Artificial Intelligence, Programming, and Computational Thinking in Physics and Science Education: A Systematic Review

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ABSTRACT

This study presents a systematic literature review on the integration of Artificial Intelligence, Programming Language, and Computational Thinking in Physics and Science Education. The review was conducted in accordance with the PRISMA 2020 protocol, including searches in the Web of Science, Scopus, and Google Scholar databases, with a time frame between 2015 and 2025. After rigorous application of eligibility and duplication criteria, 17 fully traceable studies were included in the qualitative synthesis. The results indicate recent growth in research, with a predominance of reviews and empirical studies focused on personalised learning, problem solving, computational modelling, and teacher training. Despite the identified pedagogical potential, the studies highlight challenges related to teacher training, technological infrastructure, and ethical issues. It is concluded that the integration of these technologies requires critical pedagogical approaches, aligned with educational objectives and teaching practices.

KEY WORDS

artificial intelligence; physics teaching; science teaching; computational thinking; systematic review.

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Inteligência Artificial, Programação e Pensamento Computacional no Ensino de Física e Ciências: Uma Revisão Sistemática

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RESUMO

Este estudo apresenta uma revisão sistemática da literatura sobre a integração da Inteligência Artificial, a Linguagem de Programação e o Pensamento Computacional no Ensino de Física e Ciências. A revisão foi conduzida de acordo com o protocolo PRISMA 2020, contemplando buscas nas bases Web of Science, Scopus e Google Scholar, com recorte temporal entre 2015 e 2025. Após aplicação rigorosa dos critérios de elegibilidade e de desduplicação, 17 estudos plenamente rastreáveis foram incluídos na síntese qualitativa. Os resultados indicam crescimento recente das pesquisas, com predominância de revisões e estudos empíricos voltados à personalização da aprendizagem, resolução de problemas, modelagem computacional e formação de professores. Apesar do potencial pedagógico identificado, os estudos evidenciam desafios relacionados à formação docente, infraestrutura tecnológica e questões éticas. Conclui-se que a integração dessas tecnologias requer abordagens pedagógicas críticas, alinhadas aos objetivos educacionais e às práticas docentes.

PALAVRAS-CHAVE

inteligência artificial; ensino de física; ensino de ciências; pensamento computacional; revisão sistemática.

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Resumen

Este estudio presenta una revisión sistemática de la literatura sobre la integración de la inteligencia artificial, el lenguaje de programación y el pensamiento computacional en la enseñanza de la Física y las Ciencias. La revisión se llevó a cabo de acuerdo con el protocolo PRISMA 2020, incluyendo búsquedas en las bases Web of Science, Scopus y Google Scholar, con un corte temporal entre 2015 y 2025. Tras la aplicación rigurosa de los criterios de elegibilidad y deduplicación, se incluyeron 17 estudios plenamente rastreables en la síntesis cualitativa. Los resultados indican un crecimiento reciente de las investigaciones, con predominio de revisiones y estudios empíricos orientados a la personalización del aprendizaje, la resolución de problemas, el modelado computacional y la formación de docentes. A pesar del potencial pedagógico identificado, los estudios evidencian desafíos relacionados con la formación docente, la infraestructura tecnológica y cuestiones éticas. Se concluye que la integración de estas tecnologías requiere enfoques pedagógicos críticos, alineados con los objetivos educativos y las prácticas docentes.

Palabras clave

inteligencia artificial; enseñanza de la física; enseñanza de las ciencias; pensamiento computacional; revisión sistemática.

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Artificial Intelligence, Programming, and Computational Thinking in Physics and Science Education: A Systematic Review

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INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has transformed contemporary society, influencing communication, work, decision-making processes, and, increasingly, educational practices (Aydin-Günbatar et al., 2025; Jia et al., 2024). In recent years, the widespread availability of generative AI systems, such as ChatGPT and other large language models, has accelerated the incorporation of intelligent technologies into educational contexts, creating new opportunities and challenges for teaching and learning. In parallel, Programming Languages (PL) and Computational Thinking (CT) have gained prominence as essential competencies for understanding and interacting with increasingly digital and data-driven environments (Rafiq-uz-Zaman, 2025; Shute et al., 2017; Wing, 2006).

Within educational settings, the growing presence of AI has generated intense debate regarding its pedagogical potential and its impact on students' learning processes. While these technologies can support personalised learning, automated feedback, content creation, and problem-solving activities, concerns have also emerged regarding their misuse. In many cases, students employ AI systems primarily to obtain immediate answers rather than to develop conceptual understanding, critical thinking, or scientific reasoning. This scenario raises important questions about the educational role of AI and the extent to which these technologies contribute to meaningful learning or merely facilitate the reproduction of information.

At the same time, the integration of AI into educational practice has revealed significant challenges for teachers. Although professional development opportunities related to AI have expanded considerably, many educators still demonstrate resistance, insecurity, or limited familiarity with such technologies. In some cases, AI tools are used in a fragmented or inefficient manner, while in others their use remains underreported due to concerns regarding professional perceptions, ethical issues, or uncertainty about their pedagogical value. Such challenges reinforce the need for a deeper understanding of how AI is being incorporated into teaching practices and educational environments.

These issues become particularly relevant in Physics and Science Education. Unlike many other school subjects, physics and science involve the study of dynamic phenomena, interacting variables, mathematical models, and abstract concepts that are often difficult for students to visualise and understand. One of the major obstacles in science learning is the disconnection between the physical phenomena and the mathematical representations used to describe them. In this context, the integration of AI, Programming Languages, and Computational Thinking offers significant pedagogical possibilities by enabling simulations, computational modelling, adaptive learning environments, data analysis (Kotsis, 2025; Rieser et al., 2023; Sommer &

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Moncayo, 2023), and interactive representations that can help bridge this gap between theory and observation.

