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EMERGING DIGITAL TECHNOLOGIES IN ENGINEERING EDUCATION: PEDAGOGICAL POTENTIAL FOR ACTIVE LEARNING AND COMPETENCY DEVELOPMENT

TECNOLOGIAS DIGITAIS EMERGENTES NO ENSINO DE ENGENHARIA: POTENCIAL PEDAGÓGICO PARA APRENDIZAGEM ATIVA E DESENVOLVIMENTO DE COMPETÊNCIAS

TECNOLOGÍAS DIGITALES EMERGENTES EN LA ENSEÑANZA DE LA INGENIERÍA: POTENCIAL PEDAGÓGICO PARA EL APRENDIZAJE

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ABSTRACT
Engineering education in the 21st century requires continuous modernization, driven by digital technologies and the demands of Industry 4.0. This article investigates how emerging technologies—virtual and remote laboratories, 3D printing, the Internet of Things, and immersive realities—contribute to active learning and competency development in engineering education. The study is based on an integrative literature review with a qualitative approach, analyzing 80 studies published between 2010 and 2025 through thematic content analysis. The results indicate that virtual and remote laboratories expand access to and safety in experimentation; 3D printing supports prototyping and the integration of theory and practice; IoT enables instrumentation, automation, and data analysis; and immersive realities enhance visualization and safe training. It is concluded that integrating these technologies with active methodologies, such as Project-Based Learning, is strategic for pedagogical innovation, provided it is supported by intentional curriculum planning and adequate faculty development.

Keywords: Engineering Education. Digital Technologies. Active Learning. Industry 4.0. Competencies.

RESUMO
O ensino de engenharia no século XXI demanda constante modernização, impulsionada pelas tecnologias digitais e pelas exigências da Indústria 4.0. Este artigo investiga como tecnologias emergentes — laboratórios virtuais e remotos, impressão 3D, Internet das Coisas e realidades imersivas — contribuem para a aprendizagem ativa e o desenvolvimento de competências no ensino de engenharia. A pesquisa baseia-se em uma revisão integrativa de literatura, de abordagem qualitativa, analisando 80 estudos publicados entre 2010 e 2025, por meio de análise de conteúdo temática. Os resultados indicam que laboratórios virtuais e remotos ampliam o acesso e a segurança na experimentação; a impressão 3D favorece a prototipagem e a integração entre teoria e prática; a IoT apoia a instrumentação, a automação e a análise de dados; e as realidades imersivas aprimoram a visualização e o treinamento seguro. Conclui-se que a integração dessas tecnologias com metodologias ativas, como a Aprendizagem Baseada em Projetos,

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é estratégica para a inovação pedagógica, desde que acompanhada de planejamento curricular intencional e formação docente adequada.

Palavras-chave: Ensino de Engenharia. Tecnologias Digitais. Aprendizagem Ativa. Indústria 4.0. Competências.

RESUMEN
La enseñanza de la ingeniería en el siglo XXI requiere una modernización constante, impulsada por las tecnologías digitales y las demandas de la Industria 4.0. Este artículo investiga cómo las tecnologías emergentes—laboratorios virtuales y remotos, impresión 3D, Internet de las Cosas y realidades inmersivas—contribuyen al aprendizaje activo y al desarrollo de competencias en la enseñanza de la ingeniería. El estudio se basa en una revisión integradora de la literatura, con un enfoque cualitativo, que analiza 80 estudios publicados entre 2010 y 2025 mediante un análisis de contenido temático. Los resultados indican que los laboratorios virtuales y remotos amplían el acceso y la seguridad en la experimentación; la impresión 3D favorece la prototipación y la integración entre teoría y práctica; la IoT apoya la instrumentación, la automatización y el análisis de datos; y las realidades inmersivas mejoran la visualización y el entrenamiento seguro. Se concluye que la integración de estas tecnologías con metodologías activas, como el Aprendizaje Basado en Proyectos, es estratégica para la innovación pedagógica, siempre que esté acompañada de una planificación curricular intencional y de una adecuada formación docente.

Palabras clave: Enseñanza de la Ingeniería. Tecnologías Digitales. Aprendizaje Activo. Industria 4.0. Competencias.

