Engineering Education in Industry 5.0: Competency Development and Learning Environment Strategies - A Systematic Review

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Abstract
To identify the competencies that can be developed in engineering students to address the challenges of Industry 5.0 and to demonstrate how learning environments can prepare to foster these competencies. Due to the lack of clarity in existing literature, this research aims to identify the competencies and how engineering education may be preparing to confront the evolution of Industry 5.0. A systematic literature review was conducted using the Proknow-C methodology, covering publications from 2000 to 2023 in the Scopus and Web of Science databases. After filtering, the selected articles were analyzed and compared to fulfill the study's objective. This research identified a bibliographic portfolio of relevant works on the topic of Engineering Education in Industry 5.0, extracting key competencies that can be developed in students. It also identified some characteristics of learning environments for this context. With each industrial revolution, new competencies need to be developed in engineering students. To keep pace with these transformations, engineering learning environments must be prepared to cultivate human capital. This research identified a bibliographic portfolio that enabled the identification of key competencies that can be developed in engineering students within the context of Industry 5.0, contributing to educational institutions in incorporating these references into the training of these professionals.

Keywords: Industry 5.0, Engineering Education, Competencies, Systematic Literature Review.

Introduction

Technology is changing the way companies and society relate and learn. According to Rodríguez-Abitia and Bribiesca-Correia (2021), the fourth industrial revolution has intensified digital transformation. As a result, the newest members of today's society—the new generations—are born and raised in digital environments. Like any ordinary citizen, they also use technology for various purposes, whether at work or in social interactions. In this context, the authors emphasize the need for a new type of education to meet the new way of learning in Society and Industry 5.0.

For Broo et al. (2022), engineering course curricula are not adequately preparing students for the realities of the market. Social, environmental, economic, artificial intelligence, ethics, trust, human-machine interaction, and their social implications are not yet integrated into the teaching. Therefore, education in ethical and value-oriented engineering technology in Industry 5.0 is an urgent and sensitive topic (Longo et al., 2020).

According to Magaldi and Neto (2018), the transformation process occurs through people, with education being one of its most relevant vectors. For the movement to materialize in practice, individuals need to understand the dynamics of the changes and be educated according to this new reality.

In this context, the research question arises: How can engineering education environments prepare for the context of Industry 5.0? The objectives of this research are: (i) to select a significant bibliographic portfolio of literature on engineering education in Industry 5.0; (ii) to conduct a bibliometric analysis of the portfolio; (iii) to analyse the content of articles to identify the competencies and how educational environments should be prepared for Industry 5.0.

Engineering Education

The definition of engineering is provided by the U.S. accreditation body, the Accreditation Board for Engineering and Technology (Abet, 2021): Engineering is the profession in which knowledge of the mathematical and natural sciences acquired through study, experience, and practice is applied with judgment to develop ways to economically use the materials and forces of nature for the benefit of humanity.

According to Bourne et al. (2019), engineering education is traditionally a cornerstone of content-centered, practical, and design-oriented teaching, with a particular focus on the development of analytical thinking skills (Bourne et al., 2019). Various tools and methodologies, such as active learning (Lima et al., 2017), project-based learning (Mills and Treagust, 2003), flipped classroom (Bishop and Verleger, 2013), etc., are available to educators to enhance effectiveness in engineering education.

Hernandez-de-Menendez et al. (2020) state that Industry 4.0 and Industry 5.0 will require professionals with new profiles. They will need to be more qualified in managing complex production systems, and they will also need to be more creative, strategic, and coordinated.

Industry 5.0 and Society 5.0

In 2017, the concept of Society 5.0 was introduced by Japan, defining it as a human-centered society that balances economic advancement with solving social problems through a system that highly integrates cyberspace and physical space (Cabinet Office, 2022).

In 2021, the European Commission formalized the concept of the fifth industrial revolution (I 5.0: Industry 5.0 or Society 5.0) after extensive discussions with research and technology organizations. The process began with the official publication of a document titled "Industry 5.0: Towards a sustainable, human-centered, and resilient European industry" (Breque and Nul, 2021; Mazur and Walczyna, 2022). This document followed earlier attempts to introduce the fifth industrial revolution since 2017. The introduction of the Industry 5.0 concept resulted from the assessment that Industry 4.0 focused more on digitization and AI-based technologies and less on the original principles of social justice and sustainable development (DS) (Xu et al., 2021).

