PEDAGOGICAL INNOVATION THROUGH ACTIVE METHODOLOGIES AND NANOTECHNOLOGY: INTERDISCIPLINARY STRATEGIES FOR THE TRANSFORMATION OF THE TEACHING-LEARNING PROCESS

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Abstract

The increasing complexity of scientific, technological, and social demands in the 21st century has required the reconfiguration of educational practices and the adoption of innovative pedagogical strategies capable of promoting meaningful learning and comprehensive education. In this context, the present study aimed to analyze how the articulation between active methodologies and nanotechnology, from an interdisciplinary perspective, can contribute to the transformation of the teaching-learning process. This is a systematic literature review with a qualitative and descriptive-analytical approach, based on publications indexed between 2021 and 2026 in national and international databases. Descriptors related to pedagogical innovation, active methodologies, interdisciplinarity, and nanotechnology were used, with previously defined inclusion and exclusion criteria. The results showed that active methodologies, such as project-based learning, Team Based Learning, maker culture, and structured instructional design, promote greater student protagonism, development of critical skills, and integration between theory and practice. Interdisciplinarity proved to be a central element in consolidating these strategies, fostering connections among different fields of knowledge around real and socially relevant problems. Regarding nanotechnology, the analyzed studies indicate that its curricular integration, when associated with active approaches, enhances scientific training, innovation, and ethical reflection on emerging technologies. It is concluded that pedagogical innovation supported by active methodologies and the integration of nanotechnology contributes to a more dynamic, critical, and 21st-century-aligned education, strengthening interdisciplinary education and the development of techno-scientific competencies.

Keywords: Active methodologies, Interdisciplinarity, Nanotechnology, Pedagogical innovation, Teaching-learning process.

INTRODUCTION

Contemporary education is marked by profound transformations resulting from scientific and technological advances and from shifts in social, economic, and cultural demands. In this scenario, pedagogical innovation emerges as a central element for re-signifying the teaching–learning process, requiring educational institutions to adopt strategies that foster autonomy, critical thinking, and the integration of different forms of knowledge. Projections about the future of higher education indicate that the incorporation of emerging technologies and innovative methodologies will be decisive for educating professionals capable of acting in complex and dynamic contexts (Aithal; Prabhu; Aithal, 2024). Thus, pedagogical innovation is not limited to the insertion of technological resources; rather, it involves a structural transformation of didactic practices, curricula, and conceptions of learning.

In this context, active methodologies have become consolidated as fundamental strategies for promoting meaningful learning, centered on the student as the protagonist of their own formative process. Unlike the traditional model, grounded in the passive transmission of content, active methodologies encourage problematization, collaboration, investigation, and the collective construction of knowledge (Santos; Pereira, 2023). Studies show that such approaches foster the development of socioemotional and cognitive competencies, in addition to strengthening the integration among teaching, research, and extension/outreach (Costa et al., 2026). Faculty perceptions regarding these methodologies also reveal their potential in terms of student engagement and improved academic performance, although structural and training-related challenges persist (Valente et al., 2025).

Among active strategies, models such as Team Based Learning (TBL) stand out, as they promote collaborative learning and individual and collective accountability (Costa; Cani; Sandrini, 2021), as well as the application of instructional design through the ADDIE model, which organizes pedagogical planning in a systematic way aligned with educational objectives (Convento, 2025). The complementarity between methodologies—such as the arc method and transdisciplinary itineraries—also highlights the importance of articulating theory and practice in the construction of scientific knowledge (Martins;

Carneiro, 2025). Moreover, experiences with 3D modeling and prototyping demonstrate that the integration between technology and active methodologies enhances learning at different educational levels (Soares; Ferreira, 2025).

Interdisciplinarity constitutes the structuring axis of this pedagogical innovation, as it breaks with the fragmentation of knowledge and promotes connections among different areas.Didactic strategies aimed at implementing interdisciplinarity from early childhood education through the initial years of schooling contribute to students' integral development (Boesing; Gubiani; De Santana, 2025). The integration among projects, the identification of students' interests, and technological mediation reinforces the construction of contextualized and socially relevant learning (Santos; Schimiguel, 2025). Furthermore, the articulation among environmental education, sustainability, and technology highlights the transformative potential of pedagogical innovation in forming critical citizens committed to sustainable development (Nunes et al., 2024).

