Journal of Production, Operations and Systems Management

e-ISSN: 1984-2430

Open Access

WORKFORCE SKILLS IN INDUSTRY 4.0: A SYSTEMATIC LITERATURE

COMPETÊNCIAS DA MÃO DE OBRA NA INDÚSTRIA 4.0: UMA REVISÃO SISTEMÁTICA DA LITERATURA

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How to reference this paper:

Silva, J. H. A. da, Guimarães Junior, D. S., & Gonçalves, E. C. (2025). Workforce skills in industry 4.0: A systematic literature. *Revista GEPROS*, *20*, e025010. DOI: 10.15675/gepros.3050

| **Submitted**: 13/06/2025
| **Approved:** 12/11/2025
| **Published:** 04/12/2025

Editor: Prof. Dr. Paula de Camargo Fiorini

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ABSTRACT

Objective: To analyze the professional skills required by Industry 4.0 and assess how workforce training in Brazil—with a focus on the Northeast region—can be improved to meet the new demands of this new industrial paradigm. **Theoretical framework:** The theoretical framework of the article Workforce Skills in Industry 4.0 is based on three main axes: 1. Industry 4.0 requires qualified professionals to deal with technologies such as AI, IoT, and automation. 2. It highlights the importance of technical skills (hard skills) and behavioral skills (soft skills) in the new industrial scenario. 3. It criticizes the gap in professional education in Brazil and defends international models as a reference for improving workforce qualifications. **Methodology/Approach:** It is based on a Systematic Literature Review (SLR). The adopted approach seeks to ensure transparency, reproducibility, and methodological rigor. This is qualitative, exploratory, and descriptive research, using the Systematic Literature Review (SLR) as the main technique. **Results:** The study points out gaps in professional training in Brazil, with a focus on the Northeast, such as an outdated curriculum, little connection with the productive sector and a lack of emerging technologies. It highlights successful international models (Germany, USA, Japan) and indicates opportunities for advancement in the region through partnerships, innovation hubs, and training in areas such as automation and data analysis. **Contributions, practical, and social implications:** The study contributes to various audiences—including policy makers, educational institutions, the industrial sector, and society in general. **Academic Contributions**: Theoretical and methodological advancement on the topic of professional skills in the Industry 4.0 era, synthesis of essential skills (hard and soft skills) based on a Systematic Literature Review (SLR). **Originality/Value:** The originality of this study specifically highlights the reality of the Northeast region, a rare approach in the literature, which generally addresses the topic at a national or international level. This allows for more precise diagnoses and targeted proposals, considering regional inequalities. **Integration of Skills and Public Policies**: It combines three dimensions in an original way: hard skills, soft skills and training policies, which offers a complete and systemic analysis of qualification for Industry 4.0.

Keywords: Industry 4.0. Professional qualification. Technical and behavioral skills. Professional education. Digital transformation.

RESUMO

Objetivo: Analisar as competências profissionais exigidas pela Indústria 4.0 e avaliar como a formação da mão de obra no Brasil – com foco na região Nordeste – pode ser aprimorada para atender às novas exigências desse novo paradigma industrial. **Referencial Teórico**: O referencial teórico do artigo Competências da Mão de Obra na Indústria 4.0 fundamenta-se em três eixos principais: 1. A Indústria 4.0 exige profissionais qualificados para lidar com tecnologias como IA, IoT e automação. 2. Destaca a importância de habilidades técnicas (hard skills) e comportamentais (soft skills) no novo cenário industrial. 3. Critica a defasagem da educação profissional no Brasil e defende modelos internacionais como referência para melhorar a qualificação da mão de obra. **Metodologia/Abordagem:** É baseada em uma Revisão Sistemática da Literatura (RSL), A abordagem adotada busca garantir transparência, reprodutibilidade e rigor metodológico. Tipo de pesquisa, qualitativa, de natureza exploratória e descritiva, utilizando como técnica principal a Revisão Sistemática da Literatura (RSL). **Resultados:** O estudo aponta falhas na formação profissional no Brasil, com foco no Nordeste, como currículo desatualizado, pouca conexão com o setor produtivo e carência em tecnologias emergentes. Destaca modelos internacionais bem-sucedidos (Alemanha, EUA, Japão) e indica oportunidades de avanço na região por meio de parcerias, polos de inovação e capacitação em áreas como automação e análise de dados. **Contribuições, implicações práticas e sociais:** O estudo contribui para diversos públicos — incluindo formuladores de políticas, instituições educacionais, setor industrial e a sociedade em geral. **Contribuições Acadêmicas**: Avanço teórico e metodológico sobre o tema das competências profissionais na era da Indústria 4.0, síntese das competências essenciais (hard e soft skills) com base em uma Revisão Sistemática da Literatura (RSL). **Originalidade/Valor:** A originalidade deste estudo destaca especificamente a realidade da região Nordeste, uma abordagem rara na literatura, que geralmente trata o tema em nível nacional ou internacional. Isso permite diagnósticos mais precisos e propostas direcionadas, considerando as desigualdades regionais. Integração de **Competências e Políticas Públicas**: Une de forma original três dimensões: hard skills, soft skills e políticas de capacitação, o que oferece uma análise completa e sistêmica da qualificação para a Indústria 4.0.

Palavras-chave: Indústria 4.0. Qualificação professional. Competências técnicas e comportamentais. Educação professional. Transformação digital.

Introduction

Industry 4.0 indicates a profound revolution in global manufacturing, driven by the convergence of disruptive technologies such as artificial intelligence, the Internet of Things (IoT), advanced automation, and big data analytics. This new production model redefines industrial processes by integrating cyber-physical systems and real-time communication, resulting in greater operational efficiency and flexibility in the production line (Il-Yeol Song, Yongjun Zhu, 2017). However, the full adoption of digital manufacturing is not limited to the implementation of these technologies; it requires a significant transformation in workforce skills (Schwab, 2016; Kagermann, 2015).

One of the biggest challenges facing Brazil in this scenario is preparing its population for the new requirements of the digital economy. According to the Continuous National Household Sample Survey (PNAD), only 23.1% of the Brazilian population has access to higher education (CNN Brazil, 2025), and a considerable portion of the workforce lacks the necessary skills to operate cutting-edge technologies, such as those required by Industry 4.0. This creates a skills gap that could leave millions of workers behind, especially those in sectors that cannot keep up with digitalization.

According to data from the World Economic Forum, it is estimated that around 80 million jobs could be lost worldwide by 2030 due to automation and other technological innovations, while at the same time new opportunities are emerging that require specialized skills. In Brazil, a study conducted by SENAI indicates that around 40% of the workforce could be left out of the new economy if there are no significant investments in professional training and retraining, says the Regional Council of Industrial Technicians of the 1st Region (CRT-01, 2025). Despite the advancement of industrial technologies, the transition to Industry 4.0 has generated significant challenges for emerging markets, such as Brazil, where workforce training has not yet kept pace with the demands of this new productive context. The lack of alignment between educational models—particularly the vocational training model that combines theoretical teaching in schools and practical training in companies, with the goal of providing students with solid education directly connected to the demands of the job market and the demands of digital manufacturing—compromises the competitiveness of the industrial sector, hindering the implementation of innovative solutions based on automation and artificial intelligence (Abiodun Alao, 2024). The dual education system, widely associated with the German educational model, has been highlighted as an effective solution for aligning academic

training with the needs of industry, especially in the context of Industry 4.0. This model is structured around three main pillars, which are fundamental to preparing students for the challenges of the new technological era.

Firstly, the division between theory and practice stands out in this model. Students are not limited to learning only within the walls of the classroom. They divide their time between educational institutions and companies, providing fundamental practical experience for their training. The application of knowledge acquired in the classroom is carried out directly in the work environment, which allows students to better understand the reality of the market and adapt quickly to the demands of the industry (Habekost, 2019). This approach makes learning more meaningful and prepares students for emerging technologies more effectively, promoting a contextualized education that reflects technological transformations (Pasqualeto, 2023).