According to Doyle (2021), I 5.0 focuses on the following fundamental elements: the human being, sustainability, and the ability of a system to maintain essential functions and processes under stress, resisting and then recovering or adapting to changes (resilient system). I 5.0 will create relationships between systems of different classes and technological configurations associated with I 4.0 that are interconnected for mutual benefit and among qualified operators (symbiotic relationship between technology and humans). This aims to create workplaces and environments where humans are at the center of work and capable of generating high-value, high-quality, and customized products. While I 4.0 is characterized by the implementation of cutting-edge technologies leading to better and higher performance, I 5.0 seeks to establish highly cooperative relationships of a synergistic nature between enhanced production systems with new technologies and social systems, aiming for more personalized and massive production of parts, products, solutions, and services (Bednar and Welch, 2019). I 5.0 should be considered in the training of current engineers, as, like I 4.0, I 5.0 represents technological changes and challenges in businesses and society in general.

According to Xun et al. (2021), I 5.0 is not only about comprehensive cooperation between cybernetic machines and humans but also involves aspects of sustainability and social considerations. The I 5.0 paradigm promotes the recognition that companies have the power to achieve broader social objectives beyond the benefits of labor and economic growth. They can be resilient and prosperous providers, allowing production systems to respect the planet's limits and placing workers at the center of production.

The current understanding of Industry 5.0 brings a human touch back to industry. It also involves the incorporation of Artificial Intelligence into human operations to enhance human capacity. The core of Industry 5.0 is the harmony between machines, humans, values, tasks, and ultimately, knowledge and skills that result in personalized/individualized products and services (Leng et al., 2022).

Methodology

The method used for selecting the theoretical framework and constructing the knowledge necessary for the research was the Proknow-C (Knowledge Development Process – Constructivist), proposed by Ensslin et al. (2010). This method consists of a series of steps and procedures, resulting in a bibliographic portfolio with articles relevant to the research topic (Afonso et al., 2011). The method is divided into two main phases, with the first focusing on the selection of the raw article database, and the second on the article filtering process. The first phase can be observed in Figure 1.

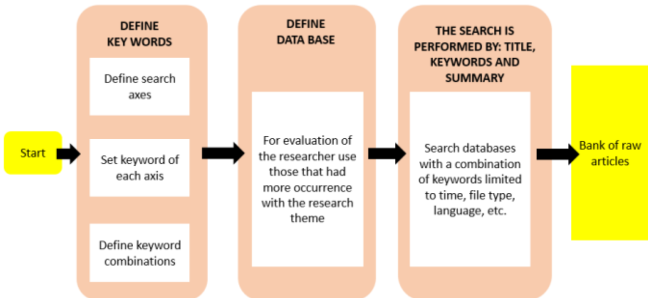

Figure 1. First phase of the Proknow-C method. Source: Ensslin et al. (2010).

Two research axes were defined, labeled "engineering education" and "Industry 5.0." For the "Industry 5.0" axis, two keywords were chosen: "Industry 5.0" and "Society 5.0." The same keyword was used for the "engineering education" axis. The search was conducted on two databases: Web of Science and Scopus, using the proposed keyword combinations and searching the fields of title, abstract, and keywords. The searches were conducted on works published between 2000 and 2023, focusing on journal articles and conference papers.

In the second phase, the process of filtering the raw article database begins, as illustrated in Figure 2.

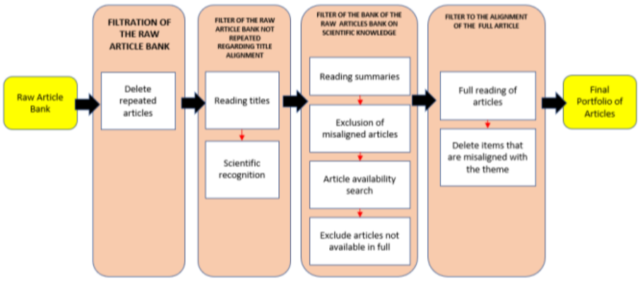

Figure 2. Second phase of the Proknow-C method. Source: Ensslin et al. (2010).

The filtering of the raw article database begins with the exclusion of duplicate articles. The second step involves reading the titles of the articles. Subsequently, the scientific recognition of the articles is verified. This starts with checking the number of citations each article has on Google Scholar. Afterward, the abstracts of the articles are read to make a selection based on the alignment with the research theme, deciding whether to keep or discard them. Following this, the selected articles are read in full. Those that align with the research theme become part of the bibliographic portfolio (ENSSLIN et al., 2010).

