ARTIFICIAL INTELLIGENCE AND DIGITAL TECHNOLOGIES: PEDAGOGICAL CONTRIBUTIONS TO THE TEACHING OF PHYSICAL AND BIOLOGICAL SCIENCES

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Abstract

The incorporation of artificial intelligence and digital technologies into the educational context has led to significant transformations in pedagogical practices, particularly in the teaching of Physical and Biological Sciences. This study aimed to analyze the pedagogical contributions of artificial intelligence and digital technologies to science education, discussing their potential, challenges, and educational implications. This is a qualitative study with a descriptive and exploratory approach, developed through a systematized literature review. Data collection was carried out using scientific articles, books, and institutional documents published between 2021 and 2026 in recognized national and international databases. The results indicate that artificial intelligence contributes to the personalization of learning, increased student engagement, the adoption of active learning methodologies, and the facilitation of understanding complex scientific phenomena through simulations, modeling, and interactive digital environments. However, relevant challenges were also identified, including ethical issues related to data use, limitations in teacher training, unequal access to technologies, and risks associated with the uncritical use of digital tools. The discussion highlights the importance of pedagogical mediation, instructional planning, and continuing teacher education for the responsible and effective use of artificial intelligence in Physical and Biological Sciences education. It is concluded that, despite its high pedagogical potential, artificial intelligence must be integrated into educational contexts in a critical and ethical manner and aligned with educational objectives in order to effectively contribute to improving the teaching and learning process.

Keywords: Artificial Intelligence, Digital Technologies, Physical and Biological Sciences, Science Education, Active Learning Methodologies.

INTRODUCTION

The rapid advance of artificial intelligence (AI) and digital technologies has promoted profound transformations across different sectors of contemporary society, with significant impacts on the

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educational field. Such technologies have been redefining pedagogical practices, teaching methodologies, and learning processes, especially in the teaching of Physical and Biological Sciences—an area that has historically required didactic approaches capable of articulating abstract concepts, experimentation, data analysis, and the understanding of complex natural phenomena (Hodson, 2022). In this context, the incorporation of AI and digital resources emerges as a promising pedagogical strategy to enhance teaching, foster active learning, and increase student engagement.

Recent literature indicates that artificial intelligence applied to education enables the personalization of teaching, the automation of assessment processes, the use of intelligent tutoring systems, and the analysis of large volumes of educational data, contributing to more adaptive, student-centered pedagogical practices (Huang; Saleh; Liu, 2021; Ouyang; Jiao, 2021). In science education, these contributions become even more relevant, since the field demands the development of scientific thinking, investigative capacity, and interdisciplinary understanding among Physics, Chemistry, Biology, and Mathematics (Dori; Mevarech; Baker, 2022).

Digital technologies, when associated with AI, expand teaching possibilities by enabling the use of virtual simulations, remote laboratories, immersive environments, adaptive platforms, and tools for visualizing complex data. Studies indicate that such resources promote meaningful learning by bringing scientific content closer to students' realities and enabling the experimentation of phenomena that would often be unfeasible in traditional school contexts (Makarova; Herbst, 2022; Costa, 2024). In the teaching of Physics, for example, simulations based on intelligent algorithms contribute to the understanding of abstract concepts, while in Biology, digital tools assist in visualizing cellular, genetic, and ecological processes (Li; Wang, 2022).

Moreover, integrating AI into Physical and Biological Sciences teaching fosters active methodologies, such as problem-based learning, project-based learning, and technology-mediated scientific inquiry. These approaches encourage student agency, collaborative work, and the development of cognitive and socioemotional competencies aligned with the educational demands of the 21st century

(Dori; Mevarech; Baker, 2022). In this sense, AI acts as a mediating resource within the pedagogical process, expanding possibilities for interaction among students, content, and teachers (Vicari, 2021).

