RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES
Social Science Journal

The training of engineers with skills for industry 4.0: challenges of university education

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Abstract

The objective of this paper is to propose some criteria that universities should consider in order to train engineers with profiles suitable for the digital revolution present in the world. A documentary review methodology is used to contrast different positions on the training of engineers in the new times. Content analysis is carried out evaluating the curricula of some Latin American universities. The results show that coordination between the State, the industry, and the university is necessary so that current and future engineering professionals can support the research and development of intelligent industries with high added value and strategic importance.

Keywords: industry 4.0, education 4.0, engineering.

Introduction

Humanity is experiencing another historical transformation in its political, social, and economic relations, driven by technological development (Montaño, 2021). Social changes in the world have been conditioned, or coincident, with technological development, which permanently changes production models and their political and social relations (Carvajal, 2017). These technological transformations denominated as industrial revolutions (Gobierno alemán, 2014), and of which, in two hundred years, three have been identified; and now there is a consensus both in academia and generally, which reveals a moment of transition towards unprecedented models of economic and social interaction. We are witnessing the fourth industrial revolution: the digital transformation (Garcés & Peña, 2020), (Ramirez, et al., 2021).

Industrial revolutions are not linear processes characterized by being drastic, disorderly, and imminent, where giant innovation leaps are presented and whose adoption tends to be irregular in terms of their global distribution (Sánchez Guzmán, 2019). Also, it has caused significant tensions in the economic, social, and political fabrics in the nations where it has occurred (Ceballos & Huaita, 2021).

At present, the consequences of computerization and automation of production processes are bringing about profound changes in labor relations, so higher education, starting from a local context, must be prepared for the new challenges, not only regional but global (Santander Universidades, 2021), (World Economic Forum, 2016). These challenges include updating the curriculum, the attitudinal profile of future professions, the duration of careers, and the soft skills needed to work in multidisciplinary and highly specialized teams (2020 Deloitte Global Human Capital Trends, 2020). In other words, models can be dynamic and relevant simultaneously (Ortiz, et al., 2020).

This paper will outline the aspects of higher education associated with engineering education in which significant challenges must be faced in order to maintain currency within the digital transformation and Industry 4.0 (Mancero, 2022).

Materials and Methods

In this work, a literature review was conducted on the professional characteristics of the engineer for Industry 4.0, evaluating the academic profiles of some Latin American universities: Ecuador, Peru, and Venezuela, in order to recognize the trends in education in the training of engineers for the new production industries.

The PRISMA review methodology was used, where the search chain established for the keywords revealed 180 academic and scientific documents, which, after a search refinement, were reduced to 60 scientific articles from indexed bases.

Delimitation of the problem: focused on the research objectives, the new industry trends, and the professional requirements to respond to the industrial reforms. For this purpose, some criteria were established: to know the reality of the new requirements in the industry, from the primary process to the software tools, to identify the current methodologies in engineering education, mainly those practical cases, as well as specific cases of scientific connotation, to value the profile of the graduates of the engineering careers and their competences to meet the current needs of the industry.

Appropriate selection of information: in this phase, the bibliographic material was evaluated, considering the indexing bases and correlating with the inclusion criteria associated with the objectives of the work.

Review of the scientific material: the selected documents were taken into account, and the results that could contribute to a better understanding of the educational trends in engineering were evaluated, defining methodological strategies for training professionals capable of meeting current industrial needs.

Characterization of the information: Information was filtered to select the industrial aspects, taking into account mainly the most developed countries, to later evaluate the trends in less developed countries. The information was also evaluated regarding future professional challenges and following the region's approach to meeting these requirements.

Inclusion criteria were:

- Articles should have at most five years of publication, i.e., between 2018 and 2022. This time interval is equivalent to the average duration of engineering careers.
- They were published in open access indexed journals, preferably Scopus, but not limited to Latin American education, which is not always in Scopus, but in other sources.
- The topic should be mainly related to Industry 4.0 and education.

A search string was used with the keywords "industry 4.0 and engineering and education or teaching-learning methods", which yielded a total of 209 results, with a purging of the string being necessary since this first selection showed articles that were not specific to the topic. The final search string was: industry 4.0 and engineering and education or teaching-learning methods or professional profile, which yielded a total of 515 documents associated with the specific topic of study (Table 1).