Results

The process yielded a gross total of 2,753 articles, with 93 found in the Scopus database and 2,660 in the Web of Science database. Of these, 239 duplicates were excluded. Next, the titles of the remaining 2,514 articles were read to assess their alignment with the research theme, resulting in 83 articles. The following step involved identifying the scientific recognition of the articles, resulting in 66 most-cited articles, accounting for 79.5% of the citations. Afterward, abstracts were read, resulting in 47 articles. Articles with unconfirmed scientific recognition totaled 17, which underwent a new filter for selection. Figure 3 illustrates the filtering process of the Proknow-C methodology.

After filtering out articles with lower scientific recognition, 3 more articles were added to the 47 for which abstracts were read, making a total of 50 articles for checking the availability of the full document. After this verification, 35 articles remained for a thorough reading to confirm alignment with the research theme. After the complete reading, 19 articles remained, representing the bibliographic portfolio on engineering education in Industry 5.0, as shown in Table 1.

A bibliometric analysis of the articles in the bibliographic portfolio was conducted to extract information about the research. One of the analyses performed was the total number of publications per year, as depicted in Figure 3.

Research on engineering education in Industry 5.0 began in 2020, reaching its peak in 2022 with 10 published articles. In 2023, only one research article appeared in the bibliographic portfolio, indicating that it is a recent and rapidly expanding research area with ample opportunities for new discoveries.

Another analysis conducted was the total number of publications by country of origin. The results are presented in Figure 4.

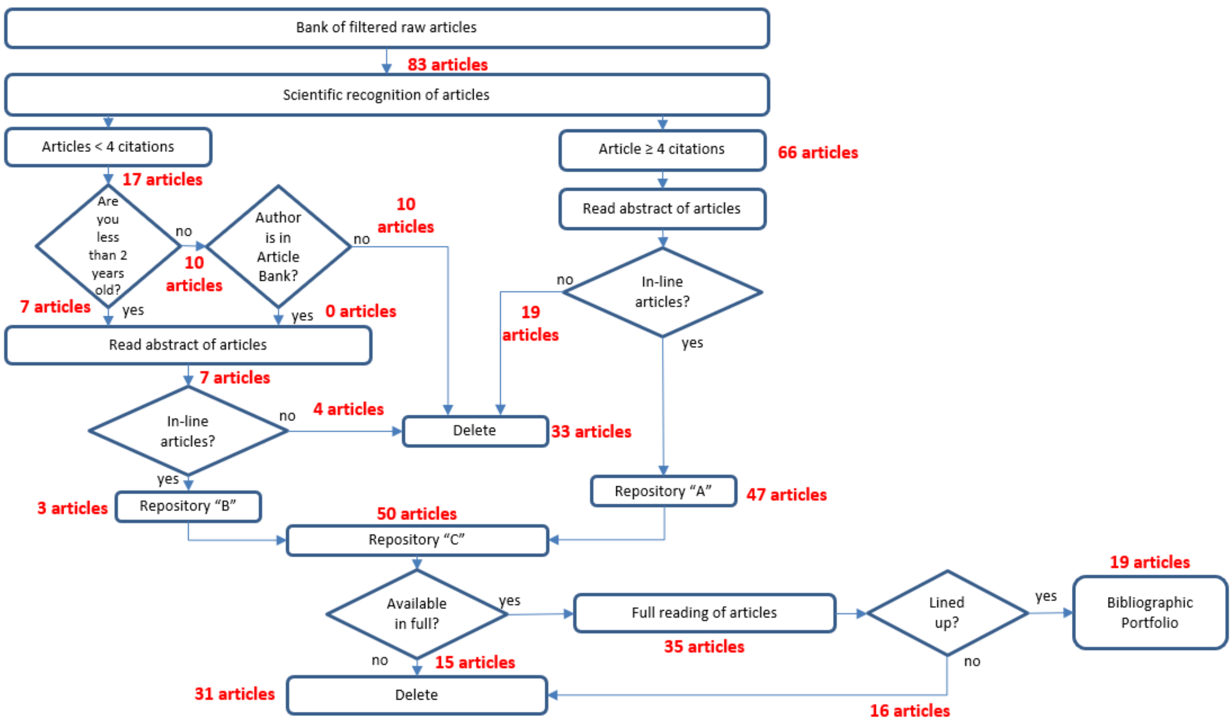

Figure 3. Filtering process leading to the bibliographic portfolio. Source: Author (2023).