Another crucial point of the dual model is the integration between educational institutions and the productive sector. Companies play an active role in the training of students, not only offering internships or practical experiences but also collaborating in defining curricular content. This close partnership model ensures that the skills taught in schools are aligned with the real needs of the market (Arbix et al., 2017). Students not only acquire skills that will be directly applied in the workplace but also have a smoother transition to the job market, which improves their employability (Santos et al., 2018).

The dual system is characterized by qualification focused on industry needs; the integration of theoretical training with industrial practices ensures that students are prepared to handle cutting-edge technologies such as automation, artificial intelligence (AI), and the Internet of Things (IoT), which are essential for Industry 4.0 (Habekost, 2019). This approach offers more specific and technical training, enabling students not only to understand the theoretical foundations but also to adapt to the constant technological innovations that shape the future of industrial production (Pasqualeto, 2023). The dual education system integrates theory and practice, creates strong collaboration between educational institutions and companies, and prepares students with qualifications directly aligned with the needs of Industry 4.0. This model, as pointed out by Arbix et al. (2017) and Pasqualeto (2023), has proven to be an effective strategy for developing skills that ensure adaptation to the new digital age. Given this scenario, understanding skills gaps and identifying effective strategies to restructure vocational training become central elements in ensuring that the workforce is prepared for the new demands of digital transformation.

In this context, this study seeks to answer the following research question: What skills are needed to meet the demands of the new economy? The rapid digitalization of production processes poses educational and structural challenges that need to be carefully analyzed so that the country can keep pace with developed economies and position itself more competitively in the global market.

To answer this question, we start from the hypothesis that the main gap in the adaptation of the workforce to Industry 4.0 stems from a lack of alignment between the skills required by new technologies and the training offered by educational and professional training institutions (Pasqualeto, 2023; Júnior et al., 2025). This system is characterized by the combination of technical education in training institutions and supervised practice in companies, promoting greater alignment between theory and practice and being internationally recognized for its effectiveness in professional qualification (Arbix et al., 2017; Andrade Lucena et al., 2020).

The overall goal of this study is to analyze the professional skills required by Industry 4.0 and to evaluate how workforce training in Brazil – with a focus on the Northeast region – can be improved to meet these new demands. Specific objectives include: (i) identifying the hard skills and essential soft skills for advanced manufacturing; (ii) mapping existing gaps in the professional qualification of Brazilian industry; (iii) comparing the Brazilian educational approach with successful international models; and (iv) proposing guidelines to strengthen workforce training in the country.

The relevance of this work lies in the need to understand the challenges and opportunities of professional qualification in the face of Industry 4.0, contributing to the development of policies and strategies that favor the modernization of the industrial sector. The scarcity of qualified professionals to operate in digitized environments represents a barrier to national competitiveness, making it essential to implement measures that promote the adaptation of technical and higher education to the new demands of the market (Lee, Jj., and Meng, J., 2021). Furthermore, this study offers support for researchers, industrial managers, and public policymakers interested in the digital transformation of Brazilian manufacturing.

The structure of this work was organized in a logical and progressive manner. Initially, the methodology of systematic literature review is presented, detailing the criteria adopted in the search and analysis of publications. Next, the relationship between professional skills and the demands of Industry 4.0 is discussed, addressing key concepts and challenges for workforce training. Subsequently, the landscape of industrial qualification in Brazil and the Northeast region is investigated, comparing it with international models.

Literature review

Industry 4.0 represents a paradigmatic shift in the production system, marked by the integration of digital technologies, advanced automation, the Internet of Things (IoT), and cyber-physical systems (Il-Yeol Song; Yongjun Zhu, 2017). Unlike previous industrial revolutions, this model is based on the digitization of processes and ubiquitous connectivity, allowing for greater efficiency, personalization, and productive flexibility (Schwab, 2016; Kagermann, 2015). Recent studies highlight that Industry 4.0 is not limited to the adoption of new tools but involves a complete reorganization of production chains, directly impacting management, logistics, and workforce skills (Barbosa; Firmino; Amorim, 2021).

Among the main technological pillars are artificial intelligence, big data analysis, collaborative robotics, additive manufacturing, and real-time monitoring systems (Abiodun Alao, 2024). Cyber-physical systems, by connecting machines, people, and processes through intelligent sensors, promote the vertical and horizontal integration of production (Kodama et al., 2019). The literature emphasizes that such transformations require highly qualified professionals to interpret data, make autonomous decisions, and interact in complex production environments (Teixeira de Souza; Almada Santos, 2020).

The adoption of Industry 4.0 intensifies the demand for new professional skills. Hard skills focus on mastering emerging technologies, such as programming, data analysis, machine learning, automation, and maintenance of cyber-physical systems (Canavarro, 2019; Do Amaral Aires; Moreira; De Sá Freire, 2017). These technical skills become a minimum requirement for entering the job market but remain a challenge in emerging countries due to curricular gaps and infrastructure limitations (Pasqualeto, 2023).

On the other hand, soft skills are assuming an increasingly strategic role. Competencies such as critical thinking, adaptability, creativity, emotional intelligence, and collaborative work are identified as essential for dealing with dynamic and uncertain digital environments (Kipper et al., 2021; Santos et al., 2018). Unlike previous industrial revolutions, where the focus was primarily technical, Industry 4.0 demands hybrid professionals capable of integrating technological and socio-emotional skills, fostering innovation and decision-making in decentralized contexts (Kodama et al., 2019; Lima et al., 2023).

Despite global technological advancements, the literature shows that Brazil faces structural barriers to aligning its workforce with Industry 4.0. One of the biggest challenges is

the curricular gap in technical and higher education courses, which still prioritize traditional content and do not fully incorporate disciplines related to digitalization, automation, and data analysis (Tessarini; Saltorato, 2018). Furthermore, the low integration between education and the productive sector compromises the applicability of the training offered, deepening regional inequalities, especially in growing industrial areas such as the Northeast (Pasqualeto, 2023).

Another significant obstacle is the fragmentation of public policies for professional qualification, which are often limited to isolated actions, lacking continuity or national scope (Santos et al., 2018). The absence of consistent government incentives for the training and retraining of workers hinders the expansion of training programs aligned with new demands. The literature also points to additional problems, such as low fluency in technical English, insufficient investment in educational innovation, and a lack of a culture of continuous learning within companies (Silva; Viana; Vilela Jr., 2020; Kipper, 2021).

The contrast between Brazil and industrialized countries reveals different strategies for facing the challenges of Industry 4.0. Germany is recognized for its dual education system, which integrates theory in educational institutions and practice in companies, guaranteeing solid training aligned with productive needs (Arbix et al., 2017; Habekost, 2019).

The United States adopts a decentralized model, with strong participation from universities and companies in strategic partnerships, promoting the rapid insertion of professionals in areas such as artificial intelligence, robotics, and data analysis (Ottonicar et al., 2021). Japan, in turn, combines initial training with continuous retraining programs, reinforcing a culture of lifelong learning (Sakurai; Zuchi, 2018).

These experiences demonstrate the importance of structured policies and cooperation between the State, the productive sector, and educational institutions to guarantee workforce qualifications. The literature suggests that adapting these models to the Brazilian context could be a way to reduce skills gaps, especially in regions with growth potential, such as the Northeast (Furtado et al., 2017; Andrade Lucena et al., 2020).

Although there is a growing body of research on skills in Industry 4.0, there are still significant gaps in the national literature. Few studies address the regional context, especially in the Northeast of Brazil, where educational and structural challenges are more intense (National Confederation of Industry, 2025). Furthermore, conceptual or review studies predominate, while empirical analyses involving companies, managers, and workers remain limited.