However, despite its benefits, the use of artificial intelligence in education also poses ethical, pedagogical, and institutional challenges. Issues related to data privacy, algorithm transparency, teacher education, and the risk of excessive dependence on digital technologies are widely discussed in the literature (Boulay, 2023; Parreira; Lehmann; Oliveira, 2021). International organizations such as UNESCO and the OECD highlight the need for public policies, ethical guidelines, and responsible practices to ensure that AI is used in an equitable, inclusive manner aligned with educational principles (OECD, 2021; UNESCO, 2021; UNESCO, 2023).

In the specific context of teaching Physical and Biological Sciences, these challenges become even more evident, since the inappropriate use of AI may compromise the development of critical thinking, intellectual autonomy, and deep conceptual understanding. Recent studies warn of the importance of integrating technology pedagogically and intentionally, avoiding its merely instrumental use or its substitution for teacher mediation (Rodrigues; Rodrigues, 2023; Picão; Silva; Costa, 2023). Thus, continuing teacher education and critical reflection on the role of AI in teaching become central elements for successful implementation (Aguiar, 2023; Lampou, 2023).

Another relevant aspect concerns AI's contributions to interdisciplinary teaching and to bridging theory and scientific practice. Recent advances in so-called physical and symbolic artificial intelligence have expanded possibilities for modeling, analyzing, and predicting natural phenomena, contributing to new forms of teaching and learning in Physical and Biological Sciences (Angelis; Sofos; Karakasidis, 2023; Li et al., 2023). These innovations allow students to engage with contemporary scientific practices, bringing school teaching closer to the actual production of scientific knowledge.

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Figure 1

Illustrative schematic of the contributions of artificial intelligence and digital technologies to the teaching of Physical and Biological Sciences!
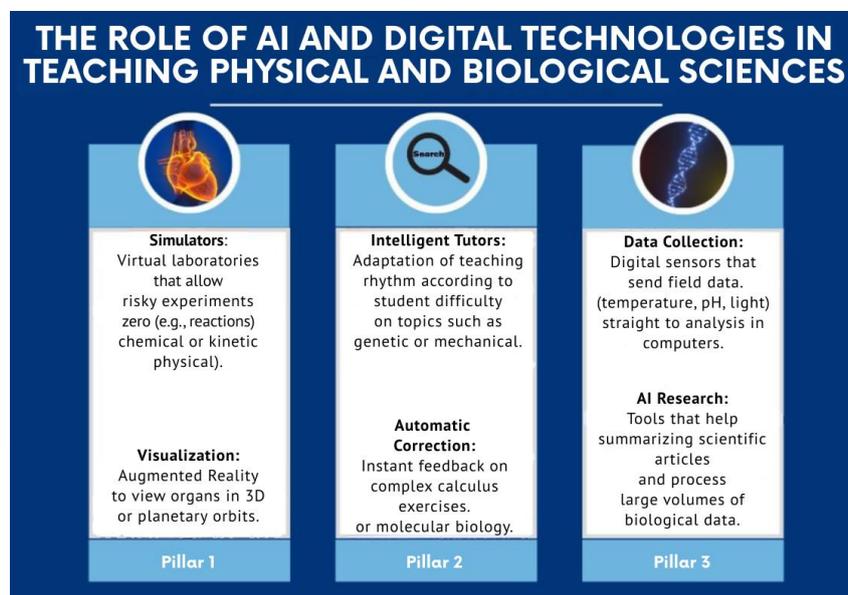
Source: Authors (2026)

Furthermore, research shows that the use of AI-based digital platforms in the teaching of Biology and Natural Sciences contributes to improvements in academic performance, motivation, and student autonomy, provided that it is associated with well-structured pedagogical strategies (Mattos, 2024; Li; Wang, 2022). In teaching physical–biological content, these technologies enable the analysis of experimental data, the simulation of ecosystems, the modeling of biological systems, and the integrated understanding of complex phenomena (Zhou et al., 2024).