Table 1. Bibliographic portfolio. Source: Author (2023).

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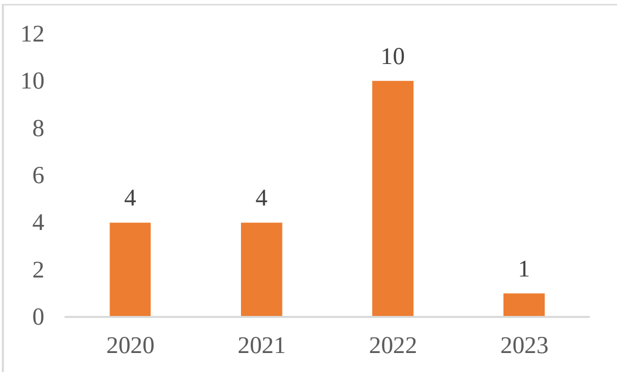

Figure 3. Total publications per year. Source: Author (2023).

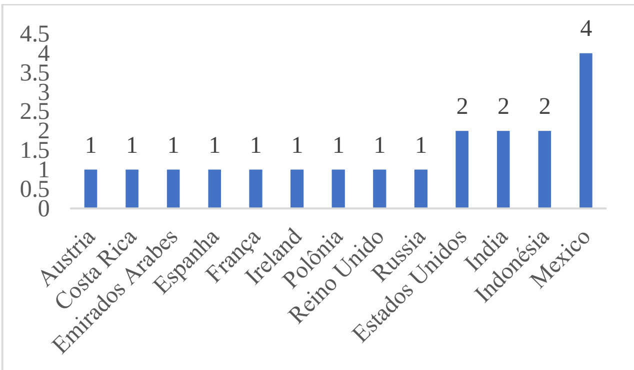

Figure 4. Total publications by country of origin. Source: Author (2023).

The country with the most publications was Mexico, totalling 4 articles, followed by Indonesia, India, and the United States, each with two articles. Other countries contributed with one article each.

Additionally, an analysis of publications by journal was conducted, as shown in Figure 5.

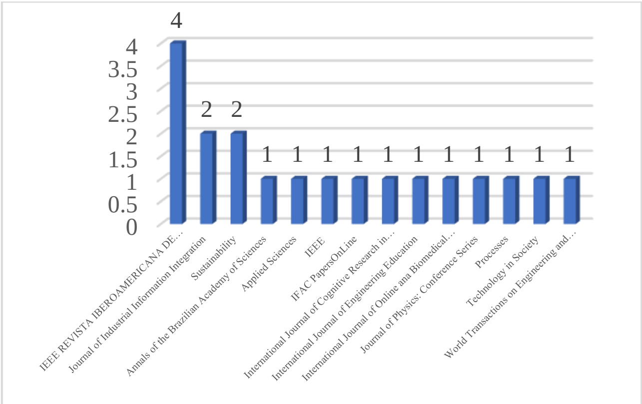

Figure 5. Total publications by journal. Source: Author (2023).

The journal with the most publications in the bibliographic portfolio was the IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, totaling 4 articles. The Journal of Industrial Information Integration and Sustainability each had two publications, while the remaining journals contributed one article each.

An analysis of the most frequently used keywords in the articles of the bibliographic portfolio was conducted, resulting in a word cloud, as shown in Figure 6.

Figure 6. Word cloud of the most used keywords in the articles. Source: Author (2023).

The main keywords identified were "Industry 5.0," "Engineering education," "Industry 4.0," and "Society 5.0," among several others, forming the word cloud of the articles in the bibliographic portfolio.

A content analysis of the articles in the bibliographic portfolio was conducted to identify relevant competencies for Industry 5.0. Additionally, the exploration of how educational environments can prepare for Industry 5.0 was performed, as presented in Table 2.

Table 2. Competencies for I 5.0 and how educational environments can prepare. Source: Author (2023).