Thus, an opportunity arises for studies that articulate hard skills, soft skills, and public

policies in a systemic diagnosis. This approach allows not only understanding the current demands of Industry 4.0 but also proposing concrete guidelines for curricular modernization, university-industry integration, and encouragement of lifelong learning in Brazil (Pasqualeto, 2023; Do Amaral Aires; Moreira; De Sá Freire, 2017).

Methodology

Methodologically, the research is based on a systematic literature review (SLR), which consists of a rigorous and replicable survey of academic studies, dissertations, technical reports, and scientific articles relevant to the topic. The choice of the Northeast region as the focus is based on the Industrial Labor Map (CNI, 2025), which predicts a need for 393,000 skilled workers by 2027, especially in areas such as automation, programming, and data analysis.

The selection process for publications followed a structured protocol, using recognized databases such as Scopus and Web of Science, as well as inclusion and exclusion criteria to ensure the quality and relevance of the findings. Data analysis was conducted based on the PRISMA protocol, allowing the categorization of studies into three main dimensions: (i) technical skills (hard skills), (ii) behavioral skills (soft skills), and (iii) professional training and retraining policies. The bibliometric analysis methodology used in this study involved compiling a documentary corpus from documents available in the Scopus and Web of Science databases from 2010 to 2025, focusing on Industry 4.0 and professional skills in the workforce. A rigorous systematic review process was employed to gather relevant articles, followed by a qualitative approach to assess their contributions (Grant & Booth, 2009).

The Scopus and Web of Science databases were selected due to their predominance of high-quality journals that address topics related to internationalization, ensuring both academic standards and the quality of the articles published and included in this research (Jones et al., 2011).

In addition to their vast scope, aspects such as multidisciplinarity—encompassing a variety of knowledge areas—the availability of advanced analytical tools, such as citation analysis, collaboration networks, and impact metrics, and the rigorous selection of sources, ensuring the quality and relevance of indexed articles and journals, especially in the areas of exact and technological sciences, stand out (Passas, 2024). These aspects collectively justify the prioritization of the Scopus and Web of Science databases for conducting this research.

In order to investigate the skills demanded by Industry 4.0, as well as to analyze training gaps and propose workforce qualification strategies in the Brazilian context—especially in the Northeast region—this study adopted a systematic literature review (SLR) approach, anchored in the principles of transparency, reproducibility, and methodological rigor (Castro, 1998; Okoli et al., 2019). The review was conducted based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which guides all stages of the process—identification, screening, eligibility, and inclusion of studies—ensuring transparency, reproducibility, and methodological rigor.

Table 1, at the end of this subsection, summarizes the steps followed—focusing on the description of the planning, execution, and presentation of the findings—systematically presenting the steps adopted in the review.

Review planing

As highlighted in the Introduction, the core of this study is to investigate the skills necessary for the workforce to operate in Industry 4.0, identifying both the hard skills and soft skills that emerge in the context of digital transformation, in addition to analyzing the training gaps in Brazil, with an emphasis on the Northeast region. This stage began with the clear delimitation of the research question: "How can workforce training be improved to meet the demands of Industry 4.0, especially with regard to professional training in the Northeast region of Brazil?"

Once the theme and guiding question were defined, the review protocol was outlined, based on the adapted PRISMA (Okoli et al., 2019). This protocol included:

- Objective of RSL;
- Selected databases;
- Inclusion and exclusion criteria;
- Search strategy (descriptors, Boolean operators, and time frame);
- Screening and analysis procedures for studies.

The protocol was developed to ensure the reliability and reproducibility of the search, describing in detail each step to be followed during the review process (Brizola & Fantin, 2016). The search parameters were defined to focus on articles published in the last 15 years,

prioritizing those that address Industry 4.0 and the skills needed for the job market. The search in the Scopus and Web of Science databases was conducted on May 12, 2025, and the filters were limited. Scopus: Thematic Area: Social Sciences, Multidisciplinary. – Document Type: Article, Book Chapter. – Language: English. – Country/Territory: Brazil, United States, where 25 articles were located. Web of Science: Quick Filter: Review Article. – Document Types: Article, Review Article, Book Chapter. – Languages: English, Portuguese. – Category: Interdisciplinary Social Sciences, Automation Control System, Ethics. – Country/Territory: Brazil, where 7 articles were located. The keyword-based search was designed to maximize the relevance of the results by carefully selecting terms such as ("Indústria 4.0" OR "Industry 4.0" OR "4th industrial revolution" OR "fourth industrial revolution") and ("competências" OR "competences" OR "skills" OR "hard skills" OR "soft skills" OR "qualificação profissional" OR "workforce qualification" OR "human resources management" OR "operator" OR "job design") AND ("transformação digital" OR "digital transformation" OR "automação avançada" OR "advanced manufacturing" OR "internet of things" OR "IoT"). The search resulted in a total of 32 articles, of which 6 were excluded as not relevant to this SLR.

Conducting the review

In order to encompass a broad and multidisciplinary spectrum of publications, the following databases were chosen: Scopus and Web of Science. This selection is justified by their internationally recognized platforms, covering peer-reviewed articles, dissertations, theses, and technical reports relevant to the topic (Okoli et al., 2019).

The time frame encompassed the last 15 years—from 2010 to 2025—seeking to encompass the rise of the Industry 4.0 concept and its formative implications from its emergence to the present day (De Souza; Santos, 2020). The decision was made to extend slightly beyond 2011 (the starting point frequently mentioned as a milestone of the "Fourth Industrial Revolution" at the Hannover Fair) to include preliminary works that could provide conceptual or empirical contributions.

The selection of descriptors considered terms directly associated with Industry 4.0 and the necessary professional skills. Thus, combinations were established—using Boolean operators (AND, OR, NOT)—integrating the following sets of keywords, in Portuguese and English:

- (“Indústria 4.0” OR “Industry 4.0” OR “4th industrial revolution” OR “fourth industrial revolution”);
- (“competências” OR “competences” OR “skills” OR “hard skills” OR “soft skills” OR “qualificação” professional” OR “workforce qualification” OR “human resources management” OR “operator*” OR “job design”);
- (“transformação digital” OR “digital transformation” OR “automação avançada” OR “advanced manufacturing” OR “internet of things” OR “IoT”).

Furthermore, asterisks were used to account for variations in spelling—for example, operator* to encompass both “operator” and “operators.” Limitations were also applied to the title, abstract, and keywords, in order to restrict the results to those directly related to the topic (Brizola; Fantin, 2016).

To ensure that the studies adhered to the objective of this systematic review, the following criteria were defined:

- Publications (scientific articles, dissertations, theses, and technical reports) that directly or indirectly address professional skills in Industry 4.0;
- Studies published between 2010 and 2025, in Portuguese and English;
- Full text available online;
- Studies that presented a clear methodology or discussion about professional training, *hard skills*, *soft skills*, public policies, or education applied to the context of the Fourth Industrial Revolution.

We excluded duplicate works from different databases, publications that addressed Industry 4.0 tangentially (without discussing the skills or qualifications component), articles without full text available, and event summaries lacking methodological depth.

