REVISTA INVECOM
ISSN en línea: 2739-0063

Educational innovation in the training of engineers within the framework of Education 4.0

Innovación educativa en la formación de ingenieros en el marco de la Educación 4.0

Received: 30/05/2025 - **Accepted:** 23/10/2025

David Ramos Piñas
https://orcid.org/0000-0002-4215-2374
d.dramos@ms.upla.edu.pe
Universidad Peruana Los Andes. Huancayo, Peru

Lipselotte de Jesús Infante Rivera
https://orcid.org/0000-0001-6094-1070
linfante@continental.edu.pe
Universidad Adventista de Chile. San Juan de los Morros, Venezuela

Abstract
This study analyzed educational innovation in the training of civil engineers in the context of Education 4.0. To this end, a documentary and content analysis methodology was applied, allowing for a systematic examination of 18 documents selected after applying exclusion criteria to an initial total of 59. The main results indicate that educational innovation within the framework of Education 4.0 is characterized by the increasing integration of advanced technologies, such as artificial intelligence, virtual reality, virtual laboratories, and digital platforms. These tools facilitate more collaborative and personalized learning. It is concluded that the success of educational innovation depends on a comprehensive approach that articulates technology, pedagogy, and institutional management. Furthermore, it is essential to promote collaboration between academia, industry, and society to train civil engineers capable of leading the digital transformation and facing current challenges with solid skills and a multidimensional vision. In this way, the training capacity to respond to the demands of the contemporary environment is strengthened.

Keywords: Education 4.0, training, civil engineering, educational innovation.

Resumen
El presente estudio analizó la innovación educativa en la formación de ingenieros civiles en el contexto de la Educación 4.0. Para ello, se aplicó una metodología de análisis documental y de contenido que permitió examinar, de manera sistemática, 18 documentos seleccionados tras aplicar criterios de exclusión a un total inicial de 59. Los principales resultados indican que la innovación educativa bajo el marco de la Educación 4.0 se distingue por la integración creciente de tecnologías avanzadas, tales como la inteligencia artificial, la realidad virtual, laboratorios virtuales y plataformas digitales. Estas herramientas facilitan un aprendizaje más colaborativo y personalizado. Se concluye que el éxito de la innovación educativa depende de un enfoque integral que articule tecnología, pedagogía y gestión institucional. Además, es fundamental promover la colaboración entre academia, industria y sociedad para formar ingenieros civiles capaces de liderar la transformación digital y enfrentar los desafíos actuales con competencias sólidas y una visión multidimensional. De este modo, se fortalece la capacidad formativa para responder a las demandas del entorno contemporáneo.

Palabras clave: Educación 4.0, formación, ingeniería civil, innovación educativa.

Introduction
Innovating in education entails proposing new methodologies for imparting knowledge; it goes beyond merely planning content and involves modifying and enhancing the structure of its components. From a global perspective, educational innovation is recognized as one of the essential demands of the 21st century to address

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the crises faced by educational systems worldwide (Kuril et al., 2023). By conceptualizing innovation as a systemic phenomenon, we can develop a more precise understanding of this trend, informed by the diverse contributions of authors who have elaborated on the concept over recent decades (Valdés & Gutiérrez-Esteban, 2023).

In the educational realm, innovation is defined as a product, process, organizational method, or a completely new or significantly improved structure developed by higher education institutions or other stakeholders associated with this level of education, which substantially impacts their activities (Menzli et al., 2022). The introduction of new high-quality content, courses, and study materials is instrumental in preparing graduates for enhanced opportunities in the labor market (Buganová & Lusková, 2015).

The results from the recent study conducted by the authors indicate that, according to the surveys administered, most graduates from the Faculty of Engineering Specialization express satisfaction with the competencies and knowledge acquired during their training. However, there remains ample room for improvement in teaching quality and for strengthening the alignment with professional practice requirements. The incorporation of innovative elements into the educational process, along with the integration of e-learning, the publication of study materials, and the execution of research activities, contributes to the establishment of a modern and effective educational environment, aimed at responding to the needs of both society and the labor market (idem).