Despite the growing number of publications on Artificial Intelligence, Programming, and Computational Thinking, the literature remains fragmented. Existing studies frequently emphasise technical, computational, or technological aspects, whereas fewer investigations focus on their pedagogical implications within Physics and Science Education. Furthermore, current reviews often address AI in broad educational contexts, with limited attention to the specific realities of science teaching, teacher practices, and classroom implementation. As a result, there is still insufficient consolidated evidence regarding how these technologies have been integrated into Physics and Science Education, what contributions they have generated, and what challenges remain unresolved (Jia et al., 2024).

Given this scenario, a systematic review is justified as a means of synthesising the available evidence and providing a comprehensive overview of the field. Therefore, this study aims to examine how Artificial Intelligence, Programming Languages, and Computational Thinking have been integrated into Physics and Science Education, identifying research trends, educational contexts, pedagogical approaches, reported contributions, challenges, and directions for future research. By organizing and critically examining the existing literature, this review seeks to support researchers, as well as Physics and Science educators interested in understanding the educational potential of these technologies and their implications for teaching and learning processes.

THEORETICAL FRAMEWORK

ARTIFICIAL INTELLIGENCE AND TRANSFORMATIONS IN SCIENCE EDUCATION

Modern society is always eager for technological advances, as it is dependent on technological agents that facilitate the daily lives of people and institutions. With these advances, which are progressively faster and increasingly necessary, Artificial Intelligence (AI) has brought significant transformations in different sectors of society, including teaching and learning processes. In recent years, tools based on AI agents, such as intelligent tutoring systems and large-scale language machine learning, have come to occupy a growing space in the debates related to educational processes (Aydin-Günbatar et al., 2025; Jia et al., 2024). This type of technology offers a multitude of possibilities for better personalization of teaching, analysis of educational data, and support for learning processes (Alhusni et al., 2025; Kotsis, 2025; Martins et al., 2026).

In the field of science education, AI has been identified as a tool that aids in the understanding of concepts, from the simplest to the most abstract, and enables more adaptive teaching practices (Santaella, 2025). In the teaching of physics and science, which have a high level of abstraction and conceptual challenges that, in many cases, transcend the immediate understanding of phenomena, incorporating technology emerges as a promising strategy to support teachers and students during the learning process (Kotsis, 2025; Yeadon & Hardy, 2024).

Nevertheless, considering all the fervour surrounding these technologies, the preference for using AI in formal scientific education requires critical thinking and further study, as issues related to system reliability, algorithmic biases, ethical context, intellectual autonomy, and the role of teachers in educational processes have been widely discussed in the literature (Garcia et al., 2025; Kotsis, 2025; Yeadon & Hardy, 2024). Thus, understanding how the use of AI is being introduced and treated in physics and science education, as well as its pedagogical impacts, is a relevant demand for contemporary educational research (Jia et al., 2024; Ulukok-Yildirim & Sonmez, 2025; Zhang & Tur, 2024).

PROGRAMMING LANGUAGE AND COMPUTATIONAL THINKING IN SCIENCE AND PHYSICS EDUCATION

Programming Language (PL) and Computational Thinking (CT) have become fundamental and indispensable components of science education in the 21st century, whether at the basic or higher levels. CT has been incorporated into the curricula of undergraduate courses in Physics and/or Science as part of a cross-curricular approach, as its use is still limited due to training deficiencies of the teachers who are currently involved in the training of other teachers (Alhusni et al., 2025; Shute et al., 2017; Wing, 2006).

In physics education, the use of computer graphics has been a recurring resource for students. This type of resource addresses the need to represent abstract phenomena, which would be difficult to visualise and perceive in controlled environments or even in nature setting. The inclusion of concepts in PL facilitates model building and assists in problem solving, which is so necessary in physics teaching for adressing all curriculum components, thus directing the teaching and learning process in a meaningful and more active way, both for teachers and students (Rafiq-uz-Zaman, 2025; Shute et al., 2017).

The integration of PL, CT, and AI amplifies their potential, enabling, for example, automated data analysis, adaptation of tasks and/or problems to the school and/or the cognitive level of students, as well as the creation of interactive learning environments (Alhusni et al., 2025; Kotsis, 2025). Thus, this integration also brings challenges related to teacher training, technological infrastructure, and the need for pedagogical alignment between technology and educational objectives.

CURRENT CHALLENGES AND GAPS IN THE LITERATURE

The significant growth of studies addressing AI, PL, and CT for education and teaching is not equally reflected in the literature. Many scientific papers present research with a technical or purely computational focus, with limited attention to the pedagogical dimensions of the teaching and learning processes (Jia et al., 2024; Ulukok-Yildirim & Sonmez, 2025).

In addition, existing reviews tend to address AI broadly, without specifically focusing on how this technology is used in the teaching and learning processes of the physics or science curriculum. This absence from the academic literature creates a significant gap between these technologies and the educational processes, as the limitations and challenges regarding the use of such tools end up generating a lot of discomfort among teachers.

Given this scenario, it is necessary to conduct a systematic review that rigorously and transparently synthesises the available evidence on the integration of AI, PL, and CT in the teaching of physics and/or science. The adoption of the PRISMA protocol ensures the traceability of the methodological process, clarity in the selection criteria for studies, and the reliability of the results presented.

CONCEPTUAL RATIONALE FOR THE REVIEW

The growing convergence between Artificial Intelligence (AI), Programming Languages (PL), and Computational Thinking (CT) has created new possibilities for innovation in Physics and Science Education. Although these concepts have often been investigated separately, contemporary educational research increasingly recognises their complementary nature in supporting the teaching and learning process of scientific concepts.

Computational Thinking provides students with cognitive strategies such as abstraction, decomposition, pattern recognition, and algorithmic reasoning, which are fundamental for understanding complex scientific phenomena. Programming Languages, in turn, enable learners to translate these cognitive processes into computational models, simulations, and problem-solving activities that make abstract concepts more tangible and observable. Artificial Intelligence further expands these possibilities by providing adaptive learning environments, intelligent tutoring systems, automated feedback mechanisms, and data-driven educational support.