Table 1. *Database review.*

Data Base	Search chain	Number of documents
Scopus	industry 4.0 and engineering and education or teaching-learning methods	209
	industry 4.0 and engineering and education or teaching-learning methods or professional profile	7
Springer	industry 4.0 and engineering and education or teaching-learning methods or professional profile	465
IEEE	“Document Title”: industry 4.0 OR “Document Title” education engineering	472
Other sources	Industry 4.0 and engineering training	98
International organizations	Education projects	9

The selection structure used for the PRISMA review process is shown in Figure 1.

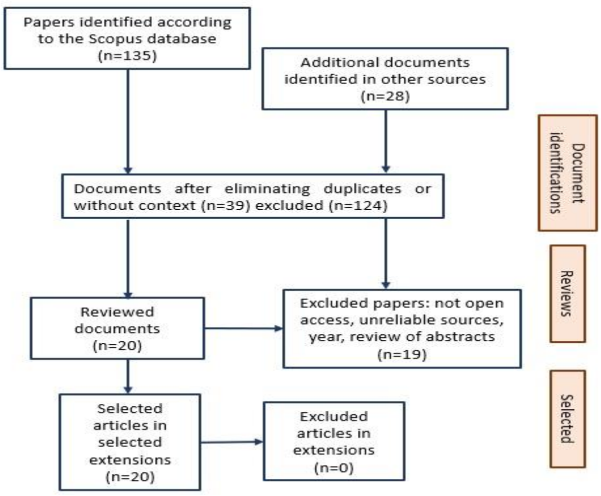

Figure 1. *Flow chart of the broad and detailed search. Source: Authors.*

The selected theoretical information was compared with the academic curricula of the leading universities in the selected regions. For each region, three universities offering engineering programs were selected. Each university was evaluated for its degree of interaction with industry, technological exchange, and vision for Industry 4.0. A total of 5 engineering programs were evaluated for each university, with 45 curricula evaluated.

For the correlation, the criteria of other authors were taken into account in terms of engineering education for Industry 4.0, i.e., as set out in Table 1.

Results

The literature review on new industrial trends yielded some relevant criteria for new educational proposals in engineering (Table 2).

Table 2. *Categories found in the literature review.*

Category	No. of documents	Subjects
Science training	10	Mathematics, Physics, Logic, Statistics
Training in programming and web technologies	27	Programming in different languages, algorithms and database processing.
Industrial participation	15	Engineering development, system simulation, automation

The other documents supported the structuring of the manuscript as arguments for the theories presented.

Based on the criteria found (Table 2), the following methodological proposals are made:

In line with Kolb's cyclical model (Rodríguez Arias, 2020) for learning competencies, creating a curricular design for engineering careers relevant to the labor market in the short and medium term is required. That is why any future university curriculum design requires business participation as part of the curriculum construction process (Katz, 2018), (Avis, 2019). On the other hand, there is the state's role as a promoter of industrial and technological progress in each country, supporting helpful public policies that allow the achievement of these objectives. Once the synergy described above is achieved, universities can create curricula that respond to these needs.

Based on the above, the CDIO (Conceive-Design-Implement-Operate) initiative is a good point of reference when undertaking the work of a curriculum redesign for Industry 4.0 (Flor, et al., 2022). The CDIO model is implemented on the traditional engineering approach, i.e., it is based on a core common to all engineering careers and its complements. The core corresponds to the fundamentals of the basic sciences such as Mathematics, Physics, and Chemistry. The complements are the applications that correspond to specific career subjects. CDIO builds on the traditional substrate and enriches it with the appropriate digital competencies. So, from a lower level, one moves up to a higher level by acquiring the basic critical skills such as analyzing, understanding, applying, and evaluating and the digital skills needed to program, model, or simulate processes. It is concluded then that the student will make his engineering career starting with the basic scientific knowledge of man-man and man-machine interaction. Then he will pass to a stage where he will know the fundamental elements of specific engineering. Finally, the student will reach the advanced knowledge of the career, where he will be able to innovate in techniques and processes with solid knowledge of digital technologies (Vera Tasama, et al., 2018).

This evolution will require professionals from different disciplines, not only in engineering, training in data science and computer science, and a set of other specialists to complement the content to be taught (Kagermann, et al., 2013). Flexibility should be another teaching pillar, where the student can learn from mobile devices (Manrique-Losada, et al., 2020), sometimes with total autonomy and sometimes with the guidance of teachers who act as tutors and within collaborative environments.