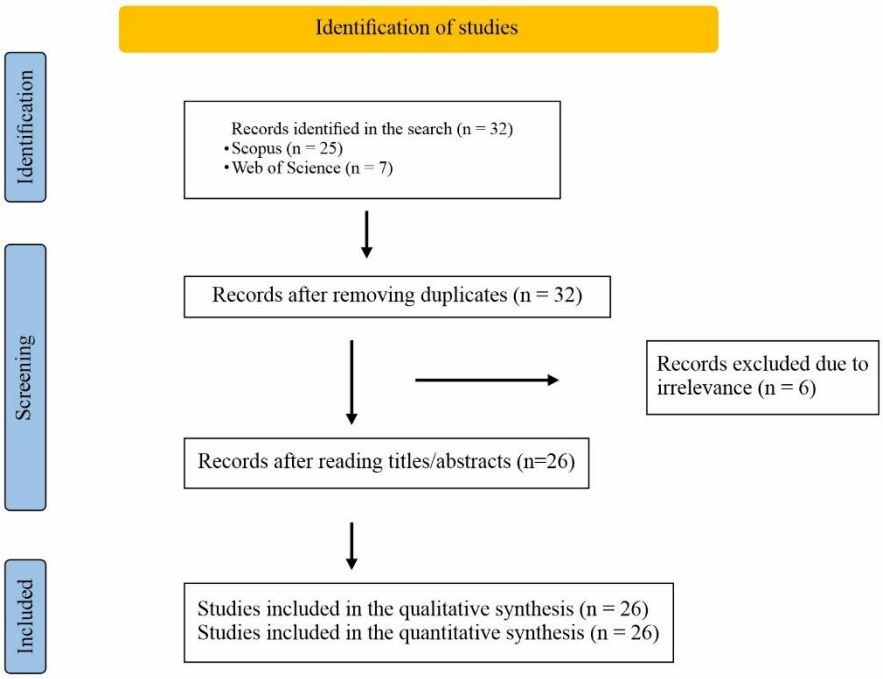
After the initial search, the results were compiled into a spreadsheet. Then, duplicates were eliminated using Bibliometrix, and titles and abstracts were read based on inclusion and exclusion criteria to arrive at a preliminary set of studies (Okoli et al., 2019). At this stage, articles outside the thematic scope or without academic–practical relevance were excluded.

The articles approved in the initial screening underwent full-text reading to assess methodological quality and the relevance of the findings. To ensure greater robustness, critical appraisal guidelines were adopted—taking into account the study design, statistical rigor (when

applicable), clarity of objectives, and relevance to the research question (Brizola; Fantin, 2016). At the end of this stage, the final corpus of articles was constituted, which formed the basis for the subsequent stages of analysis presented in Results and Discussion.

Figure 1

PRISMA flowchart adapted for the study selection process



Subsequently, a descriptive analysis was carried out (profile of publications by year, country of origin, subject area, and journal) and a content analysis, with the categorization of evidence into three dimensions: (i) technical skills (hard skills), (ii) behavioral skills (soft skills), and (iii) training and retraining policies.

The findings were discussed in an integrated manner, comparing the empirical and conceptual evidence from the different studies. In this way, the aim was to highlight the main gaps in professional training in Brazil, the good training practices identified in countries that have advanced in Industry 4.0, and, finally, to propose guidelines for strengthening the skills of the national workforce (Pasqualeto, 2023).

Finally, the main insights derived from the SLR were synthesized, highlighting the contributions of this study for researchers, managers, and public policy makers. The complete synthesis of the 26 studies analyzed can be found in Appendix 1, which presents information

about the authors, objectives, and main results of each article included in the review. The recommendations encompass curricular modernization, the encouragement of partnerships between universities and industries, and the adoption of policies to promote lifelong learning as well as the promotion of educational models inspired by the German dual system (Do Amaral Aires; Moreira; De Sá Freire, 2017).

Table 1

Stages of a Systematic Literature Review (SLR)

PHASE	STAGE	DESCRIPTION
Review Planning	1. Defining the research topic	Identifying the need to investigate professional skills in Industry 4.0, outlining the research question and study objectives.
	2. Development of the review protocol (adapted PRISMA)	Structuring the methodological procedures (objectives, databases, inclusion/exclusion criteria, analysis period, keywords) to ensure the reliability and reproducibility of the systematic review.
Conduction	3. Choosing the databases and defining the analysis period.	Choosing to use the Scopus and Web of Science databases, covering the period from 2010 to 2025.
	4. Selection of keywords and search operators	Using descriptors in Portuguese and English, with Boolean operators (AND, OR, NOT) and asterisks to cover variations of terms related to Industry 4.0 and skills.
	5. Defining inclusion and exclusion criteria	Limitations include time frame, language, availability of full text, and thematic relevance (professional skills in Industry 4.0). Exclusion criteria include duplicate works, texts lacking methodological discussion, and articles outside the scope.
	6. Screening initialization and refinement	Reading titles and abstracts, excluding duplicates and studies irrelevant to the topic.
	7. Thorough reading and quality analysis	Detailed evaluation of the selected articles, ensuring relevance and scientific rigor, resulting in the final composition of the analysis *corpus*.
Results Announcement	8. Presentation of results and summary	Developing a flowchart adapted from PRISMA; descriptive analysis of the work (period, country, area) and categorization into technical, behavioral, and political retraining competencies.

	9. Discussion of findings and implications	Integrating the results obtained, highlighting training gaps, international best practices, and proposing guidelines to improve professional qualification in Brazil.
	10. Conclusion and recommendations	Consolidating key reflections, indicating contributions for managers, researchers, and public policy makers, with an emphasis on curriculum modernization, industry-academia partnerships, and encouragement of lifelong learning.

Note. Author's own work, 2025.

Results and discussion

A systematic literature review revealed a series of challenges and opportunities for professional training in Industry 4.0, especially in the Brazilian context. The studies analyzed demonstrate that, while countries such as Germany, the United States, and Japan have already consolidated educational policies aimed at training highly qualified workers for advanced manufacturing, Brazil still presents structural gaps in its training approach. The absence of an education system integrated with the industrial sector and the curricular shortcomings of technical and higher education institutions are significant barriers to adapting the Brazilian workforce to emerging technological demands. Furthermore, it was identified that, although Brazil has advanced in some Industry 4.0 training initiatives, such as distance learning programs and partnerships between universities and companies, the supply of specific courses in critical areas such as artificial intelligence, data analysis, and the Internet of Things (IoT) is still insufficient.

As a result, 26 documents were exported from the Scopus and Web of Science databases (Scopus to .CSV and Web of Science to .TXT) for bibliometric analysis. All these documents were included in the study. R Studio, a free and open-source integrated development platform (IDE), was used for bibliometric analysis, allowing the execution of R scripts and data visualization. The Biblioshiny graphical interface, which facilitates interaction with the Bibliometrix package, was used to manage references and perform detailed analyses of the collected data. The Bibliometrix package was used to configure the tool and perform more in-

depth analyses. The R and RStudio software were essential for establishing the environment, configuring it, and analyzing the portfolio (Aria e Cuccurullo, 2017).

The RStudio version used was 2025.05.0+496. After preparation, the Bibliometrix package was configured, and the data and graphs were imported using the Biblioshiny interface. This study used several tools to analyze and visualize data related to research on Industry 4.0. Figures 2, 3, 4, 5, 6, 7, 8, 9, and 10 were generated using the bibliometric tool Bibliometrix, which offers advanced resources for network analysis and visualization of bibliometric data, such as geographic maps, word clouds, cluster analysis, and the temporal evolution of research topics.