In Physics and Science Education, the integration of these technologies is particularly relevant due to the inherent complexity of many scientific concepts. Students frequently encounter difficulties in connecting theoretical models, mathematical representations, and observable phenomena. The combined use of AI, PL, and CT can contribute to reducing this gap by promoting interactive learning experiences, computational modelling, visualisation of complex systems, and personalised instructional support.

At the same time, the incorporation of these technologies into educational contexts raises important pedagogical, ethical, and professional challenges. Issues related to teacher preparation, technological infrastructure, responsible use of AI, academic integrity, and equitable access to digital resources remain central in the literature. Understanding how these opportunities and challenges have been addressed in previous studies is, therefore, essential for advancing both research and educational practice.

Given the increasing relevance of these technologies and the fragmented nature of the existing literature, a systematic review provides an appropriate methodological approach for synthesizing current knowledge, identifying research trends, examining pedagogical applications, and highlighting directions for future investigations in Physics and Science Education.

METHODOLOGY

SYSTEMATIC REVIEW PROTOCOL

This review followed the PRISMA 2020 guidelines (Page et al., 2021), ensuring transparency, methodological rigor, and reproducibility throughout all stages of the review process. The review was planned in advance, with a clear definition of the research question, eligibility criteria, search strategies, as well as the procedures for data selection, extraction, and analysis. The focus of the synthesis was qualitative, considering the methodological diversity of the included studies and the exploratory nature of the topic under investigation.

SEARCH STRATEGY

The systematic search was conducted in three databases widely recognised in scientific literature: Web of Science (WoS), Scopus, and Google Scholar. These databases were selected for their comprehensiveness, relevance, and complementarity, allowing the identification of studies indexed in high-impact journals, as well as additional scientific literature not fully covered by traditional databases.

The search strategy was built around three main themes:

i. Teaching and learning physics and science;

ii. Computer programming language and computational thinking;

iii. Artificial intelligence and machine learning.

The search keywords were applied to the aforementioned databases. The search was conducted using English words and expanding the search radius by adding five synonyms for each keyword and using wildcard characters for variations of the suffixes of these same words, according to Table 1.

Table 1
Keywords for searching the WoS, Scopus, and Google Scholar databases

Keywords	**Words added to the databases**
Physics Teaching	“Physics teach*”, “physics educat*”, “physics learn*”, “instruction in physics”, “physics classroom*”, “science teach*”
Computer Programming	“Computer program*”, “coding”, “programming educat*”, “computational think*”, “coding instruct*”, “software develop*”
Artificial Intelligence	“Artificial intelligen*”, “AI”, “machine learn*”, “deep learn*”, “neural network”, “intelligent tutor*”

The search terms were combined using Boolean operators, resulting in the following string: (“physics teach*” OR “physics educat*” OR “physics learn*” OR “instruction in physics” OR “physics classroom*” OR “science teach*”)
AND (“computer program*” OR “coding” OR “programming educat*” OR “computational think*” OR “coding instruct*” OR “software develop*”)
AND (“artificial intelligen*” OR “AI” OR “machine learn*” OR “deep learn*” OR “neural network*” OR “intelligent tutor*”)

Specific filters were applied to each database to restrict the results to the document type article or review article, as well as the time frame between 2015 and 2025.

ELIGIBILITY CRITERIA

The eligibility criteria were defined in advance and applied consistently throughout the entire selection process.

Table 2
Inclusion and Exclusion Criteria

Inclusion Criteria	· Publication in English; · Scientific articles or review articles published in peer-reviewed journals; · Studies published between 2015 and 2025; · Research aligned with the field of Science Education or Physics Education; · Studies addressing Artificial Intelligence, Programming Language, and Computational Thinking in an educational context; · Free access to the full text.
Exclusion Criteria	· Publications in languages other than English; · Documents that do not qualify as scientific articles (e.g., conference abstracts, editorials, letters, book chapters); · Studies outside the established time frame; · Works of an exclusively technical or computational nature, without explicit educational application; · Studies not related to the teaching of Science or Physics; · Publications without free access to the full text; · Retracted articles; · Duplicate records identified between databases.

STUDY SELECTION PROCESS

The study selection process was carried out in multiple stages, as recommended by PRISMA protocol. Initially, all retrieved records were organized by database. In the case of Web of Science and Scopus, the platform itself allowed filters to be applied by research area, reducing the number of records that did not align with the scope.

For Google Scholar, due to the absence of reliable filters by subject area, an additional manual screening was performed by reading the titles, with the aim of excluding studies clearly misaligned with the scope of the research. This step resulted in a reduction in the number of records from this database before deduplication.

After the initial screening, the remaining studies were submitted for reading of titles and abstracts. Then, the full texts of potentially eligible articles were analysed in their entirety for the final decision of inclusion or exclusion.

DEDUPLICATION PROCESS

The deduplication of records was performed in two stages. First, paired deduplication was performed between databases (Web of Science x Scopus; Web of Science x Google Scholar; Scopus x Google Scholar), considering criteria such as DOI, title, authors, and year of publication.

Next, the records were consolidated globally, removing multiple duplicates and repeated versions of the same study. This procedure resulted in a final set of unique studies, which was submitted for full-text eligibility assessment.

DATA EXTRACTION, ORGANIZATION, AND SYNTHESIS

For the included studies, relevant data were systematically extracted and organized in a standardized table. The information extracted included: authors, year of publication, database, country, type of study, educational level, area (Science or Physics), technologies involved, objectives, and main results.

The extracted data were analysed using qualitative thematic synthesis. This approach was adopted due to the heterogeneity of the methods, educational contexts, and types of studies included. The analysis involved identifying recurring patterns, organizing the studies into thematic categories, and interpreting the results in light of the existing literature.