The demand for innovation in university processes necessitates adaptability to recent changes. It is crucial to modify both strategies and curricula to train professionals who can respond to contemporary realities, wherein Education 4.0 represents a new paradigm replacing traditional models and methods. This paradigm integrates the disruptive changes of Industry 4.0 through machine learning, artificial intelligence, and Internet of Things (IoT) technologies, thereby driving innovation and enhancing efficiency (Jain et al., 2025).

Key educational technologies related to Education 4.0 include the creation of technological platforms, cooperation among elements of the innovation system, the use of open educational resources, and the implementation of modern teaching and learning strategies (Akimov et al., 2023). A study focusing on the role of large language models as virtual tutors in chemical engineering concluded that AI should be employed to support faculty, allowing them to optimize their time and concentrate on educational quality and other pertinent activities (Caccavale et al., 2024).

Currently, the digital transformation in the construction industry poses a challenge for civil engineering education. Both students and society tend to underestimate this discipline, viewing it as outdated and lacking in innovation. However, despite the fragmentation and heterogeneity of the sector, significant advancements have been made, bringing construction closer to the paradigms of Construction 4.0 and 5.0 (Calvetti et al., 2024).

In the evolution from Education 1.0 to Education 3.0, the focus was on the instructor as the primary source of knowledge. Education 2.0 introduced tools such as electronic calculators and distance education via mail, while Education 3.0 emphasized the use of computers, the internet, online teaching, and active methodologies. Finally, Education 4.0 disrupts this logic by placing the student at the center of the learning process, prioritizing competencies and active methodologies supported by digital technologies as tools for learning and educational management (Akturk et al., 2022; Miranda et al., 2019; Srivani et al., 2022).

Within this context, it is evident that innovation in education is closely linked to Education 4.0, which is particularly suitable for the current educational realities of students, especially in the specific training of civil engineers. Engineering plays a vital role in addressing the major social challenges facing humanity, making it essential for engineers to understand these issues and recognize the impact of their solutions. In this regard, higher education bears a crucial responsibility in nurturing future engineers as true agents of transformation (Alcorta et al., 2023).

A study conducted in Brazil by Sigahi and Sznelwar (2023) identified emerging themes related to engineering education aimed at sustainable development, linking them to specific cases. The transition towards a sustainability paradigm in engineering education depends on the commitment of university leadership and could be accelerated by integrating initiatives at various levels within the university system. This suggests that being a professional engineer necessitates the capabilities to tackle complex challenges, resolving them with the skills acquired during training.

Concerning Education 4.0, it is important to highlight that technology serves as its foundational pillar and a principal factor driving recent educational advancements. Specifically, virtual reality emerges as a valuable tool to enhance students' cognitive development. Research by Henstrom et al. (2024) illustrates the vast potential of virtual reality to transform educational opportunities, recommending its adoption and prioritization as an effective and viable academic tool. These findings suggest that virtual reality can enrich the learning process in civil engineering, making collaborative virtual inspections of buildings more efficient and engaging.

To provide comprehensive and advanced training, it is advisable to incorporate new educational technologies underpinning Education 4.0. For instance, the use of smart materials such as shape memory alloys,

hydrogels, and biological substrates offers significant educational potential, as these materials adapt to their environment and enable dynamic structures that respond to changing environmental conditions (Firoozi & Firoozi, 2023).

Research like that conducted by Ubowska and Królikowski (2024) concludes that when implementing higher education programs, it is crucial to utilize tools tailored to national and regional socioeconomic needs. The integration of modern computational solutions into curricula is well-received by students, who recognize their utility for solving engineering tasks. This is particularly vital in engineering education, as the use of new technologies supports the achievement of goals and enables successful navigation of daily challenges in the construction field.

In Italy, a study concluded that educational systems must update their training programs to meet the emerging demands of the labor market (Spada et al., 2022). Additionally, Kleine and Pessot (2024) explored how laboratories can be virtualized and structured to support engineering education, adopting an innovative perspective that views laboratories as central assets for teaching and learning. Furthermore, the results of Diogo et al. (2023) emphasize that Educational Technology and Intelligent Education are fundamental pillars for preparing engineers capable of facing the challenges and opportunities brought about by digital transformation.

Finally, Brozovsky et al. (2024) underscore the increasing need for collaboration between industry and academia, particularly in the realm of Construction 4.0 technologies. They also highlight the urgency of integrating these technologies into education, challenging academic institutions to rethink their collaborative approaches and the very essence of their teaching methodologies. This underscores the importance of adopting educational innovation within the university system to address critical issues in construction, one of the most significant areas within civil engineering.