The incorporation of digital technologies into educational environments intensified especially during the COVID-19 pandemic, when new strategies had to be implemented to ensure continuity of teaching (Dionízio; De Paiva, 2021). Hybrid teaching (B-learning) became consolidated as a viable alternative, combining in-person and virtual activities and expanding the possibilities for personalized learning (Leal, 2025). In this scenario, technologies also play a fundamental role in educational inclusion, although they still face challenges related to access, teacher training, and infrastructure (Almeida et al., 2025; Santos et al., 2025). Maker culture and the use of digital tools, in turn, strengthen scientific literacy and combat misinformation, encouraging experimentation and student authorship (Vieira-Neto et al., 2025).

Parallel to methodological transformations, nanotechnology has emerged as a strategic area for contemporary scientific and technological development. Characterized by the manipulation of matter at the nanometric scale, this field has applications in sectors such as health, energy, the environment, and industry (Khan; Asmatulu; Asmatulu, 2025). Discussions about its development and implementation highlight both its innovative potential and the associated social, economic, and ethical implications (Verma et al., 2024). In the educational sphere, introducing content related to nanotechnology fosters rapprochement between cutting-edge science and academic training, stimulating a culture of innovation and technological safety (Deng-Guang et al., 2023).

The articulation between active methodologies and nanotechnology therefore constitutes an interdisciplinary strategy capable of promoting the transformation of the teaching–learning process. By integrating knowledge from the exact sciences, biological sciences, social sciences, and technological fields, this approach makes it possible to develop investigative projects, solve real problems, and build innovative solutions. Such integration supports not only the acquisition of content but also the development of essential competencies for the twenty-first century, such as critical thinking, creativity, collaboration, and socio-environmental responsibility.

In this way, pedagogical innovation through active methodologies and nanotechnology presents itself as a promising path toward building a more dynamic, inclusive education aligned with contemporary demands. By promoting interdisciplinarity, technological integration, and student protagonism, these strategies contribute to re-signifying educational practices and to forming critical and innovative subjects. Thus, the present study aims to analyze how the articulation between active methodologies and nanotechnology, from an interdisciplinary perspective, can transform the teaching–learning process, enhancing academic and scientific training at different educational levels.

METHODOLOGY

This study is a systematic literature review with a qualitative approach and a descriptive-analytical character, conducted with the objective of identifying, analyzing, and synthesizing scientific evidence about pedagogical innovation through active methodologies and nanotechnology, with an emphasis on interdisciplinary strategies aimed at transforming the teaching–learning process. The systematic review was chosen because it allows greater methodological rigor in the search, selection, evaluation, and synthesis of studies, ensuring transparency and reproducibility of the investigative pathway.

The research covered the period from 2021 to 2026, considering indexed publications within this time interval in order to include recent scientific production related to educational transformations intensified in the post-pandemic context and to the advance of emerging technologies. The selected databases were: Scopus, Web of Science, ERIC (Education Resources Information Center), SciELO, and Google Scholar, as they encompass relevant national and international production in the areas of Education, Science, and Technology.

To construct the search strategy, controlled and uncontrolled descriptors were used, combined through the Boolean operators AND and OR, in Portuguese and English. The main descriptors used were: “Pedagogical innovation,” “Active methodologies,” “Project-based learning,” “Interdisciplinarity,” “Higher education,” “Basic education,” “Nanotechnology,” “Nanotechnology education,” “Active learning,” and “Interdisciplinary strategies.”

The inclusion criteria adopted were: (1) original articles, systematic or integrative reviews, experience reports, and theoretical studies published between 2021 and 2026; (2) studies addressing active methodologies associated with pedagogical innovation; (3) research relating nanotechnology to the educational context or to scientific training; (4) publications in Portuguese, English, or Spanish; and (5) texts available in full electronically.