Given this scenario, it becomes evident that artificial intelligence and digital technologies constitute important allies in the teaching and learning process in Physical and Biological Sciences. However, their effective pedagogical contribution depends on a critical, ethical, and theoretically grounded integration that considers the specificities of the area, the educational context, and the teacher's mediating role (Hodson, 2022; Vicari, 2021). Thus, investigating the potentialities and limits of these technologies in science teaching becomes fundamental to support innovative pedagogical practices aligned with contemporary demands.

In this regard, the objective of this study is to analyze the pedagogical contributions of artificial intelligence and digital technologies to the teaching of Physical and Biological Sciences, discussing their potentialities, challenges, and implications for educational practices in light of recent national and international scientific production.

METHODOLOGY

The present study is characterized as qualitative research, with a descriptive and exploratory approach, developed through a systematized literature review, with the objective of analyzing the pedagogical contributions of artificial intelligence and digital technologies in the teaching of Physical and Biological Sciences. The choice of this methodological approach is justified by the need to understand, in a deep and contextualized manner, the concepts, trends, applications, and challenges related to integrating these technologies in the educational field, especially in science teaching.

Bibliographic research was adopted because it allows for the survey, critical analysis, and systematization of scientific knowledge produced on the topic, making it possible to identify different theoretical, methodological, and practical perspectives. According to methodological literature, this type of study is appropriate when the aim is to understand complex phenomena that are still being consolidated, as is the case with the application of artificial intelligence in science education.

Data collection was carried out using secondary sources, consisting of scientific articles, books, book chapters, institutional reports, documents from international organizations, and publications in recognized national and international journals. Priority was given to scientific production published between 2021 and 2026, in Portuguese and English, in order to ensure the currency and relevance of the analyzed information, given the dynamic and recent nature of digital technologies and artificial intelligence in the educational context.

The databases used to select studies included widely recognized scientific platforms such as Scopus, Web of Science, SciELO, ERIC, Google Scholar, and institutional repositories of organizations

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such as UNESCO and the OECD. The search strategy was defined through combinations of descriptors related to the topic, such as: artificial intelligence, digital technologies, science education, science teaching, biology, physics, and technology-mediated learning, used both individually and in combination through Boolean operators.

Figure 2

Flowchart of the search and selection process for studies included in the review

Source: Authors (2026)

As inclusion criteria, studies were considered that explicitly addressed the application or theoretical discussion of artificial intelligence and digital technologies in the educational context, with a focus on the teaching of Science, Physics, Biology, or related areas. Works discussing pedagogical, methodological, ethical, or teacher-education aspects related to the use of these technologies were also included. Duplicate publications were excluded, as were studies that did not present a direct relationship with the research object, as well as works of a purely technical nature without an interface with education.

After the selection stage, the included studies were subjected to an exploratory reading, followed by analytical and interpretive reading, with the objective of identifying thematic categories relevant to the analysis. Data organization occurred through content categorization, considering aspects such as: types of technologies used, associated pedagogical strategies, contributions to the teaching and learning process, ethical and pedagogical challenges, and implications for teacher education.

Data analysis was conducted based on content analysis, according to methodological assumptions widely used in qualitative research. This procedure enabled a systematic interpretation of the selected texts, making it possible to identify patterns, convergences, and divergences among the analyzed studies, as well as to build a critical synthesis regarding the contributions of artificial intelligence and digital technologies to the teaching of Physical and Biological Sciences.

Finally, it should be noted that the development of this research respected the ethical principles of scientific production, with due citation of the sources used and the valorization of the intellectual authorship of the works analyzed. In this way, the adopted methodology seeks to ensure scientific rigor, transparency, and reliability in the presented results, contributing to the advancement of discussions on the pedagogical use of artificial intelligence and digital technologies in science teaching.

RESULTS AND DISCUSSION

The analysis of the selected scientific production shows that artificial intelligence and digital technologies have been assuming an increasingly central role in the teaching of Physical and Biological Sciences, both with regard to methodological innovation and the reconfiguration of traditional pedagogical practices. The results obtained from the literature review made it possible to identify recurring thematic categories that express the main contributions, limits, and challenges associated with incorporating these technologies in the educational context.