Figure 2

Number of articles published per year

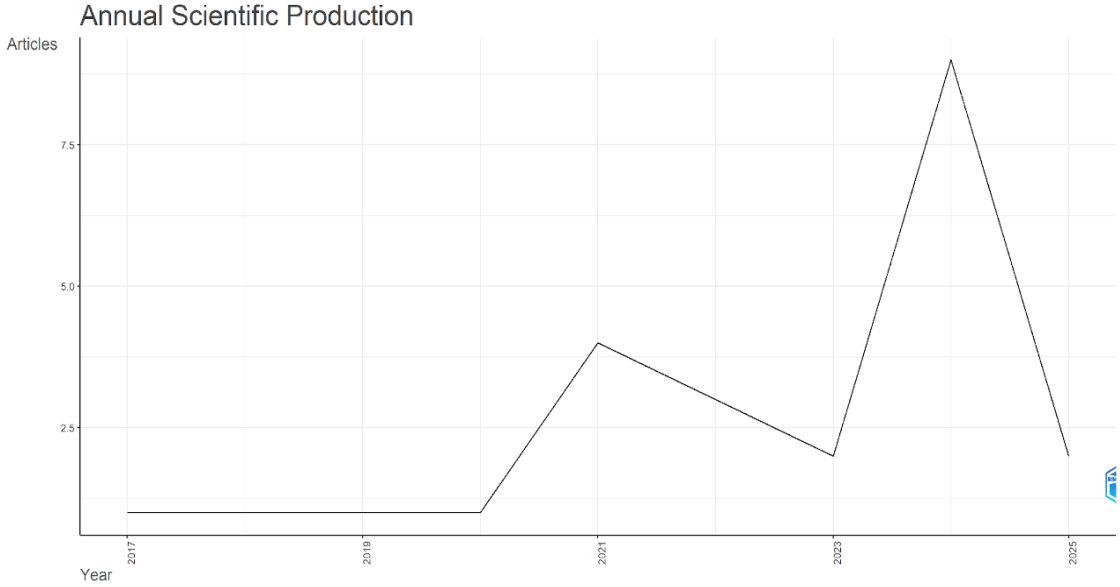


Figure 2 shows the evolution of scientific production on Industry 4.0 throughout the period analyzed, revealing significant growth from 2020 onwards and a peak in 2023. This increase indicates the consolidation of the topic as an area of academic interest and its growing relevance in the debate about innovation and professional qualification. The reduction observed in 2025 may be related to the search time frame or to the indexing range of the databases consulted.

Figure 3

Most Relevant Authors

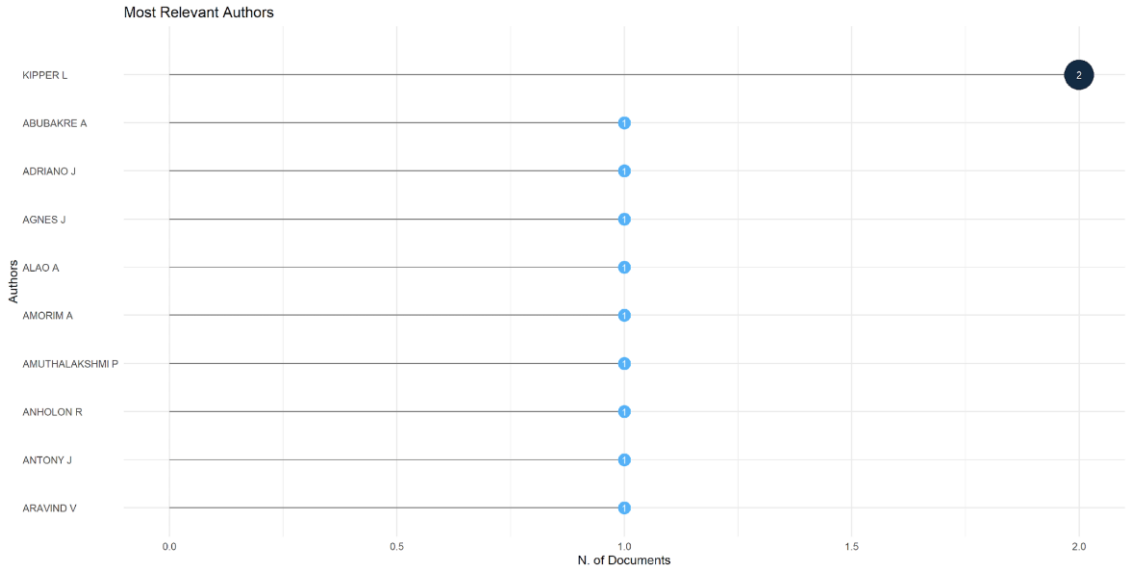


Figure 3 presents the most relevant authors identified in the systematic review. It can be observed that there is a wide dispersion of researchers, with few authors concentrating on more than one publication, such as Kipper (2 articles). This result suggests that the field of study on Industry 4.0 is still in a consolidation phase, with sporadic contributions and a diversity of theoretical approaches, without the formation of consolidated research groups.

Figure 4

Scope of knowledge areas

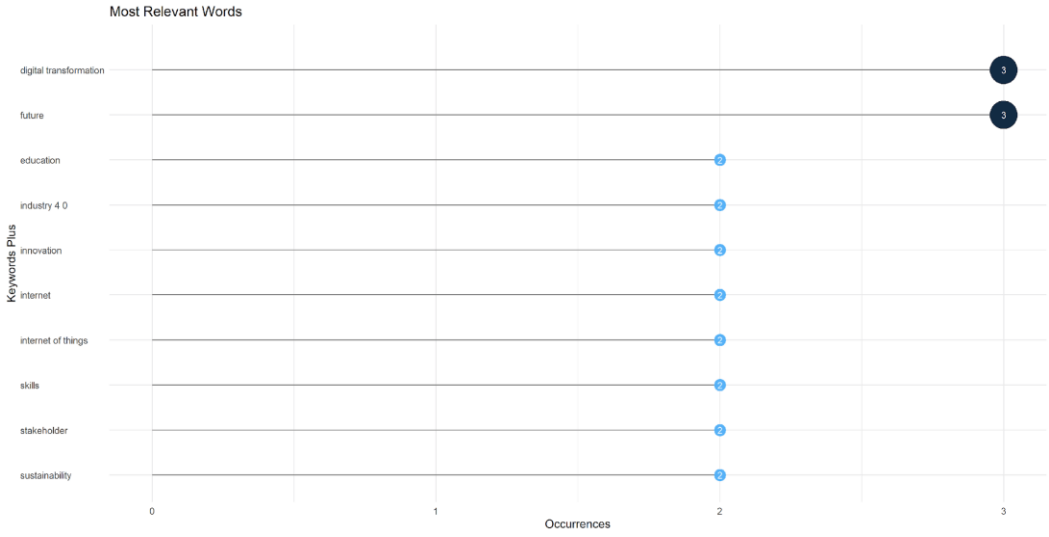


Figure 4 shows the most recurring keywords in the analyzed studies, highlighting "digital transformation" and "future" as the most frequent terms. This result indicates that the literature on Industry 4.0 is strongly focused on the discussion of digital transformation and future projections of work and education. The presence of terms such as education, skills, and sustainability reinforces the concern of researchers with professional training and the integration between technological innovation and sustainable development.

Figure 5

Keyword analysis is presented using word clouds

Figure 5 visually displays the main terms associated with the searches on Industry 4.0. The predominance of the expressions digital transformation, future, Internet of Things, and education is noticeable, reinforcing the centrality of digital transformation, future perspectives, and educational training as structuring axes of the literature analyzed. The recurrent presence of terms such as skills, innovation, and sustainability highlights the growing focus on professional qualification and the integration of technology, innovation, and sustainable development.