1 INTRODUCTION

The twenty-first century imposes an unprecedented pace of transformation on engineering education, catalyzed by the exponential advance of digital technologies, the globalization of knowledge and the new and dynamic demands of the labor market. This scenario requires higher education institutions to constantly reevaluate and modernize their pedagogical approaches, with a growing focus on innovation, interdisciplinarity, and the promotion of active and meaningful learning (KENSKI, 2012; MORAN, 2018).

Traditionally, engineering education has been marked by expository methodologies and the transmission of content, a model that has been criticized for not keeping up with the rapid pace of technological innovation (FREIRE, 1996; PRINCE; FELDER, 2006). In this context, the strategic incorporation of technological resources emerges as one of the most relevant trends for the contemporary training of engineers. Tools such as virtual and remote laboratories, computer simulation environments, 3D printers, intelligent sensors (IoT), and immersive realities are not mere accessories, but structuring elements capable of fundamentally transforming teaching and learning processes (ABENGE, 2020; FELDER; BRENT, 2016).

The relevance of these technologies lies in their ability to enhance active methodologies, which, in turn, promote student protagonism, the practical application of knowledge, and meaningful learning. As Moran (2018) and Valente (2019) emphasize, the pedagogical use of digital technologies should not be limited to the simple replacement of traditional tools, but rather to the construction of interactive learning environments where the student is challenged to investigate, create, and solve real problems.

Given this conjuncture, the main objective of this article is to investigate and discuss how emerging digital technologies – specifically virtual and remote laboratories, 3D printing, Internet of Things (IoT) and immersive realities – enhance active learning and the development of skills in engineering education. To this end, this study synthesizes theoretical and empirical evidence from an integrative literature review, highlighting the main pedagogical benefits and the ways in which these innovations contribute to an education more aligned with the demands of Industry 4.0.

2 THEORETICAL FRAMEWORK

The theoretical framework underpins the analysis of the pedagogical potential of digital technologies in engineering education from the articulation between digital education, active methodologies and learning theories. The role of emerging technologies — such as virtual and remote laboratories, 3D printing, Internet of Things (IoT) and immersive realities — in promoting active learning and the development of skills aligned with Industry 4.0 is highlighted.

2.1 DIGITAL EDUCATION AND ACTIVE METHODOLOGIES IN ENGINEERING EDUCATION

The digital transformation in engineering education implies more than the adoption of new tools, requiring the review of pedagogical practices and the valorization of student protagonism, autonomy and integration between theory and practice. In this context, active methodologies such as the flipped classroom, Project-Based Learning (PBL) and inquiry-based learning have been consolidated in the Brazilian scenario, as evidenced by Valença (2023).

Empirical studies indicate that the adoption of these methodologies contributes to engagement and learning, including in remote contexts, as demonstrated by Medeiros and Neto (2024) and Damasceno (2022). These results converge with the principles of Education 4.0, which emphasize experimentation, practical learning, and collaboration as formative axes to meet the demands of Industry 4.0 (CARVALHO NETO apud ABENGE, 2025). The literature also points out that emerging digital technologies act as structuring elements of these methodologies, favoring the development of skills such as problem solving, prototyping, data analysis and technical communication.

2.2 FUNDAMENTALS OF LEARNING AND THE ROLE OF TECHNOLOGIES

Active methodologies supported by digital technologies are supported by classical theories of learning. Bloom's taxonomy guides the definition of progressive educational objectives, especially relevant in engineering education, which demand practical application and complex problem solving.

In the cognitive field, strategies such as prior organizers, concept maps, and formative assessments favor meaningful learning. Felder and Brent (2016) highlight the importance of continuous formative assessments, structured feedback, and authentic tasks, often articulated with physical or virtual laboratory activities. The integration between interactive technologies, laboratories and training strategies is, therefore, a central axis to enhance learning and consolidate the technical reasoning of engineering students.

2.3 EMERGING DIGITAL TECHNOLOGIES AND THEIR PEDAGOGICAL POTENTIAL

Engineering education has been driven by the incorporation of digital technologies that expand the possibilities for experimentation, visualization, and the development of practical skills. Each technology contributes in a specific way to the training of the contemporary engineer.