RESULTS

STUDY IDENTIFICATION AND SELECTION PROCESS

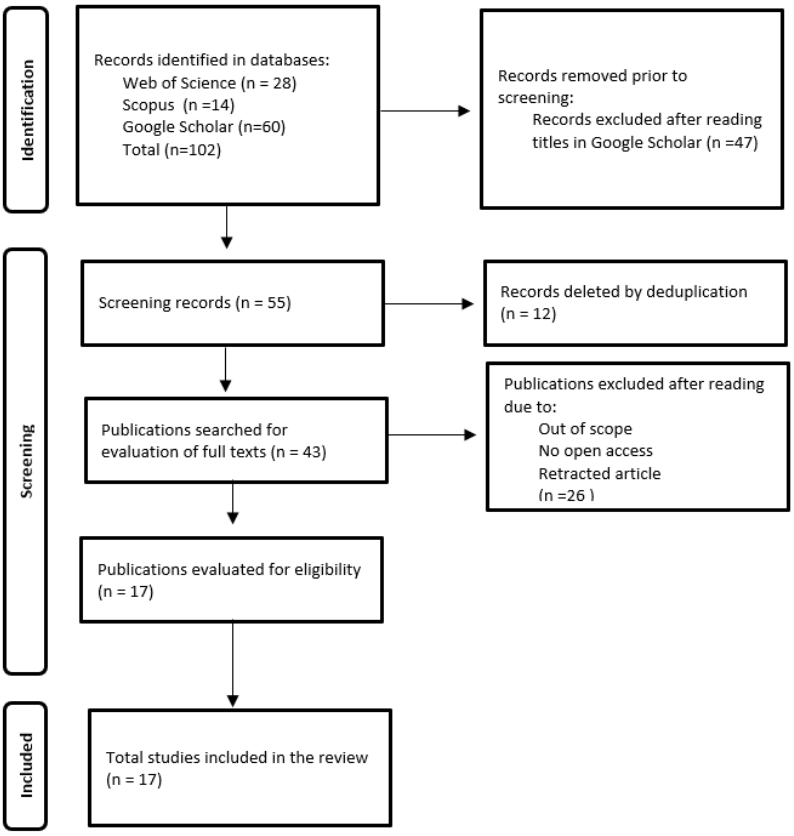
The systematic search retrieved a total of 1,342 records across the three databases: Web of Science (n = 64), Scopus (n = 38), and Google Scholar (n = 1,240). After applying document type and time frame filters, 102 records were retained (Web of Science: n = 28; Scopus: n = 14; Google Scholar: n = 60).

Given Google Scholar's limitations in filtering by subject area, an additional manual title screening was applied to records from that database, resulting in the exclusion of 47 records misaligned with the scope. This reduced the pool to 55 records, which were submitted to the deduplication stage. Paired deduplication across databases removed 12 duplicate records, yielding 43 unique studies for full-text eligibility assessment. Of these, 26 were excluded for not meeting the eligibility criteria, resulting in 17 studies included in the qualitative synthesis.

The complete identification, screening, eligibility, and inclusion process is illustrated in Figure 1, following the PRISMA 2020 flow diagram (Page et al., 2021).

Figure 1

PRISMA 2020 flow diagram illustrating the steps of identification, screening, eligibility, and inclusion of studies



GENERAL CHARACTERISATION OF THE INCLUDED STUDIES

Table 3 shows the search strategy adopted and the number of records obtained in each database, as well as the final number of studies included after applying the eligibility criteria.

Table 3

Search strategy and number of records per database

Database	**Initially Identified Records**	**Records after filtering (article/review and period 2015-2025)**	**Registration after thematic screening**	**Records included after deduplication**
Web of Science	64	28	28	3
Scopus	38	14	14	9
Google Scholar	1240	60	13	5
Total	**1342**	**102**	**55**	**17**

The 17 studies included were published between 2015 and 2025, with the highest concentration in the most recent years. Regarding the type of study, the final corpus included empirical studies, systematic reviews, scoping reviews, and narrative reviews.

In terms of educational level, the studies covered basic education, higher education, initial and continuing teacher training, as well as multilevel contexts.

DISTRIBUTION OF STUDIES BY AREA AND DATABASE

The studies included were divided between physics teaching and science teaching, highlighting the application of investigative technologies in different contexts of science education.

Table 3 presents the search strategy and number of records retrieved per database. The inclusion and exclusion criteria were applied with the rigor required by the PRISMA 2020 protocol in the stages of selecting the studies. Regarding the origin of the studies, a higher concentration of publications was found in Web of Science, followed by Scopus, while Google Scholar served as a complementary source.

THEMATIC SUMMARY OF THE STUDIES INCLUDED

The analysis of the extracted data allowed the studies to be organized into five main themes, presented below:

- T1 – Artificial Intelligence and Generative AI in Physics and Science Education;
- T2 – Programming Language and Computational Thinking;
- T3 – Artificial Intelligence in Teacher Training;
- T4 – Technological Ecosystems in Science and STEM Education;
- T5 – Challenges, Limitations, and Ethical Issues.

The articles were identified by codes (Table 4).

Table 4
Coded articles

Identification	Article Title
A1	Beyond STEM: A Narrative Review of STEAM Education's Impact on Creativity and Innovation (2020–2025)
A2	A systematic review of ChatGPT use in K-12 education
A3	Can ChatGPT pass a physics degree? Making a case for reformation of assessment of undergraduate degrees
A4	Artificial Intelligence for Physics Education in STEM Classrooms: A Narrative Review within a Pedagogy–Technology–Policy Framework

Identification	Article Title
A5	Physics language and language use in physics—What do we know and how AI might enhance language-related research and instruction
A6	Artificial Intelligence in Science Education (2013-2023): Research Trends in Ten Years
A7	Machine Learning and Artificial Intelligence in Building Physics Education: Series: Building simulation and calculation tools in teaching.
A8	A Comprehensive Bibliometric Analysis of Artificial Intelligence Research in the Field of Science Education
A9	AI-Driven Optimization of Pascal Programming Instruction for Undergraduate Physics Students at University of Mataram
A10	Tensor networks for quantum machine learning
A11	Perceptions, strategies and challenges of teachers in the integration of artificial intelligence in primary education: A systematic review
A12	Collaborative construction of artificial intelligence curriculum in primary schools
A13	Establishing common ground in empirical research on science teachers' lesson planning competence: A scoping review
A14	Blueprint for the 21st-century online learning environment in STEM education through a systematic review and qualitative synthesis
A15	Robotic telescopes in education
A16	A Survey of Smart Classroom Literature
A17	The impact of AI in physics education: a comprehensive review from GCSE to university levels

The categorized results are shown in Table 5 below.