- To summarize the above, it can be said that:
- Engineering programs should have an interdisciplinary approach.
- They require to possess both scientific and technological research programs.
- The flexibilization of learning should be translated into novel channels (learning outside university facilities) so that students can learn according to their learning methods.
- The creation of virtual, remote, and interactive laboratories.
- Closer cooperation with the surrounding industry and with the corresponding entities of the state (Katz, 2018).

From the characteristics described above, some reflections can be made on the teaching-learning models:

Technology as a tool to enhance knowledge: the purpose of technology as a means of learning is to achieve better student performance when dealing with the concepts and knowledge to be assimilated and not as an alternative to impart the same content taught by traditional means.

Learning as an end and not as a means: There is a need to be resilient with learning, to be able to add new attitudes and skills, so it is more convenient for the student to know how he learns and not only what things he needs to learn. With the first approach, the student feels a structured curiosity about the learning experience and can learn about how his brain works when learning. In contrast, in the second approach, learning is perceived as a task to be accomplished and therefore is not pleasant to perform.

From both reflections, some authors have outlined certain important academic shortcomings when defining the axes on which to base learning models (Guoyan, et al., 2021), (Jalil, 2018). Among them are:

Formal education systems have no way of evidencing non-palpable skills: the traditional education system does not stimulate the attainment of skills that cannot be evaluated in its system. It tends to make the aptitudes and attitudes of a significant group of students invisible in formal education environments, making it impossible to tap students' potential.

Communication and information technologies as tools are not invisible: when the tools are used naturally, they cease to attract attention; therefore, if ICT tools become naturalized, the ways of learning become invisible as well.

Skills are not achieved in natural environments and therefore are not naturally integrated into the individual: This aspect helps to understand that if digital tools are used naturally in informal environments, learning is possible in such environments.

Digital skills are not naturally integrated into the individual: this would change through extensive use of digital tools in natural environments (outside the classroom).

Assessment models are visible: avoid stratifying students by their ability to memorize; for this, it is necessary to replace these models with those that assess the degree of student competence in developing certain activities that show a comprehensive mastery of a specific area of knowledge (Bañuelos Márquez, 2020).

From the above, several elements are consistent with the concept of the interface in computer science, i.e., how a user (in this case, students) interacts with a program (in this case, the material under study). It was observed that the user manipulated the program better when the interface between the user and the program matched the user's natural actions. It means that the program components interacting with the user were positioned so that it was natural for the user to select or perform specific actions. This approach could transition the use of technology as a tool naturally integrated into the learning cycle of students. In order to make progress in this aspect, real-time feedback is required to make concrete and continuous improvements in the process of verifying and monitoring progress in achieving the overall learning objectives through the use of technology. (Bañuelos Márquez, 2020).

Recognizing the value of methodological proposals for the training of engineers for Industry 4.0 (Vargas, et al., 2020), (Villalobos Rodriguez, et al., 2021), a review of the academic curricula of three universities in three Latin American countries, as defined by the authors, was conducted.

Ecuadorian Industry

The World Economic Forum ranks Ecuador 89th out of 100 countries in terms of the readiness needed to achieve an economic transition to Industry 4.0 (World Economic Forum, 2018). Furthermore, it ranked 99th out of 141 at the level of competitiveness (Schwab, 2019), 94th out of 134 countries at the level of internet interconnectivity (Dutta & Lanvin, 2020), and 82nd out of 132 countries in human capital. The data reflect the difficult situation that the country must face in order to integrate into a global economy, which shows the importance of implementing policies and coordinated actions to improve these statistics.

In this sense, some articles point to the formation of production clusters that allow the integration of several companies in a single productive thread, which gives them greater commercial strength and allows the development of productive regions underpinned by innovation and competitiveness (Suárez, et al., 2021). It would be one of the concrete examples in which the Ecuadorian economy could move toward global standards of quality and production, pushing the need for engineering programs that contribute to these value chains.

Status of Education 4.0 in Ecuador

The evaluation of Ecuadorian universities consisted of assessing the academic curricula of five engineering programs of three recognized universities. A still incipient state is observed regarding the adoption of innovative methodologies and the structuring of interdisciplinary curricula (Table 3), so there is no coordinated action between the university-industry-state to obtain positive results sustainable over time. It implies a disconnect between the requirements of industries and the human capital being trained (Katz, 2018), (Universidad de los Andes, 2021). Initiatives such as that of the Ibero-American Development Bank in conjunction with the Ecuadorian Ministry of Education to transform the country's education system take as an implementation segment the middle levels of the education system but very little in higher levels and even less in careers such as engineering (Herrera Pavoa, et al., 2021).