Author(s)	Competencies for I 5.0	Educational environments for I 5.0
Ahmad (2022)	Ethics, humanism, teamwork, autonomy.	The use of MOOCs (Massive Open Online Courses) combined with cutting-edge technology and learning systems to simulate high-level learning dynamics with greater precision. Leveraging IoT, cloud computing, AI, machine learning, blockchain, digital twins, gamification, and the metaverse. Customization in teaching through adaptive learning tailored to the student's profile, creating a collaborative study environment.
Ali (2021)	Teamwork, communication, mastery of technologies.	Being prepared for the transition from Industry 4.0 to Industry 5.0 by creating environments that apply technologies, always valuing human capital.
Alvarez-Aros and Bernal-Torres (2021)	Soft skills, problem-solving, decision-making, sustainability, intelligent innovation, and the use of technologies.	Facilitate interaction with Industry 4.0 technologies, using AI, integrated sensors, extreme and intelligent automation, hyper-connected digital networks. STEM-oriented education (science, technology, engineering, and mathematics).
Broo et al. (2022)	Lifelong learning, resilience, sustainability, systemic thinking, project thinking, and future thinking, ethical and social aspects in the use of technological systems, digital and data fluency, statistics, data	Fostering transdisciplinarity, having teaching modules on sustainability, continuous learning environments, and utilizing technological systems. Practical courses on

	visualization, data literacy, ethics, mutual learning, and communication.	data fluency and management, human-agent/machine/robot/computer interaction.
Doyle-Kent and Shanahan (2022)	Problem-solving, collaborative learning, trust, ethics, curiosity.	Stimulate discussions, laboratory simulations, field trips, team projects, hands-on learning.
Ghani (2022)	Mastery of technologies, sustainability, ethical behavior.	Work with problem-based activities, using teaching and learning dynamics to solidify content in classes.
Gutierrez et al. (2022)	Investigative ability, attitude, passion for research, initiative for innovation, critical thinking, self-control, self-motivation, ability to work under pressure, teamwork, knowledge sharing, honesty, humility, respect, ethics.	Incorporate social, technological, economic, environmental, and political aspects into the students' training process.
Hidayat et al. (2021)	Work readiness, knowledge of technologies, teamwork, ethics, communication, problem-solving.	Emphasize the development of soft skills in students, preparing them for the world of work through practical activities.
Jiménez López, et al. (2022)	Problem-solving, human resource management, ethics, attitude, facing challenges.	Use active learning methodologies, employing constructivist education (student-centered), creating engineers capable of facing the challenges of the new industrial revolutions, conducting training according to the industrial needs of each region.
Kolade and Owoseni (2022)	Social intelligence, communication, resilience, knowledge worker, flexibility, autonomy, commitment, creativity, critical thinking, lifelong learning, ethics, culture. Understanding the differences between human and machine capabilities.	Take advantage of online and massive courses (MOOCs) and virtual academies, develop students' autonomy to take on roles that transcend boundaries and contribute to the tacit transfer of knowledge within companies.
Maddikunta et al. (2022)	Create synergy between autonomous machines and humans, occupational safety, flexibility, autonomy, bring the human to the center of the process.	Take advantage of interactive learning experiences using technologies, seeking blended and real-time teaching, using smart education.
Mazur and Walczyna (2022)	Decision-making, use of technologies, ethics, sustainability.	Prepare students for decision-making, technology development, social and environmental areas, ensuring sustainable development.
Mingaleva and Vukovic (2020)	Assessment of importance, identification of factors, learning from mistakes, seeking solutions, decision-making, thinking outside the box, learning ability, quick thinking.	Develop cognitive skills in students so that they learn to make important judgments during decision-making, and especially, learn from mistakes and correct them quickly.
Olvera et al. (2021)	Problem-solving, mastery of technologies, leadership, consideration of social aspects, sustainability, safety and well-being, ethics.	Prepare students with digital skills to produce engineering solutions for problems, leading the construction of a better society by addressing social, economic, and environmental aspects.
Pacher et al. (2023)	Language proficiency, mathematical problem-solving, scientific and technical knowledge, mastery of technologies, continuous learning, entrepreneurship, cultural awareness, time management, emotional intelligence, initiative, negotiation skills.	Prepare students for social realities, interpersonal relationships, negotiation skills, explore the scientific side of students by conducting research and fostering entrepreneurship.
Rodríguez-Abitia et al. (2022)	Oral and written communication, analysis and synthesis of information, problem-solving, solution modeling, autonomous learning, teamwork, decision-making, effective use of ICT tools and new technologies, social responsibility and ethics, analysis of the impact of developed solutions.	Develop competency-based curricula for Industry 5.0, placing the student at the center of the teaching process, nurturing a citizen and professional with a social, economic, and environmental perspective to meet the challenges in the job market.
Sandoval and Sánchez (2022)	Decision-making, teamwork, use of technologies, ability to formulate and manage projects, organization and time planning, appreciation of quality in the career, understanding of safety standards for human life protection, ethics for the benefit of society.	Use forums and case studies to promote situations that assist society, including in final course projects, focusing on aspects of society and Industry 5.0.