Table 5
Thematic mapping and characterization of included studies (n=17)

№	id	year	Type of study	Approach	Country	Educational level	Technology / Focus	Topic(s)
1	A1	2024	Narrative review	Qualitative	Multi-country	Multilevel	STEAM, innovation	T2, T4
2	A2	2023	Systematic review	Qualitative	China	Primary education	Generative AI (ChatGPT)	T1, T5
3	A3	2025	Empirical study	Quantitative	Iran	Higher education	LLM (ChatGPT)	T1, T2
4	A4	2025	Narrative review	Qualitative	Multi-country	Multilevel	Educational AI	T1, T5
5	A5	2022	Scoping review	Qualitative	Germany	Multilevel	Natural Language Processing	T1
6	A6	2021	Systematic review	Qualitative	Multi-country	Multilevel	Educational AI	T1, T5
7	A7	2023	Empirical study	Mixed	Germany	Higher education	machine learning + AI	T1, T2

Nº	id	year	Type of study	Approach	Country	Educational level	Technology / Focus	Topic(s)
8	A8	2020	Bibliometric analysis	Qualitative	Turkey	Primary education	Educational AI	T1, T5
9	A9	2024	Empirical study	Quantitative	Indonesia	Higher education	Programming + AI	T1, T2
10	A10	2023	Empirical study	Quantitative	Multi-country	Higher education	Programming	T1, T2
11	A11	2024	Systematic review	Qualitative	Multi-country	Teachers	Educational AI	T3, T5
12	A12	2023	Empirical study	Qualitative	China	Teachers	AI + curriculum	T3, T4
13	A13	2023	Scoping review	Qualitative	Multi-country	Teachers	Educational technologies	T3
14	A14	2023	Systematic review	Qualitative	Multi-country	Multilevel	Digital platforms + AI	T4, T5
15	A15	2017	Review	Qualitative	Australia	Multilevel	Educational robotics	T4
16	A16	2022	Systematic review	Qualitative	Multi-country	Multilevel	Smart classrooms	T4
17	A17	2024	Review	Qualitative	United Kingdom	Higher education	AI + Physics Teaching	T1, T5

THE SUBJECT MATTER OF EACH ARTICLE

T1 – Artificial Intelligence and Generative AI in Physics and Science Education

The study by Zhang and Tur (2024) identifies that ChatGPT has the potential to transform science education by acting as a personal tutor for personalised learning, adapting to each student's pace. The study found that ChatGPT demonstrated human-level performance in exams across various subjects, such as physics and mathematics. Support for STEM education through the use of the tool, from the perspective of the teachers included in the research, facilitated their teaching practices in various ways, such as in the creation of curricula, lesson plans and learning tasks, even helping to address conceptual difficulties in the design of assessment for the physics courses. According to the study, the use of the tool could revolutionise traditional teaching methodologies, making them more interactive and immersive, particularly in the field of physics and STEM practice.

The article by Pimbblet and Morrell (2025) investigates the ability of the model known as GPT-4 to complete an undergraduate degree in Physics in the United Kingdom (University of Hull). GPT-4 achieved a final average mark of 65%, which is equivalent to an upper second-class degree (2:1) under the British system. The strengths identified by the study were that the AI demonstrated excellence in multiple-choice questions, recall of facts and simple single-step calculations. However, it failed on problems requiring multi-step logical reasoning, often providing incorrect ‘standard’ answers by failing to analyse the specific context of the question. The limitations identified included the fact that the AI was unable to pass the course autonomously due to compulsory components requiring physical presence or real-time human interaction, such as laboratory experiments and oral project presentations. Consequently, the authors argue that the existence of such capable AI model calls for an urgent review of assessment practices, suggesting a return to in-person invigilated exams and practical skills tests to ensure academic integrity.

Kotsis’s (2025) manuscript presents a review of a narrative focusing on the integration of AI into physics teaching within the STEM context. AI is described as an active contributor to educational processes, moving beyond its role as a mere computational support tool. Technologies such as intelligent tutoring systems, machine learning algorithms and natural language processing enable unprecedented personalisation of instruction, responding dynamically to the individual needs of physics students.

As for teachers, AI has the potential to support their practices, particularly in primary education, in the planning and execution of physics experiments; ChatGPT is highlighted in the study due to its ability to generate experiment worksheets and detailed lesson plans, acting as a collaborative designer of educational resources. Teaching methods are also highlighted, as according to the study, AI can help connect abstract theories with examples from students’ everyday lives.

Wulff’s work (2024) explores the multifaceted nature of language in physics education and how AI technologies can serve as tools to enhance research and teaching. The article highlights that traditional qualitative research in physics education (PER) is resource-intensive and fails to capture quantitative aspects of language use. AI, through natural language processing and machine learning, enables the systematic analysis of large volumes of linguistic data at a low cost.

T2 – Programming Language and Computational Thinking

With regard to the work in Rafiq-uz-Zaman (2025), the article takes the view that computational thinking is an essential skill for the 21st century; it is already an integral part of everyday life and also exerts a significant influence on educational settings, as this is where it is developed and reinforced for educational purposes.

Curriculum integration can be examined in this study through the demonstration of STEM integration with computational thinking in the development of curriculum flexibility, rather than being limited solely to a computational approach. Coding tools are implemented using SCRATCH, where the teacher, together with the students, is able to code creatively, linking technology and design.

Furthermore, the article presents what the study refers to as Computational Pedagogy, Content Integration, and Interactive Design (CPACK), which is presented as a theoretical framework underpinning interactive computational thinking as a means of engaging and empowering students and teachers to solve complex problems.