The results indicate that one of the main contributions of artificial intelligence in teaching Physical and Biological Sciences lies in the possibility of personalizing teaching through adaptive systems capable of adjusting content, pace, and strategies to students' individual needs. According to Huang, Saleh, and Liu (2021), artificial intelligence-based educational environments enable continuous monitoring of student performance, supporting more precise and effective pedagogical interventions.

In Biology teaching, according to Li and Wang (2022), intelligent educational platforms assist in understanding complex processes such as cellular mechanisms, genetics, and ecosystem dynamics by

incorporating visualization resources, simulation, and automated feedback. As Mattos (2024) points out, such tools contribute to the construction of more consistent mental models, especially in content with a high level of conceptual abstraction.

In Physics teaching, as emphasized by Angelis, Sofos, and Karakasidis (2023), the use of symbolic regression algorithms, computational modeling, and interactive simulations supports the understanding of abstract phenomena and the development of scientific reasoning. From the perspective of Makarova and Herbst (2022), these approaches expand students' capacity to establish relationships between mathematical models and observable physical phenomena.

These contributions directly align with Hodson's conception of science teaching. According to Hodson (2022), effective pedagogical practices should promote conceptual understanding, scientific inquiry, and the articulation between theory and practice. In this context, artificial intelligence acts as a mediator of the learning process, expanding possibilities for experimentation and data analysis within educational environments.

Table 1

Main pedagogical contributions of artificial intelligence and digital technologies in the teaching of Physical and Biological Sciences

Pedagogical dimension	Identified contributions
Personalization of learning	Adaptation of content, pacing, and strategies to students' individual needs through adaptive systems and educational data analysis
Active learning	Promotion of problem-based learning, investigative projects, and blended learning, with greater student agency
Visualization of scientific phenomena	Use of simulations, computational modeling and
	interactive environments to understand complex physical and biological phenomena
Development of scientific thinking	Expansion of the capacity for analysis, data interpretation, and construction of scientific hypotheses
Integration of theory–practice	Bridging theoretical content and contemporary scientific practices mediated by digital technologies

DIGITAL TECHNOLOGIES, ACTIVE METHODOLOGIES, AND STUDENT ENGAGEMENT

Another relevant result concerns the relationship between the use of digital technologies based on artificial intelligence and the adoption of active methodologies in science teaching. According to Dori, Mevarech, and Baker (2022), integrating these technologies supports strategies such as problem-based learning, the development of investigative projects, and the implementation of blended learning, promoting greater student agency. As Costa (2024) states, such practices contribute significantly to increasing student engagement in the proposed activities.

The literature indicates that interactive digital environments stimulate students' active participation by enabling the exploration of different scenarios, the resolution of real-world problems, and collaboration among peers. According to Aguiar (2023), the pedagogical use of artificial intelligence

makes the teaching process more dynamic and aligned with contemporary demands, provided that it is guided by clear and well-defined educational objectives.

Moreover, according to findings from the OECD (2021), the use of digital technologies in the teaching of Physical and Biological Sciences contributes to developing competencies such as critical thinking, intellectual autonomy, and scientific literacy. In line with UNESCO (2021), these competencies are fundamental for educating citizens capable of understanding and intervening in increasingly complex scientific and technological contexts.

ETHICAL, PEDAGOGICAL, AND TEACHER-EDUCATION CHALLENGES IN THE USE OF ARTIFICIAL INTELLIGENCE

Despite the identified contributions, the review results reveal significant challenges related to incorporating artificial intelligence in science teaching. As Boulay (2023) points out, among the main challenges are ethical issues, teacher education, and the risk of an uncritical use of digital technologies.