Siegfried et al. (2020)	Interpersonal relationships, communication using technologies, adaptability to changes, empathy, judgment and decision-making ability, taking responsibility, ethics, autonomous learning, contributing to professional knowledge and practice.	Develop competencies in their students for Industry 5.0, exploring digital platforms for autonomous learning, working on concepts where students will take responsibility for their actions, striving for continuous improvement, and engaging in practical activities that simulate real situations.

A framework with the main competencies mentioned in the articles from the bibliographic portfolio was designed to understand how to prepare engineering students for Industry 5.0, as presented in Figure 7.

Figure 7. Framework with the main competencies for Industry 5.0. Source: Author (2023).

It was possible to observe that in the process of developing these competencies, many human aspects must be developed to deal with the transition to Industry 5.0, such as ethics, communication, leadership, responsibility, decision-making, attitude, autonomy, time management, lifelong learning, and mastery of new technologies. These competencies align with what was mentioned by Gopalakrishna et al. (2021): Industry 5.0 will be based on decision-making, human creativity, innovations, and critical thinking, which will generate more personalized products, articles, and services with higher added value, while robotic systems will perform repetitive, high-risk, and labor-intensive tasks.

Educational environments must be prepared to operate in engineering education in Industry 5.0. Some characteristics of preparing these environments were extracted, as presented in Figure 8.

These environments must be prepared with their physical, technological, and personnel structure to deal with the development of competencies and the training of engineers for Industry 5.0. Well-qualified human resources will now be more important than ever, and universities will play a key role in shaping the future workforce. Today's and tomorrow's students need to have knowledge and skills useful for facing a highly technological and interconnected environment (Coskun et al., 2019). It was possible to identify that training should develop students in personal, social, environmental, and economic aspects to deal with the human and technological capital of companies. Additionally, using technological resources in education, encouraging autonomy in learning, and valuing interpersonal relationships.

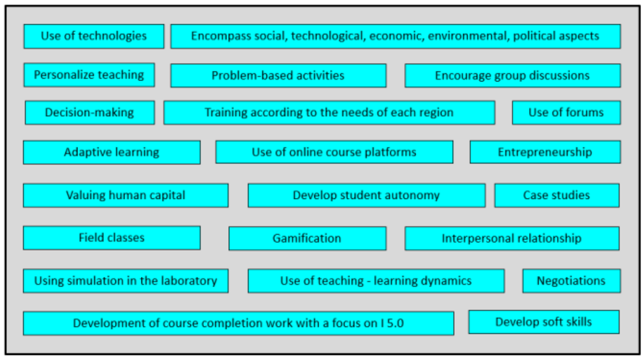

Figure 8. Framework for the preparation of educational environments for Industry 5.0. Source: Author (2023).

The transition to Industry 5.0 brings with it a series of significant challenges for higher education environments in engineering. Educational institutions will need to update and revise course curricula to include new technologies and concepts that are relevant to this context. Another challenge is the integration between industry and academia, to foster strong collaboration and ensure alignment with the needs of the job market, providing students with access to relevant internship opportunities and practical projects.

Conclusion

This research conducted a systematic literature review on engineering education in the context of Industry 5.0, selecting a bibliographic portfolio on the subject by searching the Scopus and Web of Science databases using the Proknow-C methodology. The portfolio comprised 19 articles. A bibliometric analysis was then performed to identify the years and countries of publication, major journals, and a word cloud with the main keywords used in the articles. Subsequently, a content analysis of the articles was conducted to identify key competencies and how engineering education environments can prepare for Industry 5.0. With these findings, it will be possible to prepare engineering students to face the challenges posed by this transformation process, guiding the actions of educational institutions in shaping their students.

As a suggestion for future work, these competencies can be tested along with actions for engineering education environments to verify their effectiveness in training engineers and their applicability in industrial settings.

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