Figure 6

Keyword clusters

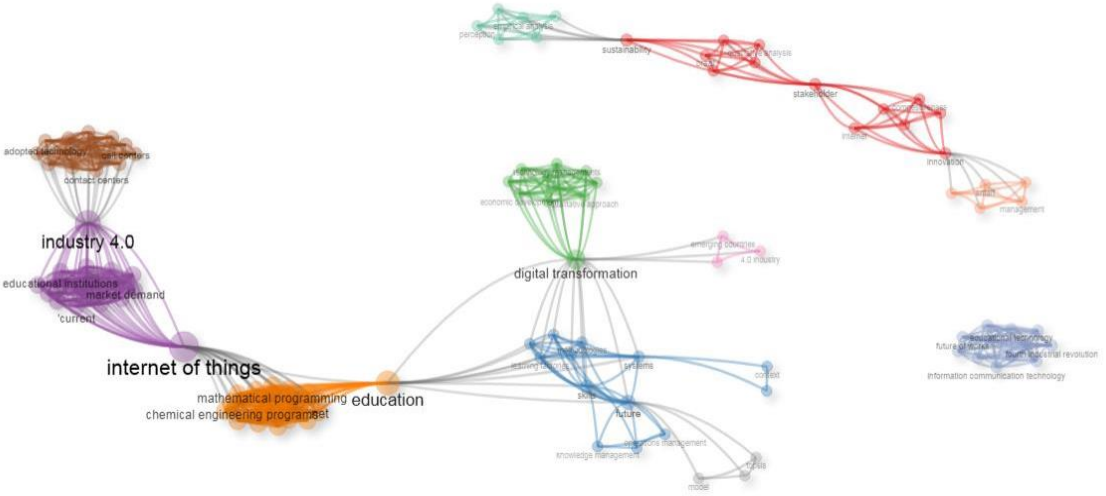


Figure 6 highlights the formation of different thematic groupings in the literature on Industry 4.0. It can be observed that terms such as digital transformation, Internet of Things, and education are strongly connected, forming the core of the discussions. Other groups highlight emerging themes, such as sustainability, innovation, and management, which point to the broadening of the field's perspectives, relating technology, management, and socio-environmental responsibility. This structure reveals the interdisciplinary nature of the research and the convergence between digital transformation, professional training, and sustainable development.

Figure 7

Most cited countries

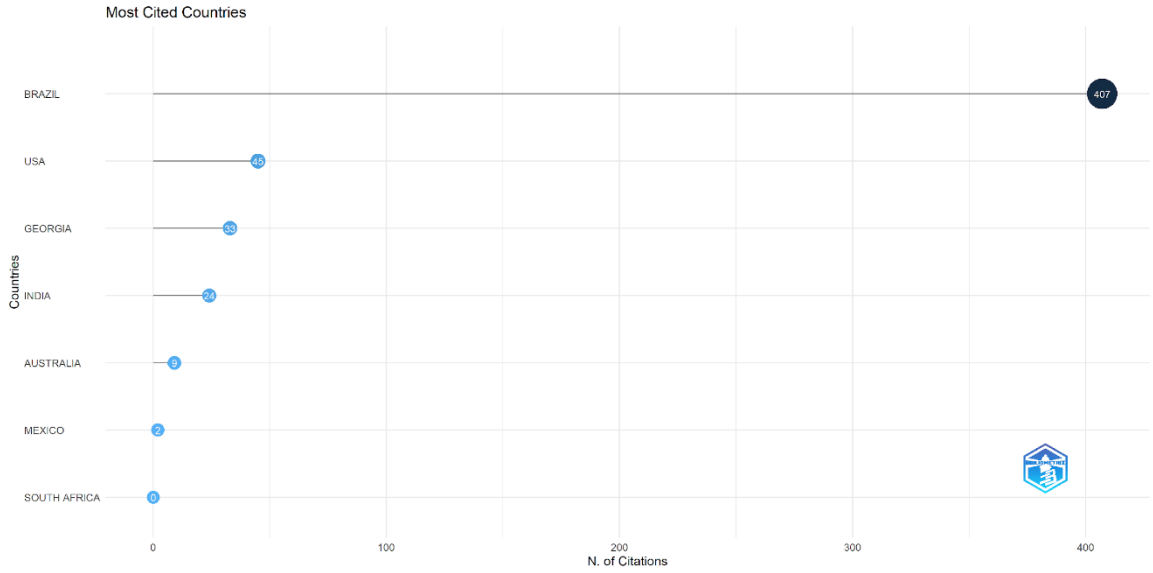


Figure 7 demonstrates that Brazil holds a significant leading position in the number of citations, highlighting the country's prominent role in scientific production on Industry 4.0 within the Latin American context. The presence of the United States and countries such as Georgia, India, and Australia indicates the global expansion of discussions on digital transformation and professional qualification. This geographical diversity reflects the consolidation of the topic as an interdisciplinary field of international interest, emphasizing the strengthening of Brazilian research on the world stage.

Figure 8

Most global cited documents

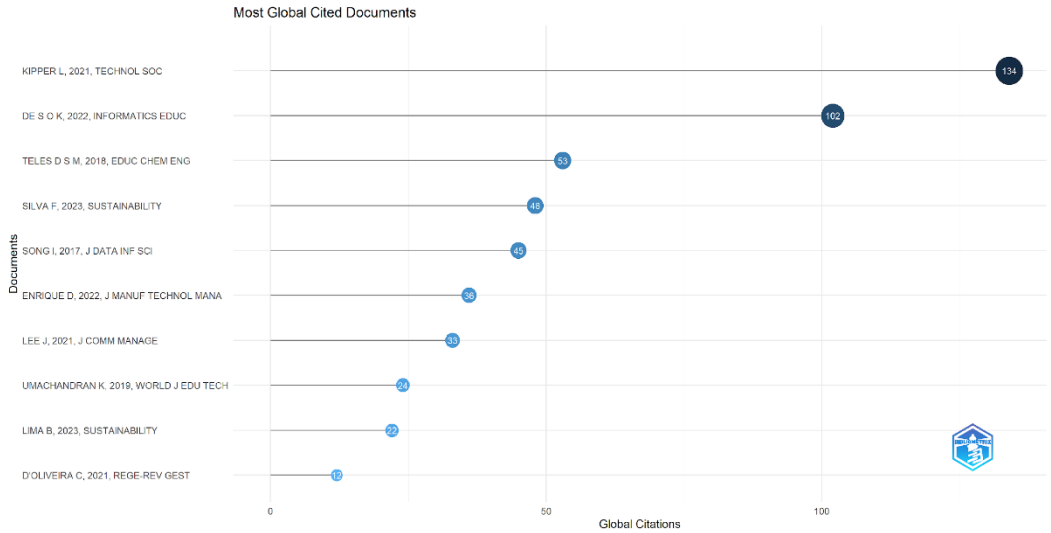


Figure 8 shows that the studies by Kipper (2021) and De Sok (2022) stand out for concentrating the largest number of citations, establishing themselves as central references in the debate on Industry 4.0. These works address topics such as digital transformation, emerging technologies, and impacts on education and vocational training, which justifies their broad influence in the literature. The presence of authors from different countries reinforces the interdisciplinary and global nature of the discussions, consolidating a diverse theoretical body that underpins recent research on the subject.

Global Citations

Figure 9

Map of the country's scientific output

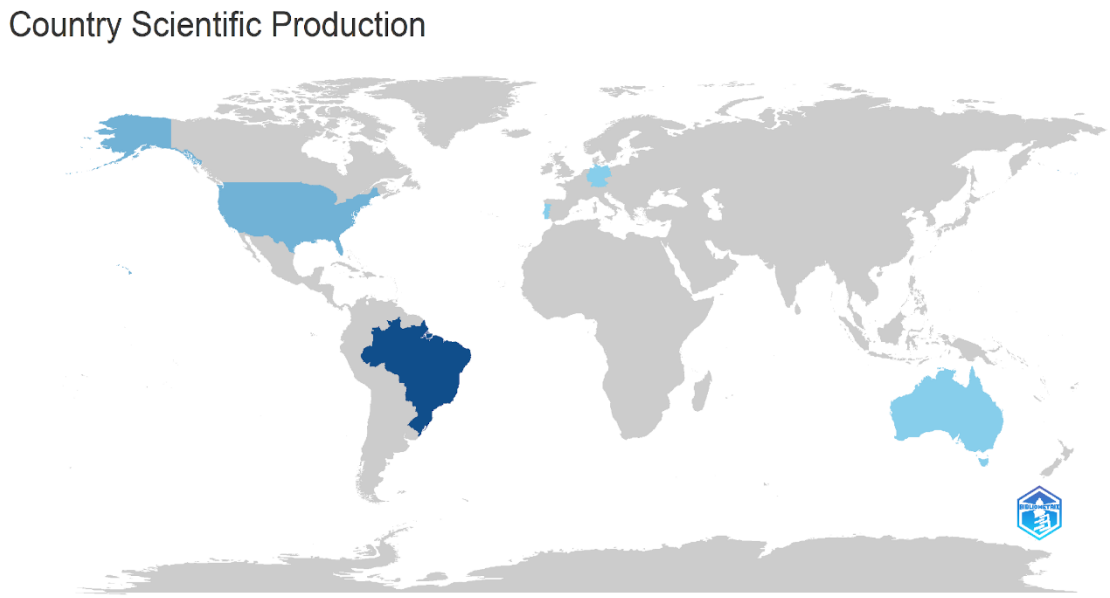


Figure 9 presents a geographical overview of scientific production on Industry 4.0, highlighting Brazil as the main publication hub in Latin America and its growing integration into international collaboration networks. The strong presence of developed countries, such as the United States, Germany, and the United Kingdom, which concentrate a significant portion of global partnerships and publications, is also observed. This pattern reinforces the importance of transnational cooperation for the advancement of knowledge and the dissemination of innovative practices on a global scale.