2.3.1 Virtual and remote labs

Virtual (LV) and remote (LR) laboratories have consolidated themselves as relevant alternatives in the face of infrastructure limitations, especially in public institutions. These environments expand access to experimentation, reduce costs and increase safety, in addition to enabling the repetition and personalization of experiments (HERADIO et al., 2016; MENDES et al., 2021). Systematic reviews indicate that the integration of immersive technologies in these laboratories enhances engagement and understanding of complex content (SLR, 2024). Evidence indicates that its effectiveness is amplified when associated with active methodologies and qualified teacher mediation.

2.3.2 3D Printing and Rapid Prototyping

3D printing has stood out as a pedagogical resource for curricular modernization, by allowing rapid prototyping and the development of iterative projects. This technology brings theory and practice closer together, strengthens design thinking, and favors contextualized learning (FLORES; SILVA; OLIVEIRA, 2016; CHONG et al., 2018). Studies demonstrate its applicability in different educational contexts, including during the COVID-19 pandemic (GÓMEZ et al., 2020; KUMAR; JHA; SINGH, 2022), contributing to the development of technical, analytical and collaborative skills.

2.3.3 Internet of Things (IoT)

The Internet of Things (IoT) stands out in engineering education for enabling instrumentation, automation, and real-time data collection activities, in line with the principles of Industry 4.0. Research indicates that IoT expands student autonomy and the practical applicability of knowledge, especially in remote laboratories and multidisciplinary projects (ZUTIN; LOWE; GÜTL, 2018; FAEZIPOUR; KARR, 2018; ZHAO et al., 2020; KIM; PARK, 2023). By enabling the monitoring and analysis of connected systems, IoT contributes to the development of analytical and problem-solving skills.

2.3.4 Immersive Environments and Virtual Reality (VR)

Immersive environments and virtual reality (VR), although still in the consolidation phase, have high pedagogical potential in engineering education. These technologies favor spatial visualization, simulation of complex processes, and safe training in risk scenarios (DEDE, 2009). Recent studies point to improvements in motivation, conceptual understanding and student retention with the use of VR (ALALWAN; ALZAHRANI, 2020; GÓMEZ; MENENDEZ; GARCÍA, 2021). Applications in different areas of engineering, including Software Engineering and Mechanical Engineering, indicate its potential for immersive hands-on experiences and hands-on learning (ANDRADE et al., 2022; ROHR et al., 2022; PEREZ; KELEŞ, 2025).

3 METHODOLOGY

This article is based on an integrative literature review, according to the model proposed by Whittemore & Knafl (2005). The research was designed with a qualitative approach, of a theoretical and documentary nature, with the objective of identifying, analyzing and synthesizing, in a systematic way, the existing evidence on the use of virtual and remote laboratories, 3D printing, Internet of Things (IoT) and immersive realities in engineering education. The main focus was on the context of public higher education institutions, where these resources are strategic to overcome structural challenges and promote pedagogical innovation.

The stages of search, selection, extraction, and synthesis of the data were guided and reported according to the guidelines of the PRISMA 2020 protocol (Page et al., 2021), adapted for integrative reviews, aiming to maximize the transparency and reproducibility of the process. According to Mendes-da-Silva (2019), integrative reviews are particularly effective in articulating different types of studies, providing a comprehensive and comparative understanding of the phenomenon investigated.

3.1 GUIDING QUESTION AND PCC STRATEGY

The review was guided by the following guiding question: How have virtual and remote laboratories been used in engineering education to promote active learning, experimentation and pedagogical innovation in public institutions?

To structure the question, the PCC (Population-Concept-Context) strategy was used:

- Population (P): engineering students and professors;

- Concept (C): virtual and remote laboratories (including related technologies: 3D printing, IoT, VR/AR, simulations);
- Context (C): public institutions of higher education.

3.2 SEARCH STRATEGY

The searches were carried out between January and September 2025 in the following databases: *SciELO, ERIC*, *Scopus*, *ScienceDirect*, *IEEE Xplore,* and *Google Scholar*. To ensure comprehensiveness and relevance, descriptors in Portuguese and English combined with Boolean operators (AND/OR) were used. The general strings used included, among others, the following:

- **Portuguese:**
  ("engineering education" OR "engineering education") AND ("virtual labs" OR "remote labs" OR "virtual learning environments") AND ("active learning" OR "active methodologies" OR "project-based learning")
- **English:**
  ("engineering education") AND ("virtual laboratories" OR "remote labs" OR "virtual experimentation environments") AND ("active learning" OR "project-based learning" OR "problem-based learning")