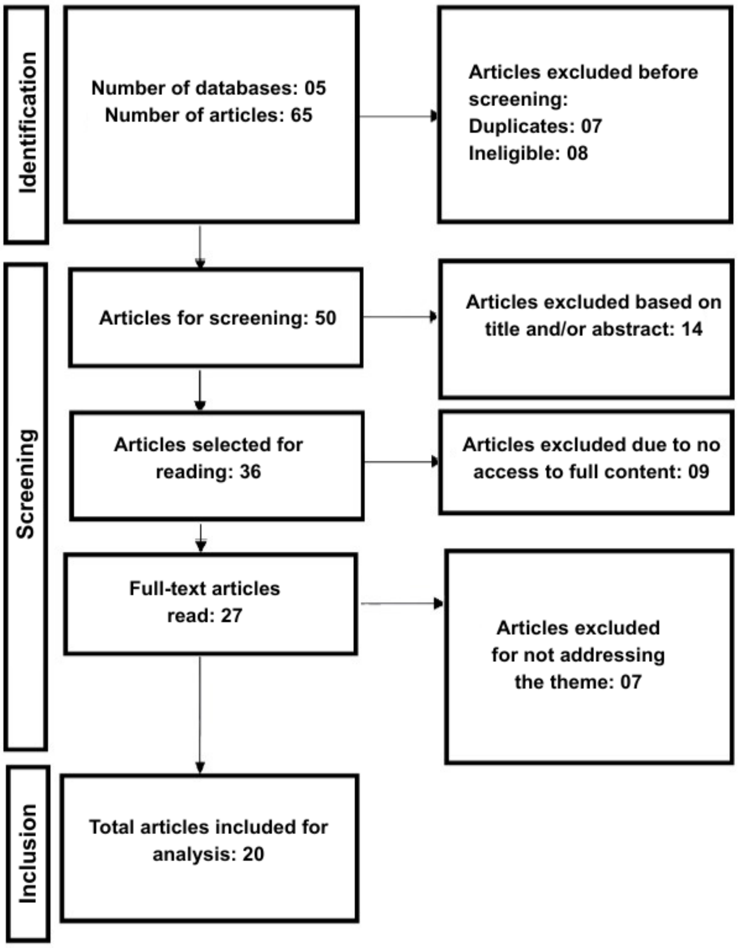
The exclusion criteria were: (1) studies published before 2021; (2) duplicate works across databases; (3) productions addressing exclusively technical aspects of nanotechnology without relation to the educational context; (4) articles dealing with traditional methodologies without an interface with active approaches; and (5) simple abstracts, editorials, letters to the editor, and works without peer review.

The study selection process occurred in four stages: (1) identification of records in the databases; (2) screening by reading titles and abstracts; (3) eligibility assessment by reading the full text; and (4) final inclusion of studies that met the established criteria. Reference organization and management were carried out with the aid of bibliographic management software, enabling the removal of duplicates and the systematization of data.

The methodological quality of the included studies was assessed based on criteria adapted from international protocols for systematic reviews, considering clarity of objectives, methodological design, coherence between methods and results, and consistency of conclusions. This procedure aimed to ensure greater reliability of the synthesized evidence. The systematization of the search and selection process will be presented in a flowchart, as illustrated below:

Figure 1

Flowchart of the process of identification, screening, eligibility, and inclusion of studies.



Source: Authors (2026)

In this manner, the adopted methodology ensures scientific rigor and transparency in conducting the systematic review, enabling a consistent analysis of evidence regarding the articulation between active methodologies and nanotechnology as interdisciplinary strategies for transforming the teaching–learning process.

RESULTS AND DISCUSSION

Analysis of the selected studies showed that pedagogical innovation, articulated with active methodologies and nanotechnology, has promoted significant transformations in the teaching–learning process across different educational levels. The results were organized into three analytical axes: (1) consolidation of active methodologies as a strategy for student protagonism; (2) interdisciplinary and technological integration in the curriculum; and (3) insertion of nanotechnology as a strategic field for scientific and innovative training.

In the first axis, it was observed that active methodologies have been widely recognized as catalysts of meaningful learning. Santos and Pereira (2023) emphasize that such methodologies foster the development of critical and reflective competencies by shifting the focus from content transmission to the collaborative construction of knowledge.

From this perspective, Costa et al. (2026) stress that integration among teaching, research, and extension/outreach strengthens academic formation, expanding the articulation between theory and practice.

Emphasizing the authors' perspective, Aithal, Prabhu, and Aithal (2024) argue that innovation in higher education depends on incorporating emerging technologies associated with new pedagogical approaches, stating that:

> The transformation of higher education requires convergence between technological forecasting, curricular innovation, and student-centered methodologies capable of anticipating emerging social and professional demands.

This statement reinforces the need to align pedagogical practices with contemporary scientific and technological trends. Team Based Learning (TBL), for example, demonstrated a positive impact on student engagement and collaborative learning (Costa; Cani; Sandrini, 2021), while the ADDIE model contributed to the structured planning of innovative formative experiences (Convento, 2025).

In addition, Trindade and Santos (2025) emphasize that applying active methodologies in Portuguese language teaching promotes greater student participation and contextualization of content. Similarly, Santos and Schimiguel (2025) show that technology-mediated projects based on students' interests enhance engagement and autonomy.

The second analytical axis revealed that interdisciplinarity is an essential element for consolidating pedagogical innovation. Boesing, Gubiani, and De Santana (2025) demonstrate that interdisciplinary strategies from early childhood education favor the construction of integrated and contextualized knowledge. Martins and Carneiro (2025) defend the complementarity between the arc method and transdisciplinary itineraries, strengthening articulation among different fields of knowledge.