Table 3. *Contrast Relationship of the Teaching Criteria for Industry 4.0, Ecuador case*

Assessed Institution	Subjects Science training	Subjects Technology training	Industrial participation	Industrial projects
University 1	3	4	Yes	No
University 2	5	4	Yes	No
University 3	3	3	Yes	No

Source: *Author's elaboration*

In Ecuador, most graduates are inclined towards traditional careers such as accounting, law, or economics (El Comercio, Sección Sociedad., 2021), despite the saturation in these segments. It reflects the lack of diversity in the Ecuadorian economy and the scarcity of innovative initiatives in existing curricula. In the absence of articulated programs between the productive and educational sectors, the results obtained favor diversifying and strengthening the local economy are scarce. Consequently, it leads to economic stagnation, which is detrimental to the country.

Therefore, it is a challenge to attract future students to engineering careers to train professionals who will work in the various productive branches of the nation (UNESCO, 2010) (Carvajal, 2017) from the perspective of the digital revolution.

In the universities evaluated, the industrial participation of students in production companies is not carried out for the development of engineering, project development, process automation, or participation in industrial improvements.

Peruvian Industry

Peruvian industry is mainly composed of companies dedicated to textile manufacturing, agricultural sectors, and those dedicated to extracting and processing minerals such as copper, gold, iron, and petroleum, among others (Ministerio de la Producción de Perú, 2017) However, due to external and internal factors, most Peruvian industries do not have a technological level that allows them to compete in a high-tech and high-value-added market (Huang, et al., 2021). Looking at government statistics, in 2015, 74.4% of Peruvian MSME exports were low-tech products, and only 0.6% belonged to products of a higher rank in technological level. These statistics allow us to understand the reason for the country's place in the global indexes collected by the World Economic Forum and other specialized organizations (Schwab, 2019)For example, according to these organizations, Peru ranks 76th out of 100 countries regarding the readiness required to achieve a successful economic transition toward the country's incorporation into the fundamental processes of Industry 4.0. Regarding the country's competitiveness, Peru ranks 65th out of 141 countries (Schwab, 2019). Regarding Internet access and connectivity, Peru ranks 90th out of 134 countries (Deloitte, 2019). Finally, regarding the level of specialization of its human capital, Peru ranks 77th out of 132 countries (Schwab, 2019). Despite being, in general, in better conditions than its Ecuadorian neighbors, the data reflect a similar difficulty when facing a transition towards productive processes with more significant presence and integration in global production chains under the paradigms of digital transformation (Table 4). Peru, like the Ecuadorian scenario, faces the necessary transformations that are taking place globally in terms of high technology in the production and distribution of goods and services without the necessary plans that would allow it to access global markets competitively.

Table 4. *Contrast ratio of teaching criteria for Industry 4.0, Peru case.*

Assessed Institution	Subjects Science training	Subjects Technology training	Industrial participation	Industrial projects
University 1	4	4	Yes	No
University 2	5	4	Yes	No
University 3	3	3	Yes	No

Source: *Author's elaboration.*

Insights on Peruvian education

The educational planning of the Peruvian State does not contemplate, for the moment, the implementation of public policies aimed at promoting the learning of technical skills and abilities. These skills are necessary for the establishment in the country of industries that drive the digital revolution (Ministerio de Educación, 2021) At the national planning level, the Ministry of Education formalized 2021, a public document that aims to organize and regulate the different aspects of education in the country. It includes technological components to achieve a higher level of democratization of access to quality education, both at the initial and secondary education levels and in higher education, among other aspects (Consejo Nacional de Educacion, Ministerio de Educación., 2021). However, these policies result in innovation, and human capital development is yet to come.

Following ECLAC's observations in Latin America, educational programs in Peru maintain an apparent dissociation between the requirements of the national economy and the skills and abilities developed in their academic programs, which hinders the labor insertion process and the general competitiveness of the labor force. The situation requires a development perspective not only integrated within each of the region's countries but also as part of an economic, social, and educational policy that contemplates the standardization of processes within the region. It would place them in the same educational line adopted in higher education worldwide (Sá & Serpa, 2020), allowing adequate management of human talent and thinking about future challenges (Inga, et al., 2021).