According to UNESCO (2023), attention to ethics in the use of educational artificial intelligence is essential, especially with regard to data protection, algorithm transparency, and equity of access to technologies. In science teaching, these issues become even more sensitive, since the indiscriminate use of automated tools may compromise the development of scientific thinking and students' cognitive autonomy.

Regarding teacher education, according to Parreira, Lehmann, and Oliveira (2021), many teachers still feel insecure about the pedagogical use of artificial intelligence, either due to the lack of specific training or due to fear of the teacher's role being replaced. As Rodrigues and Rodrigues (2023) assert, this scenario highlights the need for continuing education policies that promote a critical and reflective appropriation of digital technologies in the educational context.

Table 2

Ethical, pedagogical, and institutional challenges associated with the use of artificial intelligence in science teaching

Challenge category	Description
Ethical	Risks related to data privacy, algorithm opacity, and non-transparent use of AI tools
Pedagogical	Uncritical use of technology, with possible superficialization of learning and reduction of teacher mediation
Teacher-education	Insufficient initial and continuing training for the pedagogical use of AI in science teaching
Institutional	Inequality of access to digital technologies and the absence of structured educational policies
Assessment-related	Difficulties in adapting assessment processes in view of the use of automated tools

ARTIFICIAL INTELLIGENCE, SCIENTIFIC INNOVATION, AND INTERDISCIPLINARITY

The results also indicate that artificial intelligence contributes to bringing the teaching of Physical and Biological Sciences closer to contemporary scientific practices. According to Li et al. (2023), advanced applications of artificial intelligence enable new forms of modeling, analysis, and scientific prediction, expanding didactic possibilities in science teaching and favoring interdisciplinary approaches.

In this sense, in Hodson's analysis (2022), incorporating artificial intelligence into teaching enables students to come into contact with tools similar to those used in current scientific research, promoting greater articulation between education and science. This perspective reinforces the importance of pedagogical practices that integrate Physics, Biology, Mathematics, and Technology, fostering a systemic view of scientific knowledge.

Rosiane Almeida Minet Marsaioli | Rennie Pantoja Nogueira | Arthur Marroquim do Nascimento | Flavia Frade de Mello | Susana de Sousa Araújo | Carolina Toledo Santos | Naiara Cristina de Souza Garajau | José Heber de Souza Aguiar

However, as Lampou (2023) emphasizes, promoting interdisciplinarity mediated by digital technologies requires careful pedagogical planning and clarity regarding educational objectives. As defended by Picão, Silva, and Costa (2023), the absence of these elements may result in fragmentation of content or superficial use of digital tools.

SYNTHESIS OF RESULTS AND PEDAGOGICAL IMPLICATIONS

The synthesis of results shows that artificial intelligence and digital technologies present high pedagogical potential for teaching Physical and Biological Sciences. According to Vicari (2021), when integrated with active methodologies and grounded theoretically, these technologies contribute to personalizing learning and increasing student engagement. As Dori, Mevarech, and Baker (2022) indicate, they also foster a closer relationship between theory and scientific practice, enhancing the quality of the educational process.

On the other hand, in line with the OECD (2021) and UNESCO (2021; 2023), the identified challenges reinforce the need for educational policies, ethical guidelines, and continuous investments in teacher education. The responsible and critical use of artificial intelligence in science teaching is fundamental to ensuring that these technologies act as supportive instruments within the educational process, rather than as substitutes for pedagogical mediation.

Table 3

Synthesis of contributions, challenges, and pedagogical implications of artificial intelligence in the teaching of Physical and Biological Sciences

Aspect	Synthesis of findings
Contributions	Artificial intelligence and digital technologies enhance personalization of teaching, student engagement, active learning, and understanding of complex scientific phenomena
Challenges	Ethical issues, limitations in teacher education, inequality of access, and the risk of instrumental use of technology
Pedagogical implications	Need for critical integration of AI into teaching methodologies, with instructional planning and qualified teacher mediation
Teacher-education implications	Urgency of continuing education programs focused on the pedagogical, ethical, and reflective use of artificial intelligence
Future directions	Expansion of empirical research and formulation of educational policies to guide the responsible use of AI in science teaching

Thus, the results and discussion presented reinforce that artificial intelligence and digital technologies constitute important allies in the teaching and learning process in Physical and Biological Sciences, provided they are integrated in an ethical, critical, and pedagogically oriented manner. The literature analysis highlights the need to advance empirical research that systematically investigates the impacts of these technologies across different levels of education, contributing to the consolidation of innovative and socially responsible educational practices.

