoretical frameworks sensitive to the epistemological structure of the physics discipline.

Recommendations

Based on the findings of this review, several recommendations can be proposed for the integration of generative AI in physics education. First, AI tools should be implemented under teacher guidance and within a clear pedagogical framework, rather than being provided directly to students. This approach ensures that AI serves as a supportive and complementary tool rather than a replacement for instructional guidance. Second, efforts should be made to enhance the reliability of AI in conceptual explanations, problem-solving, and feedback generation through model development and accuracy verification. Third, personalized and adaptive learning systems should be integrated into physics instruction to promote student motivation and improve learning outcomes. Fourth, both teachers and students should receive education on ethical AI use, critical literacy, and responsible data practices to address potential risks related to misinformation and over-reliance. Fifth, future research should adopt long-term, discipline-specific experimental designs to evaluate the sustained impact of AI on learning and teaching in physics. Finally, hybrid AI systems that combine simulations, data-driven approaches, and language-based tools should be developed to support modeling, experimentation, and conceptual structuring, reflecting the core nature of physics education.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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