Venezuelan Industry

The Venezuelan economy depended on oil production in a modern historical context. The oil boom during the 1950s-1980s allowed the creation of the business infrastructure and industrial fabric that propelled the country to become one of the fastest-growing economies in the world during that period. In the 1980s, due to events triggered by the over-indebtedness of the local economy, the change from the gold standard to fiat money, and fiscal mismanagement, Venezuela entered a period of an economic crisis that persists to this day (Puente & Rodríguez, 2020). Venezuelan industry was not immune to political tensions and has suffered a progressive deterioration in which all productivity and innovation indicators have plummeted (Nuñez Carrión, 2020). To date, the problems of Venezuelan industries have not experienced a sustainable change towards continuous improvement over time. Except for a few exceptions, such as the Polar companies, which have bet on internationalization (Países, 2021), the primary industries of the Guayana region, the metal-mechanic and automobile assembly industries of the Central Region, and the agricultural and livestock production of the Western and Central Regions of the country are still in crisis (Rivas, 2021) (Uzcátegui, 2021) (Machado-Allison & Tapia, 2021). Therefore, industrial-technological innovation has occurred in specific sectors such as payments and electronic banking. In Venezuela, online operations and transactions represent 98% of the transactions carried out in the country. It has allowed a level of sophistication and practicality of monetary transactions that much more industrialized and modern countries such as Sweden or the United States do not have. However, in general, no data allow us to analyze the Venezuelan situation in terms of quality of internet connection, quality of infrastructure, etcetera. However, according to Deloitte's Global Competitiveness Report 2019, Venezuela ranks 118 out of 130 countries in infrastructure (including roads, airports, ports, railroads, water, and energy). Regarding competitiveness, Venezuela is in the last position within the Latin American indices in this index, with 41.8 points out of a possible 100. In this aspect, Chile presents a competitiveness level of 70.5, being the most competitive in South America (Deloitte, 2019).

Educational situation in Venezuela

Venezuela had, for many years, one of the most robust educational systems in South America (González Nápoles & Sucre Rodríguez, 2021) (Table 5). The country had important and very competent technical education centers and higher education institutions integrated with the national productive apparatus through research agreements and internships that allowed a competent managerial and technical integration that allowed the nationalization of large industries such as oil and iron. Unfortunately, Venezuelan educational institutions have lost competitiveness and relevance due to the prolonged economic, political and social crisis since the mid-1980s (López-Leyva, 2020).

Venezuela is in the group of laggards in adopting the core technologies of Industry 4.0 (Carrillo, et al., 2020). On the other hand, this situation could evolve towards small ventures based on 4.0 technologies that could give way to a whole network of small technology-based companies that could change part of the internal economic dynamics of the country, achieving economic diversification outside the influence of oil.

Table 5. *Comparative ratio of teaching criteria for Industry 4.0, Venezuela case*

Assessed Institution	Subjects Science training	Subjects Technology training	Industrial participation	Industrial projects
University 1	12	6	Yes	No
University 2	11	4	Yes	No
University 3	13	7	Yes	No

Source: *Author's elaboration*

Results analysis

In the bibliographic material consulted, a specific concern is observed in need to adapt engineering education programs to the demands imposed by global economic dynamics (Carvajal, 2017). The technologies inherent to the digital revolution in the different segments of the goods and services production chain require a workforce with specific knowledge of these technologies (Florelva, 2020). It is required that the curricular programs of engineering careers integrate with their curriculum disciplines such as cloud computing, programming, the internet of things, augmented reality, and process simulation, among others (Gonçalves Antunes, et al., 2018). This situation necessitates that the student requires learning on two axes, namely: A horizontal one, where the basic knowledge of the career is located, among which are the fundamental skills in mathematics, technology, science, finance, and socio-cultural development, with a vertical or transversal axis that includes the ability to analyze different types of data, critical thinking for problem-solving at multiple levels, the ability to collaborate in multidisciplinary teams, effectively communicating proposals, processes and ideas. Another critical aspect of the studies consulted is the need to provide students with tools that allow them to develop the appropriate competencies and attitudes inherent to engineering work. It means fostering initiative, sustained interest in achieving answers, solutions, or results, leadership capacity, and adapting their skills according to the environment in which they must develop. The effort involved in adapting engineering careers to digital competencies is not a minor challenge (Ramirez-Mendoza, et al., 2018). However, the efforts of educational institutions in this regard are insufficient on their own. Industry and state institutions must collaborate to sustain the transformation of countries' productive fabric and achieve an advantageous position in terms of socioeconomic well-being for the population through a competent workforce. Competition within the 4.0 economy is not viable if there is no coordination between the State, universities, and private industry to identify possibilities for a country's growth. Creating sustainable economic zones in isolation will not be possible without concrete policies promoting such a transformation. Moreover, having suitable engineers with the profiles of industry 4.0 requires an investment of significant economic and technical resources that makes educational programs more expensive (Pujiwati, et al., 2021), (Valencia-Cárdenas, et al., 2019). Therefore, all stakeholders must make an effort: state, industry, and educational systems.