In light of the above, the present study aims to analyze how educational innovation has developed within civil engineering training in the context of Education 4.0, seeking to provide an updated and innovative perspective that promotes the use of new technologies for developing the competencies and skills necessary to effectively tackle the challenges inherent to the engineering domain.

Methodology

The methodology centered on a qualitative content and document analysis. Through this approach, relevant documents related to educational innovation in the training of engineers within the framework of Education 4.0 were examined. Articles published within the last ten years were selected from both Spanish and English databases, applying inclusion criteria to ensure their relevance and currency. Subsequently, the documents were organized and coded to extract key categories previously defined, such as digital technologies, active methodologies, developed competencies, infrastructure and educational resources, as well as institutional impact and challenges.

During the analysis, relevant excerpts within each category were identified and classified through an iterative process of reading and synthesis to interpret significant patterns and trends. To ensure the validity and reliability of the results, document triangulation and peer review were employed, meticulously recording the coding and methodological decisions.

Document triangulation

To enhance validity and reliability, document triangulation was carried out, utilizing various sources to contrast, complement, and enrich findings. A total of 20 documents were collected, of which 18 were analyzed, including:

- Scientific articles and systematic reviews that provide experimental and theoretical evidence, such as the works by Akimov et al. (2023), Caccavale et al. (2024), and Diogo et al. (2023).
- Case studies and institutional experiences addressing the adoption of technologies and active methodologies in educational innovation: Brozovsky et al. (2024), Henstrom et al. (2024), Kleine & Pessot (2024).
- Reports and normative texts reflecting educational policies and guidelines for curricular transformations in engineering: Menzli et al. (2022), Valdés & Gutiérrez-Esteban (2023).
- Documents related to the development of competencies and social and labor demands: Buganová & Lusková (2015), Alcorta et al. (2023).

These sources facilitated a comparison of different approaches, identifying convergences and divergences in practices, and evaluating the robustness of their conclusions. The triangulation minimized the risk of biases

stemming from limited or homogeneous analyses, thereby enhancing the objectivity and depth of the study, ensuring that the results reflect a broad and updated perspective on Education 4.0 in civil engineering.

Peer review

To ensure the quality, academic rigor, and relevance of the interpretations, the manuscript was subjected to external peer review by experts recognized in education, engineering training, and educational technologies. The reviewers evaluated key aspects such as:

- Clarity and coherence in the introduction of the article.
- Adequacy and detailed description of the methodology, particularly in document analysis and thematic categorization.
- Rigor in the selection, coding, and analysis of documentary sources, as well as in the triangulation process.
- Well-founded interpretation of the results, linking them with the literature and principles of Education 4.0.
- Relevance and applicability of the conclusions for improving curricular designs and innovative educational practices in civil engineering.

The feedback received contributed to enhancing the narrative structure, clarifying the criteria for document selection, and strengthening the critical analysis in the discussion. Additionally, it emphasized the importance of highlighting teacher training and institutional management to implement Education 4.0 more effectively in civil engineering education.

Results

From a total of 59 documents retrieved from the ScienceDirect database, 18 scientific and academic documents published between 2015 and 2025 were selected for analysis after applying exclusion criteria. These studies focus on educational innovation and the implementation of Education 4.0 in engineering training, particularly in fields such as civil, chemical, and environmental engineering, with a notable emphasis on the strengths of civil engineering, which was the primary case of this analysis.

Table 1

Thematic categories and findings from the document analysis of 18 studies on Education 4.0 in engineering

Category	Most representative documents	Key findings	Number of documents with relevant evidence	Total selected
Applied digital technologies	Akimov et al. (2023), Caccavale et al. (2024), Henstrom et al. (2024), Ubowska & Królikowski (2024)	Intensive use of AI, virtual reality, simulators, and digital platforms that facilitate personalized and collaborative learning.	15	4
Active methodologies and strategies	Akturk et al. (2022), Diogo et al. (2023), Miranda et al. (2019), Kuril et al. (2023)	Growing implementation of project-based, problem-based, and gamification learning, placing the student at the center of learning.	13	4
Competency development	Buganová & Lusková (2015), Srivani et al. (2022), Sigahi & Sznelwar (2023), Alcorta et al. (2023)	Emphasis on digital, transversal, and sustainability competencies aligned with the demands of Education 4.0.	12	4