The study by Rieser et al. (2023) details how the logic of tensor networks translates complex physics problems into manageable computational structures. Computational thinking is applied to break down large tensors (which are difficult to handle) into a network of smaller, interconnected tensors, which reduces storage costs and improves processing efficiency. This approach can be implemented in educational practice for the training of new teachers and researchers.

The article by Pimbblet and Morrell (2025) highlights that computing and coding tasks are areas where AI demonstrates its most robust performance, posing a significant threat to the reliability of traditional assessments. Proficiency in the Python language was a key factor in GPT-4's academic training, as its performance in this area was described as exceptional.

The text shows that the pass rate for certain curriculum components of the course's syllabus reached 89%. Some results were perfect, such as in the curriculum component on Intermediate Quantum Mechanics with Advanced Computing, where the AI achieved a 100% pass rate in the computational part of the projects. However, the vulnerability of the tasks is something that must be given due consideration, as programming problems in physics education already have solutions or well-documented logic available online, which facilitates the AI's work in generating functional code, although not always the most efficient. Consequently, the pedagogical risk highlighted by the authors is that activities carried out outside the classroom environment have the potential to be performed using AI, which may widen the gap between what is classified as learning and what is merely copying.

The study by Jia et al. (2024) highlights a trend in STEM practices for physics education towards teaching through educational robotics with a programming platform within a project-based learning framework. In the work by Sommer and Moncayo (2023), computational thinking is practised at the intersection of the physical and digital worlds. Students develop C++ components to integrate real-time sensor data (such as Arduino and LiDAR) directly into simulation models, allowing the design to react dynamically to real environmental phenomena, thereby enabling teaching to undergo a process of evolution by incorporating 'conversation with the machine'. In it students can use prompts to generate code that facilitates physical connection via the computer's serial port, optimising workflows that were previously manual and inefficient.

T3 – Artificial Intelligence in Teacher Training

The studies by Garcia et al. (2025) and Dai et al. (2023) emphasise that teacher training is the cornerstone of successful technology implementation, highlighting a gap between teachers' enthusiasm and their technical competence.

There is an urgent need for ongoing digital literacy training to facilitate the implementation of AI in teacher training programmes, as these are already emerging trends that teachers must keep pace with. Competency frameworks must be established with equal urgency, as practical planning and activities must be incorporated into curricula as soon as possible.

The study by Großmann et al. (2025) also emphasises that AI must feature in lesson planning as a crucial competence that should be taught and learnt in initial and continuing teacher training programmes. It is highlighted that the development of this competence occurs through formal and non-formal learning opportunities.

T4 – Technological Ecosystems in Science and STEM Education

The review presented by Rafiq-uz-Zaman (2025) argues that the success of STEM in practice depends on the creation of a technological ecosystem that promotes studentcentred experiences. It also states that physical and hybrid spaces are vital for the ecosystem to function, and for this to happen smoothly, the use of FABLABS and MAKERSPACES is essential. By using these tools, students can prototype, experiment and work on real-world problems and projects, thereby modelling everyday problems on a virtual platform.

The virtual environments highlighted in the study are Virtual Classroom Learning Environments and the use of gamification platforms with the aim of motivating, challenging and fostering the self-efficacy of the students involved in the process. As for infrastructure and emerging technologies, the text makes clear the need to invest in advanced digital structures and to explore the great transformative potential of technologies such as robotics, immersive virtual reality and simulators in formal educational settings.

However, for this to happen, school environments must be underpinned by strong political support, ensuring that teachers receive ongoing training in these skills, in order to guarantee that new technologies are not excluded from teaching practices.

Meylani's (2024) work proposes a model for learning in online environments that integrates various advanced technologies to democratise STEM education. This ecosystem encompasses the use of Virtual and Augmented Reality to make abstract concepts tangible, and the Metaverse to create immersive environments that transcend physical limitations.

The study by Gomez and Fitzgerald (2017), meanwhile, follows a similar line to that of Kaur et al. (2022), as it also concerns a learning ecosystem, but utilises internet-operated robotic telescopes, and this system is used for teaching astronomy and physics. These ecosystems enable schools that lack the appropriate spaces and equipment for this type of practice to utilise a virtual, easily accessible solution that has the same positive effect on the teaching and learning process, including students with physical and intellectual disabilities. Kaur et al. (2022) take a similar approach, using what the authors call a 'smart classroom' as an ICT-enabled environment to improve the teaching process.

T5 – Challenges, Limitations, and Ethical Issues

The study by Zhang and Tur (2024) focuses on a range of critical threats and weaknesses associated with the integration of Artificial Intelligence (AI) into teaching practice. Academic integrity is a central concern for the study, as potential academic dishonesty and plagiarism could call future research into question. Therefore, the work calls for the creation of policies aimed at regulating the use of AI tools, such as ChatGPT, in scientific research environments.

Another point of discussion concerns the quality of the information generated by these AI tools, which is often questionable, as it may be inaccurate or rely on unreliable sources to generate rapid responses to command prompts. Regarding ethical and social issues, the risks related to data privacy and algorithmic biases are highlighted, as these can perpetuate harmful stereotypes or inequalities in access to technology.

Overuse is another point that must be taken into account, as dependence on the AI platform ends up stunting cognitive development and critical thinking, reducing the student's autonomy.

Another point worth noting, in the works of Zhang and Tur (2024) and of Ulukok-Yildirim and Sonmez (2025), is the issue of teaching practice and the barriers to the use of prompt engineering, as teachers require training in these skills. This barrier also involves the resistance to the use of these tools, both from a significant proportion of teachers and even from the educational system.

Studies by Kotsis (2025), Ulukok-Yildirim and Sonmez (2025) and Yeadon and Hardy (2024) emphasise that, without regulatory frameworks and ethical guidelines, AI may undermine educational equity. There are significant risks that the disproportionate allocation of technological infrastructure between rich and poor schools will exacerbate inequality in access to advanced educational opportunities. The lack of teacher readiness is another factor that must be considered, as specialised professional development is necessary for teachers to be able to use AI as a supporting tool in teaching and learning processes.