Table 1

Interdisciplinary strategies and active methodologies identified in the analyzed studies.

Author(s)/Year	Methodology or Pedagogical Strategy	Main Contributions to Innovating the Teaching–Learning Process
Costa et al. (2026)	Integration of teaching–research–extension/outreach	Strengthening critical and reflective training; articulation between theory and practice; expansion of student protagonism in real learning contexts.
Convento (2025)	Instructional design (ADDIE model) associated with active methodologies	Systematized pedagogical planning; alignment among objectives, strategies, and assessment; promotion of meaningful and structured learning.

Costa; Cani; Sandrini (2021)	Team Based Learning (TBL)	Stimulus to collaborative learning; development of individual and collective accountability; improvement of logical and argumentative reasoning.
Martins; Carneiro (2025)	Arc method and transdisciplinary itineraries	Integration between theory and practice; contextualization of scientific knowledge; promotion of interdisciplinarity and the problematization of reality.
Soares; Ferreira (2025)	3D modeling and prototyping with an active approach	Development of technological and creative competencies; encouragement of maker culture; strengthening of experiential and investigative learning.
Vieira-Neto et al. (2025)	Maker culture and digital tools	Expansion of scientific literacy; combating misinformation; encouragement of authorship, experimentation, and innovation.

Source: Authors (2026)

Maker culture and the use of digital tools also stood out as relevant interdisciplinary strategies. Vieira-Neto et al. (2025) show that such approaches strengthen scientific literacy and combat misinformation, promoting active and contextualized learning. Nunes et al. (2024) reinforce that environmental education in the digital era expands socio-environmental awareness by integrating technology and innovation.

In the context of educational inclusion, Almeida et al. (2025) highlight that the use of technologies can reduce pedagogical barriers, although challenges related to infrastructure and teacher training still persist. Santos et al. (2025) corroborate this analysis by stating that integrating digital technologies in the early years requires consistent pedagogical planning and continuing education.

Emphasizing the author's perspective, Leal (2025) observes that hybrid teaching (B-learning) represents one of the main strategies for contemporary educational transformation, as it articulately combines in-person and virtual environments. According to the author:

> Hybrid teaching expands possibilities for personalized learning and strengthens student autonomy by integrating digital technologies with innovative pedagogical practices.

This perspective aligns with the findings of Dionízio and De Paiva (2021), who identified, during the COVID-19 pandemic, the need to reconfigure didactic practices to ensure continuity of the formative process.

The third axis highlighted the relevance of nanotechnology as a strategic field for educational innovation. Khan, Asmatulu, and Asmatulu (2025) emphasize that nanotechnology presents emerging trends with significant impact across various productive sectors, requiring academic training aligned with global techno-scientific demands. Verma et al. (2024) stress that the development and implementation of nanotechnology involve not only technical aspects but also social and ethical implications.

Emphasizing the authors' perspective, Deng-Guang et al. (2023) advocate integrating education for innovation and education for safety in higher education, stating that:

> Contemporary scientific training must combine technological innovation with ethical awareness and safety, especially in strategic areas such as nanotechnology.

This approach indicates that inserting nanotechnology into the curriculum should occur in an interdisciplinary and responsible manner, promoting both technical competencies and critical reflection.

Table 2

Contributions of nanotechnology to interdisciplinary pedagogical innovation.

Author(s)/Year	Analytical Focus	Scientific Contributions	Implications for Academic Training and Educational Innovation
Khan; Asmatulu; Asmatulu (2025)	Emerging trends, markets, and safety in nanotechnology	Analysis of industrial, biomedical, and environmental applications; identification of regulatory and ethical challenges.	Need for curricular updating; insertion of interdisciplinary content; training aligned with global techno-scientific demands.
Verma et al. (2024)	Development and social implementation of nanotechnology	Discussion of the social, economic, and technological impacts of nanotechnology on sustainable development.	Integration among science, ethics, and society; promotion of critical awareness and social responsibility in scientific training.
Deng-Guang et al. (2023)	Education for innovation and safety in higher education	Proposal of an integrated model that articulates technological innovation and education for scientific safety.	Critical and responsible scientific training; strengthening a culture of innovation associated with ethics and technological safety.