CONCLUSION

The present investigation showed that artificial intelligence and digital technologies constitute strategic elements for renewing pedagogical practices in the teaching of Physical and Biological Sciences. The analysis of the scientific literature demonstrated that such resources have the potential to expand didactic possibilities, promote meaningful learning, and contribute to the construction of scientific knowledge in a more dynamic and contextualized way. In this sense, integrating these technologies into the educational process responds to contemporary demands for an education aligned with society's scientific and technological advancement.

Rosiane Almeida Minet Marsaioli | Rennie Pantoja Nogueira | Arthur Marroquim do Nascimento | Flavia Frade de Mello | Susana de Sousa Araújo | Carolina Toledo Santos | Naiara Cristina de Souza Garajau | José Heber de Souza Aguiar

The analyzed results indicate that artificial intelligence contributes significantly to personalizing teaching by enabling monitoring of student performance, adapting content, and providing automated feedback. In the teaching of Physical and Biological Sciences, this personalization supports understanding complex phenomena, visualizing abstract processes, and developing scientific thinking—fundamental aspects for educating critical and investigative students.

Another relevant aspect identified concerns the articulation among artificial intelligence, digital technologies, and active teaching methodologies. The literature indicates that the pedagogical use of these technologies strengthens strategies centered on student agency, such as problem- and project-based learning, promoting greater engagement, autonomy, and participation of students in the learning process. In this way, technology ceases to occupy a merely instrumental role and begins to act as a mediator of scientific knowledge construction.

However, incorporating artificial intelligence into the teaching of Physical and Biological Sciences also presents significant challenges, especially regarding ethical, pedagogical, and teacher-education issues. Problems related to data privacy, algorithm transparency, and the uncritical use of digital technologies demand attention from educational institutions and public policy makers. These challenges reinforce the need for an ethical and responsible approach to adopting AI in the educational context.

Teacher education emerges as a central element for the effective integration of artificial intelligence in science teaching. The analyzed studies indicate that the absence of adequate preparation can limit the pedagogical potential of these technologies, compromising their critical and reflective use. Thus, it becomes essential to invest in initial and continuing education programs that prepare teachers for the pedagogical, ethical, and conscious use of artificial intelligence and digital technologies.

In addition, the research showed that the use of artificial intelligence can contribute to bringing school teaching closer to contemporary scientific practices, promoting interdisciplinarity and integrated understanding of natural phenomena. By enabling students to engage with tools similar to those used in

current scientific production, AI expands learning opportunities and strengthens scientific literacy in the teaching of Physical and Biological Sciences.

Finally, it is concluded that artificial intelligence and digital technologies have high potential to transform the teaching of Physical and Biological Sciences, provided they are integrated in a critical, ethical, and pedagogically oriented manner. Further empirical studies are recommended to investigate the impacts of these technologies across different levels of education, as well as the formulation of educational policies to guide their responsible use, contributing to the consolidation of innovative and socially committed educational practices.

As a suggestion for future research, the development of empirical studies is recommended to analyze the impacts of artificial intelligence and digital technologies in the teaching of Physical and Biological Sciences across different educational levels and contexts. Quantitative, qualitative, or mixed-methods research can contribute to understanding their effects on academic performance, student engagement, and the development of scientific thinking, as well as investigating teacher education and the institutional guidelines necessary for an ethical and pedagogical implementation of these technologies.

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