The study by Jia et al. (2024) highlights the lack of research focused on the use of AI in education. The paper recommends that future research should explore the interrelationships between technology, pedagogy and learning outcomes in greater depth, whilst also focusing on the development of robust ethical and regulatory frameworks.

DISCUSSION

CONTRIBUTION OF ARTIFICIAL INTELLIGENCE TO THE TEACHING OF PHYSICS AND SCIENCES

The results of this systematic review indicate that artificial intelligence has been incorporated into physics and science education mainly as a tool to support conceptual learning, problem solving, and personalised teaching. The analysed empirical studies and reviews converge in suggesting that AI-based systems, including machine learning algorithms and large-scale language models, can promote student engagement and expand opportunities for formative feedback.

In physics education, in particular, AI has been used to address historically identified difficulties, such as conceptual abstraction, mathematical modelling, and the interpretation of scientific language. The results suggest that these technologies can act as cognitive mediators, when integrated into well-structured pedagogical practices and guided by clear educational objectives.

The findings reveal convergence among studies A2, A4, A6, and A17 regarding the potential of AI to support personalised learning and conceptual understanding in Physics and Science Education. Although the studies differ in methodology and educational context, they consistently emphasise the role of AI as a pedagogical support tool rather than a replacement for teachers. Furthermore, these studies highlight that the effectiveness of AI depends on its alignment with educational objectives and on the active mediation of teachers during the teaching and learning process.

However, studies also emphasise that the benefits of AI do not automatically result from its adoption. Positive pedagogical impact is strongly associated with how technology is incorporated into the curriculum and teaching practices, reinforcing the idea that AI should be understood as a complementary pedagogical resource, not a substitute for teachers.

PROGRAMMING LANGUAGE AND COMPUTATIONAL THINKING AS A PEDAGOGICAL ELEMENT

Programming Languages and Computational Thinking emerge in the studies examined as relevant pedagogical strategies for teaching Physics and Science, especially when linked to problem solving and phenomenon modelling.

Study A1 (Rafiq-uz-Zaman, 2025) illustrates this integration through the CPACK framework, in which students and teachers collaboratively use SCRATCH to connect technology, design, and scientific content, shifting programming from an isolated technical skill to a strategy integrated with scientific learning. Study A7 (Sommer & Moncayo, 2023) offers a complementary example, where students develop C++ components to integrate real-time sensor data into simulation models, enabling the modelling of physical phenomena through direct interaction with computational tools.

Studies A9 (Taufik et al., 2024) and A10 (Rieser et al., 2023) extend this evidence to higher education. A9 reports that AI-optimized Pascal programming instruction improved student performance and conceptual engagement in undergraduate physics courses, while A10 demonstrates how tensor network logic can structure complex quantum physics problems into manageable computational tasks, with direct implications for teacher and researcher training.

Study A3 (Pimbblet & Morrell, 2025) introduces a critical pedagogical warning: GPT-4 achieved a 100% pass rate in the computational component of Intermediate Quantum Mechanics, exposing a significant vulnerability in programming-based assessments conducted outside supervised environments. This finding points to the urgent need to redesign assessment practices in physics education, prioritising in-person, process-oriented evaluation to ensure genuine student engagement rather than superficial technological use.

ARTIFICIAL INTELLIGENCE IN TEACHER TRAINING

The studies included in this review consistently identify initial and continuing teacher training as one of the main challenges for the effective integration of AI in physics and science education.

Study A11 (Garcia et al., 2025) documents a persistent gap between teachers' interest in AI and their actual competence to implement it pedagogically, identifying resistance and insecurity as recurring barriers and calling for competency frameworks that incorporate practical activities into training curricula.

Study A12 (Dai et al., 2023) reports that collaborative co-design of AI learning experiences by teachers and students proved more effective in building teacher confidence and pedagogical coherence than top-down technology implementation.

Study A13 (Großmann et al., 2025) reinforces this perspective, demonstrating that AI-integrated lesson planning is an emerging and undertheorized competence in science education that must be explicitly taught and assessed in both pre-service and in-service teacher education programs, through formal and non-formal professional learning opportunities.

Thus, teacher training emerges as a central element in ensuring that the adoption of AI in science and physics education occurs in a conscious and responsible manner.

Training programs must address not only technical aspects, but also pedagogical, ethical, and social dimensions, equipping teachers to act as critical mediators of technology in educational contexts.

COMPARISONS BETWEEN TYPES OF STUDIES

Empirical studies, including A3 (Pimbblet & Morrell, 2025), A7 (Sommer & Moncayo, 2023), and A9 (Taufik et al., 2024), provided direct evidence of AI and computational thinking in classroom contexts, documenting measurable improvements in student performance and phenomenon modelling. Although these studies offer actionable pedagogical evidence, their scope is limited to specific institutional and national contexts, which restricts broader generalisability.

Systematic and scoping reviews, including A2 (Zhang & Tur, 2024), A6 (Jia et al., 2024), A8 (Ulukok-Yildirim & Sonmez, 2025), A11 (Garcia et al., 2025), A13 (Großmann et al., 2025), and A14 (Meylani, 2024), offered broader perspectives on research trends and gaps in the literature. Study A6 mapped a decade of AI research in science education, identifying a shift toward personalised learning, while A8 confirmed the concentration of publications in high-income countries as a persistent structural gap in the field.

Narrative reviews, including A1 (Rafiq-uz-Zaman, 2025), A4 (Kotsis, 2025), and A17 (Yeadon & Hardy, 2024), contributed theoretical contextualization and critical discussion. Study A4 positioned AI as an active contributor to physics pedagogy through a pedagogy–technology–policy framework, while A17 provided a longitudinal perspective on the evolving pedagogical role of AI from secondary school to university. Together, these different methodological approaches reinforce the importance of diverse research designs for understanding the complexity of the topic.