In addition to these, specific strings and filters were applied by base (summarized examples):

- **SciELO** (search in Jan/2025) — filters: 2010–2025; articles; languages: PT/EN/ES.
- **ERIC** (Feb/2025) — filters: 2010–2025; types: journal article, dissertation, report; language: English.
- **Scopus** (Mar/2025) — filters: 2010–2025; types: article, review, conference paper; languages: PT/EN/ES.
- **ScienceDirect** (Apr/2025) — filters: 2010–2025; article/review; language: English.
- **IEEE Xplore** (May/2025) — filters: 2010–2025; journals/conferences; language: English.
- **Google Scholar** (Sep/2025) — filters: 2010–2025; include citations; exclude patents; PT/EN/ES.

3.3 SELECTION AND ORGANIZATION OF STUDIES

The selection process followed the PRISMA 2020 protocol (Page et al., 2021). The stages were:

1. Identification: initial survey in the selected databases — *n* = 412 records.
2. Screening: removal of duplicates and reading of titles/abstracts; deleted 189 records.
3. Eligibility: full reading of 223 potential studies; 143 were excluded because they did not meet the criteria.
4. Inclusion: final selection of 80 studies that composed the corpus of the analysis.

3.4 INCLUSION CRITERIA

- Published between 2010–2025;
- Peer-reviewed research (with the exception of relevant reports from public universities);
- Studies directly related to engineering education;
- Research on core technologies (LV, LR, 3D printing, IoT, VR/AR, simulations);
- Languages: Portuguese, English and Spanish.