Source: Authors (2026)

The results show that articulating active methodologies and nanotechnology enhances problem-based learning grounded in concrete issues, favoring investigative, experimental, and innovative processes. As systematized in Table 1, different pedagogical strategies—such as Team Based Learning, the ADDIE model, maker culture, and 3D prototyping—converge in promoting student protagonism, collaboration, and contextualization of knowledge. In this regard, Soares and Ferreira (2025) highlight that practices involving modeling and prototyping increase students' interest in scientific and technological areas by integrating theory and practice into actively experienced activities. Complementarily, Valente et al. (2025) point out that faculty perceptions regarding active methodologies are predominantly positive, especially with respect to student engagement and improved academic performance, even as they emphasize the need for greater institutional investment, continuing education, and adequate infrastructure.

It is also observed that interdisciplinarity constitutes a structuring element of this innovative process. As shown in Table 1, the analyzed strategies surpass disciplinary fragmentation and promote articulations among different areas of knowledge, allowing scientific content to be addressed in an integrated and contextualized manner. This integration is deepened when associated with nanotechnology, whose curricular insertion, as presented in Table 2, expands possibilities for an interdisciplinary approach by connecting scientific, technological, ethical, and social dimensions. The analyzed literature converges in indicating that nanotechnology should not be understood solely as specialized technical content, but as a strategic field for developing investigative and innovative competencies.

Moreover, Table 2 shows that training in nanotechnology requires curricular updating and a critical approach, considering both emerging trends and the social and ethical impacts associated with its application. When incorporated through active methodologies, nanotechnology becomes an articulating axis for interdisciplinary projects, favoring the resolution of real problems and the development of innovative solutions. Such articulation strengthens meaningful learning by bringing students closer to contemporary scientific contexts and concrete technological demands.

Overall, the findings indicate convergence among the studies regarding the transformative potential of active methodologies when associated with emerging technologies. The integrated analysis of Tables 1 and 2 demonstrates that pedagogical innovation occurs more consistently when there is alignment among structured didactic planning, collaborative strategies, and the insertion of advanced scientific content such as nanotechnology. In this way, the results reinforce that pedagogical innovation sustained by active methodologies and by the strategic insertion of nanotechnology into the curriculum contributes significantly to transforming the teaching–learning process, aligning it with twenty-first-century demands and strengthening interdisciplinary, critical, and socially responsible scientific education.

CONCLUSION

This systematic review showed that pedagogical innovation, when articulated with active methodologies and nanotechnology, constitutes a powerful strategy for transforming the teaching–learning process. The analyzed studies converge on the need to overcome traditional models centered on content transmission, indicating that pedagogical practices grounded in student protagonism, problematization, and collaborative learning favor the development of cognitive, socioemotional, and techno-scientific competencies. In this context, innovation is not limited to inserting technological resources, but implies curricular restructuring, intentional didactic planning, and a change in educational paradigms.

The results also revealed that active methodologies—such as project-based learning, Team Based Learning, maker culture, and structured instructional design—promote greater student engagement and strengthen the articulation between theory and practice. Interdisciplinarity proved to be a structuring element of this process, as it enables the integration of different areas of knowledge around complex and socially relevant problems. Such integration favors the construction of contextualized, critical learning aligned with contemporary demands, expanding the social meaning of education.

Regarding nanotechnology, it was found that its insertion in the educational context goes beyond the technical dimension, assuming a strategic role in scientific and innovative training. When addressed through active methodologies, nanotechnology becomes an articulating axis for interdisciplinary experiences that stimulate investigation, experimentation, and ethical reflection. This approach helps bring students closer to the frontiers of scientific knowledge, while also promoting critical awareness of the social, environmental, and economic impacts of emerging technologies.

Furthermore, analysis of the studies reinforces that consolidating these practices depends on institutional investment, continuing teacher education, and educational policies that encourage curricular innovation. Although evidence points to significant benefits, challenges persist related to infrastructure, resistance to change, and the need for greater integration among teaching, research, and extension/outreach. Thus, implementing pedagogical innovation requires institutional commitment and strategic planning to ensure the sustainability of the proposed transformations.

The articulation between active methodologies and nanotechnology shows potential to align education with twenty-first-century demands, promoting critical, creative, and socially responsible formation. By integrating advanced scientific knowledge, collaborative strategies, and the problematization of reality, this approach strengthens the development of essential competencies for acting in complex and technologically dynamic contexts. Therefore, the pedagogical innovation analyzed in this review constitutes a promising path for improving basic and higher education.

As a suggestion for future research, it is recommended to conduct empirical studies of a quasi-experimental or longitudinal nature to investigate the impacts of inserting nanotechnology associated with active methodologies on academic performance, the development of scientific competencies, and students' ethical formation. In addition, studies that assess student and teacher perceptions at different educational levels may contribute to improving interdisciplinary strategies and consolidating sustainable, contextualized innovative pedagogical practices.

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