Infrastructure and educational resources	Kleine & Pessot (2024), Spada et al. (2022), Jain et al. (2025)	Need for virtual laboratories, open resources, and curriculum adjustments to integrate 4.0 technologies and methodologies.	10	3
Institutional impact and challenges	Menzli et al. (2022), Brozovsky et al. (2024), Valdés & Gutiérrez-Esteban (2023)	Variable recognition of educational innovation in universities; challenges in faculty training and institutional alignment.	9	3

Source. Authors' own elaboration

Table 1 summarizes the five main thematic categories identified in the document analysis of the 18 reviewed studies. For each category, representative documents, key findings, and the number of studies that provided relevant evidence are indicated. The analysis illustrates that educational innovation and Education 4.0 in engineering training address technological, methodological, competency-related, resource-based, and institutional challenges.

In terms of the technological component, AI and VR emerge as widely utilized technologies within Education 4.0. They have successfully been applied in virtual tutoring and immersive practices that significantly enhance learning (Caccavale et al., 2024; Henstrom et al., 2024). The recurrent use of digital platforms and simulators also facilitates new forms of evaluation and collaboration (Akimov et al., 2023; Ubowska & Królikowski, 2024).

Regarding the pedagogical component, a broad adoption of active methodologies such as project-based and problem-based learning stands out, positioning the student as the protagonist of the process. This promotes autonomy and develops critical skills essential for addressing the challenges of modern engineering (Akturk et al., 2022; Kuril et al., 2023). In many instances, these methodologies are combined with technological resources to enhance the students' learning experience (Diogo et al., 2023; Miranda et al., 2019).

Concerning competency development, the reviewed documents consistently highlight the integration of digital skills, critical thinking, sustainability, and entrepreneurship as key elements that Education 4.0 promotes for cultivating professionals who are more adaptable and aware of the social impact of their work (Buganová & Lusková, 2015; Alcorta et al., 2023; Sigahi & Sznelwar, 2023). However, a significant gap remains in both physical and digital infrastructure and educational resources, which still require improvements. In this regard, there is a strong emphasis on the need to virtualize laboratories and update curricular content to keep them aligned with and at the forefront of technological advancements (Kleine & Pessot, 2024; Spada et al., 2022).

Finally, several institutional challenges were identified, stemming from the need for broader and more effective faculty training, the promotion of changes in institutional culture, and fostering a more coordinated integration between academia and industry. These actions are fundamental to ensuring the sustainability of innovation within Education 4.0 (Brozovsky et al., 2024; Menzli et al., 2022).

Table 2

Summary of key technologies and methodologies in Education 4.0 applied to engineer training

Technology / Methodology	Brief description	Observed benefits	Key references
Artificial Intelligence (AI)	Large language models as virtual tutors	Teaching support, personalization, time savings	Caccavale et al. (2024), Jain et al. (2025)
Virtual Reality (VR)	Immersive simulations for inspections and practical training	Improved motivation and comprehension	Henstrom et al. (2024)
Project-Based Learning (PBL)	Design and execution of multi-competency projects	Holistic development, critical thinking	Akturk et al. (2022), Miranda et al. (2019)

Problem-Based Learning (PBL)	Solving complex real-world problems	Fosters autonomy and research	Kuril et al. (2023), Diogo et al. (2023)
Virtual Laboratories	Virtualized spaces for experimentation	Increased access and flexibility, better curricular integration	Kleine & Pessot (2024)
Digital Platforms and Open Educational Resources	Accessible resources and tools for learning	Facilitate collaboration and continuous updates	Akimov et al. (2023)

Source. Authors' own elaboration

Table 2 summarizes the key technologies and methodologies associated with Education 4.0 that are applied in civil engineering education and related fields. For each technology or methodology, a brief description, observed benefits in educational application, and the main references supporting their use and effectiveness are presented. It is clear that the integration of digital tools and active pedagogical approaches are central elements in the educational transformation toward Education 4.0.