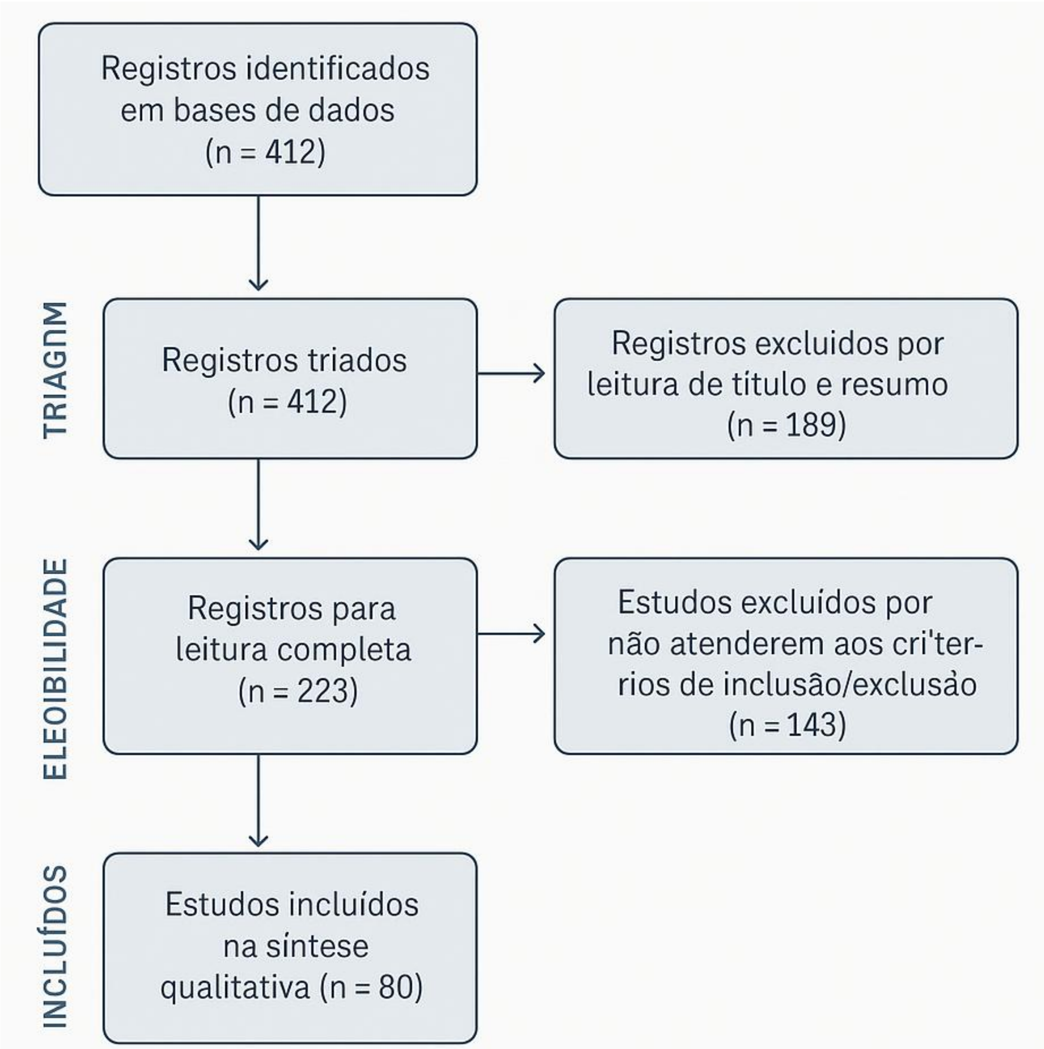
3.5 EXCLUSION CRITERIA

- Publications prior to 2010;
- Productions without peer review (except specific reports from public universities);
- Studies without direct link to engineering education;
- Technologies not related to experimentation or outside the defined scope;
- Texts without access to the full content.

The management of references was performed with *the Zotero®* software; data extraction was recorded in spreadsheets containing, at least: Author, Year, Country, Type of Study, Technology, Method and Main Findings.

Figure 1

PRISMA 2020 flowchart of the study selection process



Source: Authors.

3.6 DATA ANALYSIS

The qualitative analysis of the 80 studies followed the thematic content analysis technique of Bardin (2011), in three phases:

1. **Pre-analysis:** exploratory reading and preliminary organization of the material;
2. **Exploration of the material:** identification and thematic categorization (pedagogical practices, infrastructure, teaching challenges, impact on learning);
3. **Interpretation:** analytical synthesis, identification of emerging trends and integration with the theoretical framework.

The findings were grouped into three analytical categories: (a) pedagogical potential of virtual and remote laboratories; (b) technical and institutional limits and challenges; and (c) implementation strategies in public institutions.

3.7 VALIDITY AND RELIABILITY

Procedures were adopted to ensure methodological rigor, according to Kitchenham (2004) and Whittemore & Knafl (2005):

- Traceability: complete record of search strings, stages and dates of searches;
- Explicit criteria: transparent application of inclusion/exclusion criteria;
- Theoretical triangulation: integration of engineering literature, education and digital technologies;
- Cross-review and divergence resolution: two independent evaluators on screening and eligibility; divergences resolved by consensus, with consultation with a third researcher in deadlocks;
- Systematic record: continuous documentation of all methodological decisions.

4 RESULTS AND DISCUSSIONS

This section presents and discusses the results of the integrative literature review, highlighting the pedagogical potential of emerging digital technologies for active learning and the development of competencies in engineering education. The analysis of the 80 studies published between 2010 and 2025 revealed consistent patterns regarding the effectiveness of these technologies in the training of engineers.

4.1 SELECTION PROCESS AND CHARACTERIZATION OF STUDIES

The selection of studies strictly followed the PRISMA 2020 protocol (PAGE et al., 2021), resulting in the inclusion of 80 articles from an initial universe of 412 publications. There was a significant growth in publications from 2016 onwards, reflecting the consolidation of Industry 4.0 benchmarks and the expansion of the use of digital technologies in engineering education, as highlighted by Heradio et al. (2016) and Zhang et al. (2020).

Geographically, the studies are concentrated in Europe (38%), Latin America (27%), Asia (22%) and North America (13%). In Brazil, scientific production reveals a strong role of public universities, aligned with curriculum modernization policies and the National Curriculum Guidelines for Engineering, according to ABENGE. Initiatives described by

Fernandes Brum, Purcidonio and Azevedo Ferreira (2017) and Mendes, Ferreira and Campos (2021) illustrate this movement.

4.2 DIGITAL TECHNOLOGIES AS CATALYSTS FOR ACTIVE LEARNING

The thematic analysis identified four core technological categories that act as catalysts for pedagogical innovation: virtual and remote labs, 3D printing, IoT, and immersive environments. Although distinct, these technologies converge in the promotion of experimentation, student engagement and the development of skills.