The situation of Latin American economies is still far from competing at the same level as industries in more industrialized countries. It is mainly due to the absence of a policy framework that promotes innovation and the promotion of initiatives that adopt the paradigms of the digital transition. Furthermore, in the absence of educational programs coordinated with industries, adopting technologies for developing productive activities within future smart factories is impossible. This situation does not allow the identification of those segments in which countries could be more competitive on a global scale. Although some institutions and countries have increased their concern about adapting to the new times, where economies are moving towards highly efficient production models, it is observed that such efforts are isolated, uncoordinated, and superficial. Therefore, to train engineers with the skills and abilities necessary for the transition from current production models to more efficient and diversified economies, national agreements involving the state, universities, and state education systems are necessary. The search for concrete objectives regarding the economic action plan to be implemented is fundamental, as well as a primary legislative and regulatory framework that expands the infrastructure and digital architectures that support innovation and technology initiatives. Latin America is disadvantaged compared to Asian, European, and North American blocs. Therefore, the dynamics of adoption and coordinated implementation of concrete actions between the state, companies, and education systems cannot be postponed.

On the other hand, in Latin America, knowledge and adoption of production models in line with the digital revolution are incipient. Unfortunately, research works on issues related to the digital revolution, education 4.0, and industry 4.0 are still very scarce. However, it is evident in the first instance that recent interest in these issues and the late adoption of countries such as Mexico, Brazil, and Colombia have developed more extensive literature, although insufficient.

Latin America is still in the technological updating phase of the third industrial revolution, and government agencies have not yet structured action policies to promote a comprehensive economic development that promotes a proper diversification of markets supported by new technologies. As a result, on the industrial side, industrial performance has been unstable, with periods of growth and decline, little presence of highly automated processes, and with low adoption of production technologies.

Only recently have some interesting private initiatives, such as productive clusters, been adopted in the productive Ecuadorian fabric. These conglomerates seek to group several related industries and consolidate efficient production processes using technologies from the industrial revolution. The objective is to support efficiency, quality, and internal competitiveness to be present in global markets.

In Latin America, there are no significant interdisciplinary educational plans that promote education in the technologies of the digital revolution. Future university students prefer traditional careers, reflecting the scarcity of options in technological and productive industries with an innovative profile

Conclusions

Once the research has been carried out, it is possible to draw the following conclusions:

1. Some methodologies can help build engineering curricula that can adapt to the demands of the labor market resulting from the transformations driven by changes in global production models. It means that from the moment the need or demand for products or services is identified, industries, through the analysis of large amounts of data, can offer the products or services demanded, even if it is necessary to transform the production model being used. This flexibility is achieved through implementing cyber-physical systems and using tools and platforms that help achieve these objectives.
2. No strategies at the higher education level are in tune with the productive paradigms being adopted globally, making it difficult for new generations of professionals to enter competitive labor markets. Latin America must implement strategies that promote a vision of sustainable economic development and training plans necessary to compete shortly in areas with greater strength, such as food and textiles. Coordinating plans involving the state, companies, and higher education centers are fundamental for the progressive and integral development of the countries. Unfortunately, at the time of this study, there were no articulated strategies to promote competitiveness and the development of the local industry.
3. Latin America requires a more significant research effort on issues related to an education appropriate to the current digital transformation. Unfortunately, not much literature focuses on developing mechanisms that can be implemented to create, finance, and sustain efforts to transform current production models. This paper provides guidelines regarding the methodological techniques that should be considered for the engineering education needed to operate intelligent factories in the country.

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