Discussion

The results indicate significant advancements in the use of digital technologies, active methodologies, and the development of competencies that respond to 21st-century demands. Studies such as that by Akimov et al. (2023) highlight the relevance of competency frameworks in open innovation, considering technical and digital skills, autonomous learning, critical thinking, and interdisciplinary collaboration as fundamental elements. This process not only involves the incorporation of new technologies but also necessitates transforming institutional culture to promote flexible, adaptive, and student-centered learning environments.

Regarding emerging technologies and their impact on education, the literature demonstrates that the integration of AI, virtual laboratories, and immersive environments like virtual reality significantly enhances educational experiences in engineering. For instance, research by Caccavale et al. (2024) shows that the use of AI-based virtual tutors facilitates personalized learning, fosters student autonomy, and enables real-time monitoring. Similarly, Henstrom et al. (2024) emphasize that virtual reality enhances motivation, spatial understanding, and the effectiveness of practical experiences in civil engineering by enabling the simulation of complex, collaborative scenarios that many in-person programs cannot provide.

The contributions of Kleine and Pessot (2024) regarding the virtualization of laboratories confirm that these resources help overcome geographical and logistical barriers, ensuring safe, repeatable, and context-aware practices in digital engineering projects. On the other hand, Diogo et al. (2023) highlight that digital transformation also poses an organizational challenge requiring academic leadership, resource investment, and faculty capacity development oriented towards the innovative use of new tools.

Concerning active methodologies such as project-based and problem-based learning, these are closely linked to the 4.0 paradigm, emerging as key strategies for developing transversal and technical competencies. Akimov et al. (2023) and Miranda et al. (2019) indicate that these methodologies are strengthened when integrated with digital tools, facilitating collaboration, creativity, and the resolution of complex engineering problems. However, challenges persist related to aligning curricula with social demands, designing authentic experiences, and providing teacher training oriented toward technology, as noted by Brozovsky et al. (2024) and Buganová and Lusková (2015).

Finally, barriers were identified, such as institutional inertia, inequality in access to digital resources, resistance to change, and the need for professional development for educators. Consequently, research by Valdés and Gutiérrez-Esteban (2023) emphasizes the importance of educational policies that foster innovation ecosystems and effective change management strategies.

Conclusions

Educational innovation in the training of civil engineers within the framework of Education 4.0 is characterized by the systematic integration of advanced digital technologies, such as artificial intelligence, virtual reality, and collaborative learning platforms, which, alongside active methodologies, place the student at the center of the educational process. This transformation brings about a profound shift in training processes, oriented toward

technical mastery as well as the development of transversal competencies, problem-solving capabilities, and adaptability to dynamic and multi-technical contexts.

The document review and content analysis revealed a considerable advancement in the adoption of these innovative technologies and methods. However, significant challenges remain concerning curriculum updates, ongoing teacher training, and institutional technological infrastructure, essential aspects for consolidating an effective and transformative educational model.

The data collected demonstrate that educational innovation under Education 4.0 enhances student motivation and engagement through the use of virtual simulations, remote laboratories, and challenge-based projects that integrate theory with professional practice. Additionally, the alignment with social demand, sustainability, and digitalization in the construction sector fosters a more contextualized and relevant training for contemporary civil engineers.

Ultimately, it is crucial to emphasize that the success of educational innovation relies on a comprehensive approach that integrates technology, pedagogy, and institutional management, promoting collaboration between academia, industry, and society. Only by doing so can we train civil engineers capable of leading digital transformation and addressing current challenges with solid competencies and a multidimensional vision.

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AUTHORSHIP CONTRIBUTION

1. Conceptualization: Lipselotte de Jesús Infante Rivera
2. Data curation: David Ramos Piñas
3. Formal analysis: David Ramos Piñas
4. Funding acquisition: David Ramos Piñas
5. Research: David Ramos Piñas
6. Methodology: Lipselotte de Jesús Infante Rivera
7. Project administration: David Ramos Piñas
8. Resources: David Ramos Piñas
9. Software: David Ramos Piñas
10. Supervision: Lipselotte de Jesús Infante Rivera
11. Validation: David Ramos Piñas
12. Visualization: Lipselotte de Jesús Infante Rivera
13. Writing – original draft: Lipselotte de Jesús Infante Rivera
14. Writing – proofreading and editing: Lipselotte de Jesús Infante Rivera