Figure 10

Summary of the TreeMap of scientific publications on the topic

Figure 10 summarizes, using the TreeMap format, the most recurring themes in the abstracts of the analyzed articles. The predominance of topics related to digital transformation, technological education, and the qualification of professional skills is noticeable, accompanied by emerging themes such as sustainability and innovation. This thematic distribution reveals the broadening scope of Industry 4.0, indicating a trend of integration between technology, training, and sustainable development in contemporary research.

Definition of Industry 4.0: key concepts and technological pillars

Industry 4.0 is a new production paradigm that integrates digital technologies, intelligent automation, and connectivity, requiring new skills from the workforce (Il-Yeol Song, Yongjun Zhu, 2017). Its concept stems from the evolution of industrial models, standing out for the integration of cyber-physical systems, artificial intelligence, and real-time data analysis (Abiodun Alao, 2024). This revolution involves not only new tools, but also a reorganization of production chains and an impact on workers' skills (Do Amaral Aires; Moreira; De Sá Freire, 2017). Industry 4.0 is strongly linked to the digitalization of processes, with interconnected and adaptive autonomous systems (Barbosa, Firmino, Amorim, 2020), allowing for personalization and efficiency, but it also faces challenges, especially in professional qualification, an obstacle in emerging countries (Pasqualeto, 2023). While developed countries are advancing in training,

Brazil still suffers from training gaps that hinder the adaptation of its workforce (Santos et al., 2018).

The pillars of Industry 4.0 include intelligent automation, ubiquitous connectivity, and large-scale data analysis, which increase efficiency, optimize decisions, and predict failures (Teixeira De Souza; Almada Santos, 2020; Tessarini; Saltorato, 2018). Advanced manufacturing, with intelligent and adaptable systems, demands technical skills and cognitive and socio-emotional competencies, creating a professional active in process management (RBD et al., 2025). Furthermore, cyber-physical systems, which integrate sensors and AI, are essential for monitoring and optimizing processes in real time (Kodama et al., 2019), but their implementation depends on a skilled workforce (Pasqualeto, 2023). Massive connectivity via IoT is also crucial, requiring new professional profiles focused on data analysis and the management of complex systems (Tessarini; Saltorato, 2018; Teixeira De Souza; Almada Santos, 2020).

Industry 4.0 impacts professional qualification, requiring technical, interpersonal, and managerial skills, as well as promoting decentralization and collaboration in decision-making (Hall, Scott & Elshennawy, Ahmad, 2024). In Brazil, the lack of public policies and the curricular shortcomings in technical and higher education institutions hinder the preparation of the workforce for this new context, which may affect the competitiveness of the national industry (Tessarini; Saltorato, 2018; Teixeira De Souza; Almada Santos, 2020).

Essential skills for the workforce in Industry 4.0: necessary soft skills and hard skills

The transition to Industry 4.0 requires a reconfiguration of professional skills, encompassing both hard skills (technical and technological) and soft skills (interpersonal and socio-emotional) (Lima, BF; Neto, JV; Santos, RS; Caiado, RGG, 2023). Increasing automation and digitalization demand professionals capable of operating and interpreting cyber-physical systems and dealing with dynamic and interconnected environments, developing analytical and adaptive skills (De Souza; Santos, 2020). Mastery of emerging technologies such as AI, big data, IoT, and advanced automation is essential, but traditional technical training often fails to keep pace with these transformations (Do Amaral Aires; Moreira; De Sá Freire, 2017; Pasqualeto, 2023). The analysis of large volumes of data and data literacy, including statistics and machine learning, become important differentiators (Santos et al., 2018; Teixeira De Souza; Almada Santos, 2020; Tessarini; Saltorato, 2018).

Beyond technological skills, Industry 4.0 demands professionals with high adaptability, critical thinking, and emotional intelligence to deal with highly uncertain environments (Kipper, L, 2021). Interdisciplinary collaboration skills, effective communication, and fluency in technical English are also fundamental (Kodama et al., 2019; Pasqualeto, 2023; Santos et al., 2018). A culture of innovation requires a mindset of continuous learning, or "lifelong learning," so that professionals can adapt quickly to technological changes (Teixeira De Souza; Almada Santos, 2020; Tessarini; Saltorato, 2018).

Furthermore, creativity and innovation skills are crucial, as automation does not replace the need for original thinking and complex problem-solving (Kipper, L, 2021). Industry 4.0 redefines the concept of employability, shifting the focus from manual operation to the supervision and management of intelligent systems (Kodama et al., 2019; Pasqualeto, 2023). Thus, vocational training must balance technical and behavioral skills to meet the challenges of a dynamic and constantly evolving job market (Santos et al., 2018).

Challenges and opportunities for workforce training in the face of digital transformation

The digital transformation of Industry 4.0 poses significant challenges for workforce qualification, requiring changes in educational models and training programs (Kipper, L, 2021). Emerging technologies, such as AI, advanced automation, and IoT, profoundly alter the dynamics of production, making many traditional skills obsolete (De Souza; Santos, 2020). The greatest challenge is aligning skills development with the new context of smart manufacturing (Do Amaral Aires; Moreira; De Sá Freire, 2017).

One of the barriers is the curricular gap in technical and higher education courses, which still focus on traditional processes (Kodama et al., 2019). The rapid evolution of technologies demands a reformulation of educational guidelines to include automation and data analysis (Katyeudo K, De S. Oliveira, Ricardo AC De Souza, 2022). Furthermore, the fragmentation of public qualification policies creates regional inequalities (Santos et al., 2018). The lack of a culture of continuous learning in companies is also an obstacle, as many adopt sporadic and insufficient training (Turcato, CRP; Pedroso, B.; Arnold, M.; Picinin, 2024).

However, digital transformation offers opportunities to modernize training, with educational technologies such as distance learning and augmented reality simulators (Kipper, L, 2021). Partnerships between the industrial sector and educational institutions, such as Germany's dual system model, can also boost skills development (Pasqualeto, 2023; Santos et

al., 2018). In Brazil, the lack of incentives and infrastructure hinders the expansion of these initiatives (Teixeira De Souza; Almada Santos, 2020). The adoption of structured public policies for professional retraining, as in the USA and Japan, could accelerate the training process (Tessarini; Saltorato, 2018; Canavarro, 2019). Investing in technical and higher education and encouraging internal training in companies can reduce the skills deficit (De Souza; Santos, 2020). In addition to technical skills, Industry 4.0 requires the development of interpersonal and socio-emotional skills, such as critical thinking and creativity, which are essential for interacting with digitized production environments (Turcato, CRP; Pedroso, B.; Arnold, M.; Picinin, 2024).