CHALLENGES, LIMITATIONS, AND ETHICAL ISSUES

Despite the identified potential, the reviewed literature highlights significant challenges associated with the adoption of AI in Physics and Science Education. Academic integrity represents one of the most pressing concerns: study A3 (Pimbblet & Morrell, 2025) demonstrates that GPT-4 achieved a 100% pass rate in computing-based physics assessments, raising serious questions about the validity of unproctored assignments and pointing to the need for structural reform of assessment practices.

Study A2 (Zhang & Tur, 2024) corroborates this concern in K-12 contexts, documenting cases in which students used AI primarily to obtain immediate answers rather than develop scientific reasoning, while also identifying risks related to data privacy, algorithmic bias, and unequal access to AI tools, further confirmed by A6 (Jia et al., 2024) and A8 (Ulukok-Yildirim & Sonmez, 2025).

Infrastructural inequality is addressed in A14 (Meylani, 2024) and A16 (Kaur et al., 2022), which argue that realising the potential of AI-enabled STEM education requires sustained institutional investment in digital infrastructure, which remains unavailable to the majority of schools, particularly in the Global South.

Teacher readiness and resistance are documented across A4 (Kotsis, 2025), A11 (Garcia et al., 2025), and A17 (Yeadon & Hardy, 2024), which consistently report that educators lack the technical preparation and pedagogical confidence to integrate AI effectively without targeted professional development and institutional support.

These findings reinforce the need for a critical and regulated approach to the use of AI in educational contexts.

The integration of AI in physics and science education must be accompanied by clear educational policies, ethical guidelines, and investment in training and infrastructure in order to maximize pedagogical benefits and minimize potential risks.

LIMITATIONS OF THE REVIEW

This systematic review has some limitations that should be considered when interpreting the results. First, the inclusion of only English-language studies may have excluded relevant research in other languages. In addition, the requirement for open access to the full text may have restricted the corpus analysed.

Another limitation relates to the use of Google Scholar as a complementary source, whose lack of filters by subject area required additional manual screening. Despite these limitations, strict adherence to the PRISMA protocol and methodological transparency contribute to the reliability of the results presented.

CONCLUSIONS AND FINAL CONSIDERATIONS

This systematic review aimed to analyse how Artificial Intelligence, Programming Language, and Computational Thinking have been integrated into Physics and Science Education, based on studies published between 2015 and 2025. Strictly following the PRISMA 2020 protocol, 17 articles were included, which allowed us to map trends, pedagogical approaches, educational contexts, and challenges associated with these technologies.

The results show consistent growth in scientific production on the topic, especially in recent years, driven by the popularization of AI systems, including machine learning tools and generative AI models. It was observed that AI has been used mainly as a resource to support learning, personalize teaching, analyse educational data, and provide automated feedback.

In physics education, applications focused on computational modelling, problem solving, and the mediation of abstract concepts stand out. In science education broadly, AI appears integrated into digital environments, online platforms, and STEM/STEAM approaches, expanding the possibilities for innovative pedagogical practices.

The analysis of the results included indicates that the integration of Programming and Computational Thinking contributes to the development of relevant cognitive skills, such as logical reasoning, abstraction, and complex problem solving. When combined with Artificial Intelligence, these approaches expand the pedagogical potential of digital technologies, promoting more active and investigative learning.

However, the results also reinforce that the pedagogical benefits of AI are not automatic. Its positive impact depends heavily on the alignment between technology, curriculum, and teaching practices, as well as conscious mediation by the teacher. Thus, AI should be understood as a complementary resource, inserted into well-founded pedagogical proposals, and not as an isolated solution to complex educational challenges.

One of the central findings of this review refers to the importance of initial and continuing teacher training for the effective and responsible adoption of AI in physics and science education. Although many studies point to openness and interest on the part of teachers, challenges remain related to a lack of technical and pedagogical preparation, insecurity in the use of technologies, and ethical concerns.

Thus, the results suggest the need for teacher training programmes that address AI in an integrated manner, covering not only technical aspects, but also pedagogical, ethical, and social aspects. This training is essential for teachers to play a critical and active role in mediating the use of AI in educational contexts.

The review highlighted recurring challenges associated with integrating AI into physics and science education, including inequalities in access to technological infrastructure, institutional limitations, and the absence of clear guidelines for the educational use of these technologies. Ethical issues, such as algorithmic biases, the reliability of information generated by AI systems, data privacy, and intellectual authorship, were also widely discussed in the studies analysed.

These challenges reinforce the need for critical, ethical, and regulated adoption of AI in education, supported by public policies, institutional guidelines, and investments in infrastructure and training.

Although this systematic review strictly followed the PRISMA protocol, some limitations should be considered. The inclusion of only English-language studies with free access to the full text may have restricted the scope of the analysis. In addition, the methodological heterogeneity of the included studies made it impossible to perform a quantitative meta-analysis.

With a view to future research, the following needs are highlighted:

- Longitudinal empirical studies that assess the long-term impacts of AI on learning;
- Research focused on diverse educational contexts, especially in developing countries;
- Research that explores critical and ethical pedagogical models for the use of AI in physics and science education;
- Greater coordination between educational research, public policy, and school practices.

In summary, this systematic review contributes to the understanding of the emerging role of Artificial Intelligence, Programming Language, and Computational Thinking in Physics and Science Education. By critically organizing and synthesizing the existing literature, the study offers relevant insights for researchers, teachers, and educational policymakers interested in the responsible and pedagogically grounded integration of these technologies.

DISCLOSURE ON THE USE OF ARTIFICIAL INTELLIGENCE TOOLS

This study utilised two artificial intelligence tools: the first was Notebooklm, which was used to assist with the systematic review by linking the selected articles, thereby facilitating understanding and speeding up the reading of the papers; the second was Deepl, a tool that uses AI to translate text whilst remaining faithful to the source material. We declare that neither of the two AIs used was involved in the automatic creation of text, figures or tables.

AUTHORS' CONTRIBUTION

Conceptualization, Research, Methodologies, Formal Analysis, Writing: Dadson Luis Ferreira Leite; Conceptualization, Research, Methodologies, Formal Analysis, Writing: Wellington Cantanhede dos Santos; Review, Edition: Edvan Moreira.

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