4.2.1 Virtual and Remote Labs (LV/LR)

VL/LR are the most recurrent category, present in 43% of the studies. The literature highlights its ability to expand access to experimentation, reduce costs and risks, and enable repeatable and personalized practices. Empirical evidence points to significant gains in autonomy, motivation and conceptual performance of students (HERADIO et al., 2016; MENDES et al., 2021).

Classic and recent studies emphasize that VL/LR complement physical laboratories, especially when integrated with active methodologies and mediated by qualified professors (BALAMURALITHARA; WOODS, 2009; DE LA TORRE; SANCHEZ; DORMIDO, 2013; SLEEPING; VARGAS; SÁNCHEZ, 2015; NAKAYAMA; YAMAMOTO, 2021; KELLER; MARTINS; SILVEIRA, 2022).

4.2.2 3D Printing and Rapid Prototyping

3D printing appears in 31% of the studies, standing out for integrating theory and practice through iterative cycles of design, modeling, prototyping and testing. This approach strengthens project-based learning, design thinking, and problem-solving (FLORES; SILVA; OLIVEIRA, 2016; CHONG et al., 2018; TORRES et al., 2022).

Applications reported by Gómez et al. (2020) and Kumar, Jha, and Singh (2022) show their effectiveness even in adverse contexts, such as the pandemic, contributing to the development of technical, analytical, creative, and collaborative skills.

4.2.3 Internet of Things (IoT)

IoT was identified in 24% of the studies, mainly in instrumentation, automation, and data analysis activities. The literature highlights its role in collecting data in real time, remotely monitoring systems, and supporting formative evaluations and multidisciplinary projects (ZUTIN; LOWE; GÜTL, 2018; FAEZIPOUR; KARR, 2018; ZHAO et al., 2020; KIM; PARK, 2023).

In addition, recent studies point to the use of IoT as a support for continuous feedback and authentic assessments, strengthening active learning and data-driven decision-making (FERREIRA; OLIVEIRA; MATOS, 2019; ABREU; MACHADO; TORRES, 2024; PADILLA et al., 2025).

4.2.4 Immersive Environments and Virtual Reality (VR)

Although less frequent (12% of studies), VR demonstrates a high pedagogical impact, especially in spatial visualization, simulation of complex processes, and safe training in risk scenarios (DEDE, 2009; ALALWAN; ALZAHRANI, 2020; GÓMEZ; MENENDEZ; GARCÍA, 2021).

Research in different areas of engineering indicates increased motivation, better conceptual understanding, and support for practical learning, including applications in Software Engineering and Mechanical Engineering (ANDRADE et al., 2022; ROHR et al., 2022; PEREZ; KELEŞ, 2025; KELEŞ; PEREZ, 2025).

4.3 INTEGRATION WITH ACTIVE METHODOLOGIES AND SKILLS DEVELOPMENT

The studies analyzed converge in indicating that digital technologies act as facilitators of active methodologies, and not as ends in themselves, corroborating Moran (2018) and Kenski (2012). Its integration enhances approaches such as PBL, flipped classroom, and inquiry-based learning (VALENÇA, 2023; FERREIRA; OLIVEIRA; MATOS, 2019; MEDEIROS; NETO, 2024).

This articulation contributes directly to the development of essential competencies of contemporary engineering, such as complex problem solving, iterative prototyping, data analysis, collaborative work, and technical communication (CHONG et al., 2018; KIM; PARK, 2023; MENDES et al., 2021; VALENTE, 2019). Such competencies are essential to meet the demands of Industry 4.0 (SPINELLI; LEMOS; BARBOSA, 2022).

4.4 INTEGRATED DISCUSSION

The results indicate that engineering education is at a turning point, in which emerging digital technologies play a central role in redefining the learning experience. The predominance of LV/LR confirms its consolidation as an effective solution for experimentation, while the growing adoption of 3D printing, IoT and VR signals the evolution towards more immersive and contextualized environments.

The pedagogical potential of these technologies lies in their ability to enable active learning, promoting student protagonism and the integration between theory and practice. However, studies reinforce that its benefits depend on intentional curriculum planning and articulation with active methodologies. Thus, the synergy between digital technologies and innovative pedagogical approaches emerges as the most promising path for a relevant engineering education aligned with the challenges of the twenty-first century.

5 CONCLUSION

This integrative review delved into the transformative pedagogical potential of emerging digital technologies—virtual and remote labs (LV/LR), 3D printing, Internet of Things (IoT), and immersive realities (Virtual/Augmented Reality)—in engineering education. Our primary focus was to understand how these tools promote active learning and the development of core competencies, positioning future engineers for the complex and dynamic challenges of Industry 4.0.

The results consolidate the evidence that digital technologies significantly expand access to experimentation, providing safe, flexible and often more cost-efficient learning environments. LV/LR, in particular, allow continuous (24/7) and personalized access to practice, overcoming geographical and structural barriers. 3D printing, in turn, enables rapid prototyping, fluidly integrating theory and practice and fostering iterative design. IoT emerges as an indispensable pillar for instrumentation, automation, and real-time data collection, aligning student training with the demands of intelligent systems and data analysis. Concurrently, virtual reality provides immersive experiences that substantially enhance spatial visualization and enable safe training in high-risk scenarios, without the implications of the actual physical environment.

The integration of these technologies with active methodologies is not only a crucial factor, but a symmetrical and enhancer factor. They act as powerful facilitators for approaches such as Project-Based Learning (PBL) and the flipped classroom, in which the student transcends the role of mere receiver, becoming an active protagonist of his or her learning process, engaging in real problem solving, experimentation, and creation. This synergy robustly fosters the development of a set of multidisciplinary competencies indispensable for the modern engineer, including the ability to solve complex problems, expertise in prototyping and iterative design, proficiency in data analysis and interpretation, the ability to work collaboratively in multidisciplinary teams, and effective technical communication.

However, the full realisation of this potential is intrinsically linked to overcoming significant institutional and structural challenges.

The review highlighted persistent barriers such as insufficient teacher training for the new tools and methodologies, limitations in the technological infrastructure of institutions, and the urgent need for robust institutional policies that ensure the democratization of access and the sustainable integration of these innovations. Addressing these issues, especially in public institutions, is critical to ensuring the equity and quality of engineering education in the country.

In short, the answer to the question that guided this study is affirmative and multifaceted: emerging digital technologies are undeniably strategic and powerful resources for pedagogical innovation in engineering education. They enhance active learning and the development of skills, creating more dynamic, engaging learning environments aligned with the complex demands of the twenty-first century.

However, its enduring success requires not only technological adoption, but also intentional curriculum planning, continued investment in teacher training, and the development of institutional policies that promote articulation with collaborative practices and comprehensive formative assessment, ensuring that technology serves as a strategic means to well-defined educational objectives and to the training of professionals able to innovate and lead.

5.1 STUDY LIMITATIONS

It is important to recognize that this article, being derived from an integrative review, inherits some of the limitations intrinsic to the original research. The methodological heterogeneity of the included studies—although characteristic of this type of review—and the restriction of the search to indexed databases may have influenced the breadth and depth of the evidence collected, potentially omitting other relevant experiences.

In addition, the temporality of the data (2010-2025) means that very recent innovations may not yet have been fully incorporated into the literature analyzed here, suggesting a field in constant evolution.

5.2 IMPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The findings of this study have significant implications for educators, academic managers, and public policy makers. For educators, we suggest broader and more informed adoption of digital technologies, with an unwavering focus on their synergistic integration with active methodologies. For academic managers, the urgency of investing in the continuing education of teachers and in the improvement and maintenance of technological infrastructure is emphasized. For policymakers, it is crucial to develop strategies that mitigate regional and institutional inequalities while ensuring equitable access to these resources.

For future research, we recommend:

The realization of longitudinal empirical studies that evaluate the long-term impact of these technologies on the development of engineering skills and on the professional trajectory of graduates.

In-depth comparative analyses between different types of institutions (public vs. private, large vs. small) to understand the nuances of implementation and the specific challenges faced.

Research focused on teacher training, investigating the most effective strategies to train teachers in the pedagogical and methodological use of these technologies.

Detailed case studies on the implementation of successful institutional policies for the integration of digital technologies, identifying replicable models.

The exploration of other emerging technologies or the combination of multiple technologies in engineering learning environments, deepening the understanding of the mechanisms that enhance complex learning.

By addressing these gaps and following these recommendations, the scientific community and educational institutions will be able to contribute even more significantly to the advancement of engineering education, ensuring that future generations of professionals are fully equipped for the technological and societal challenges of the 21st century.

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