Industry 4.0 not only challenges professional qualification models but also opens up space for educational innovations, which must be accompanied by public policies and private initiatives to ensure effective training (Kipper, L, 2021). The following table summarizes the main findings of the SLR, highlighting international training models, training gaps in Brazil, and proposals for adapting to the new industrial paradigm.

Table 2

Summary of Findings

Category	Main Findings	References
Hard Skills	Proficiency in programming, data analysis, cyber-physical systems maintenance, and industrial automation.	CANAVARRO (2019); DE SOUZA & SANTOS (2020); DO AMARAL AIRES *et al*. (2017) LIMA *et al*. (2023)
Soft Skills	Critical thinking, creativity, adaptability, and emotional intelligence as essential skills.	PASQUALETO (2023); KODAMA *et al*. (2019); SANTOS *et al*. (2018)
Challenges Educational	Curricular shortcomings, lack of integration between education and industry, and a low supply of up-to-date technical courses.	TESSARINI & SALTORATO (2018); TEIXEIRA DE SOUZA & ALMADA SANTOS (2020)
Models International	German dual system, university-industry partnership in the USA, continuous training in Japan.	ARBIX *et al*. (2017); FURTADO *et al*. (2017); HABEKOST (2019)
Gaps in Brazil	Low fluency in technical English, poor technological infrastructure for training, and a lack of investment in educational innovation.	ANHOLON, R. (2024); SILVA *et al*. (2020); OTTONICAR *et al*. (2021); ANDRADE LUCENA *et al*. (2020)
Policies Public	The need for incentives for professional training and greater integration between companies and technical education.	FURTADO *et al.* (2017); KIPPER, L. (2021); PASQUALETO (2023); SAKURAI & ZUCHI (2018)

Note. Author Adherence of own.

Table 2 shows that, regarding hard skills, there is a consensus in the literature on the need for proficiency in programming, data analysis, maintenance of cyber-physical systems, and industrial automation. This technical knowledge is a minimum requirement for professional insertion in the context of Industry 4.0. However, it is observed that the Brazilian reality is still marked by a significant gap, since many technical and higher education courses remain focused on traditional processes, without fully incorporating disciplines geared toward emerging technologies. This gap compromises the preparation of the national workforce to meet the demands of digital manufacturing.

Regarding soft skills, the literature indicates that critical thinking, creativity, adaptability, and emotional intelligence are essential competencies for Industry 4.0 workers. These skills reinforce the need to not only seek a technically skilled professional, but rather a hybrid profile capable of integrating technical knowledge with socio-emotional and managerial competencies. However, in Brazil, this aspect remains underexplored in curricula and training programs, which are still heavily oriented toward operational training. This deficiency may limit the participation of Brazilian workers in strategic innovation activities and digital process management.

The highlighted educational challenges—curricular shortcomings, low integration between education and industry, and insufficient updated courses—reveal the urgent need for systemic modernization of vocational education. These obstacles not only restrict the adequate training of students but also deepen regional inequalities, especially in areas of industrial expansion, such as the Northeast. Thus, the structural inadequacy of the educational system constitutes a concrete barrier to aligning Brazil with the transformations of Industry 4.0.

Comparison with international models reveals alternative paths. Germany, with its dual system; the United States, through university-industry partnerships; and Japan, with its focus on continuous retraining, present successful strategies for aligning vocational training with productive demands. In common, these countries adopt the integration of theory and practice, as well as the constant updating of skills. Brazil, however, maintains fragmented structures where universities, industry, and government operate in a poorly coordinated manner, hindering more solid progress.

The identified national gaps—such as low fluency in technical English, insufficient technological infrastructure for education, and a lack of investment in educational innovation—reinforce the country's difficulty in competing on the global stage. These structural deficiencies limit workers' access to cutting-edge technologies and reduce the capacity for international

cooperation. Without directly addressing these limitations, there is a risk of deepening inequalities and excluding significant portions of the workforce from the opportunities of the new digital economy.

Finally, public policies emerge as a central axis for overcoming the weaknesses identified. The literature unanimously points to the need for government incentives and greater integration between companies and educational institutions. The absence of robust policies explains why many Brazilian initiatives remain sporadic and of limited scope. In this sense, it is essential to promote structured professional retraining programs, tax incentives for companies that invest in training, and the modernization of curricula in technical and higher education institutions.

Adherence of professional competencies in the Northeast and Brazilian industries: Diagnosis of current professional competencies in the industrial sector of the region.

The choice of the Northeast region as the focus of this analysis is justified by its strategic relevance in the Brazilian industrial context and by the specific challenges related to professional qualification and the adoption of Industry 4.0 technologies. Although the region has registered advances in infrastructure and attracted new industrial investments, it still presents significant asymmetries compared to the South and Southeast regions, especially regarding the technical and technological training of the workforce. This reality makes the Northeast a territory of interest for understanding how professional skills are being developed and applied in the face of the transformations of Industry 4.0, allowing the identification of gaps and opportunities for improvement in the integration between education, innovation, and productive development.

The industrial sector in the Northeast has experienced significant expansion, driven by investments in infrastructure and technological innovation, but workforce qualification has not yet kept pace with this growth, creating challenges for the integration of Industry 4.0 (Pasqualeto, 2023). Projections indicate that states like Pernambuco and Piauí will need to qualify thousands of workers by 2027, with greater demand in areas such as industrial automation, programming, and data analysis (Ne9, 2025; Federation of Industries of the State of Piauí, 2025). However, local training is still based on conventional models of technical education, which hinders adaptation to the new demands (Santos et al., 2018). In addition to technical skills, Industry 4.0 requires soft skills such as critical thinking, emotional intelligence,

and complex problem-solving (Canavarro, 2019), but most qualification programs focus only on operational skills (Do Amaral Aires; Moreira; De Sá Freire, 2017). The lack of courses in emerging technologies, such as AI and IoT, in institutions in the region exacerbates the shortage of qualified labor (EG Mendes et al., 2024).

On the other hand, the sector's expansion has generated opportunities to strengthen professional qualification, with private investments and partnerships between companies and educational institutions, in addition to the creation of technological hubs and innovation centers in states such as Ceará and Bahia, which are promoting training geared toward Industry 4.0 (Kodama et al., 2019; Santos et al., 2018). However, it is essential to strengthen public policies for professional training and retraining to align workforce training with the demands of digital manufacturing (RBd et al., 2025).

The evolution of Industry 4.0 in the Northeast depends not only on the adoption of new technologies, but also on the adaptability of workers (Canavarro, 2019). To achieve this, a joint effort is needed between companies, educational institutions, and governments to promote digital inclusion and continuous training, ensuring the sustainable growth of the industrial sector and its competitiveness in the national and global markets (De Souza; Santos, 2020).

Comparison with the needs imposed by Industry 4.0

Industry 4.0, with its focus on automation, digitalization, and interconnectivity, demands a new set of skills from professionals in the industrial sector, including technical skills (hard skills) and behavioral skills (soft skills) (Canavarro, 2019). In the Northeast, despite industrial growth and the demand for skilled workers, there is a mismatch between the skills available and those required by the new digital manufacturing model (National Confederation of Industry, 2025). Traditional training in the region is still based on conventional operational processes, without an adequate focus on emerging technologies such as programming, data analysis, and industrial automation, which are essential for Industry 4.0 (Do Amaral Aires; Moreira; De Sá Freire, 2017; Kodama et al., 2019).

One of the main challenges is the scarcity of courses in areas such as programming, big data, artificial intelligence, and the Internet of Things (IoT), which are essential for the sector's competitiveness (Tessarini; Saltorato, 2018; Pasqualeto, 2023). Furthermore, soft skills, such as critical thinking, creativity, and collaboration, are still insufficiently addressed in the region's professional training, hindering adaptation to dynamic and decentralized industrial

environments (De Souza; Santos, 2020). Low fluency in technical English also represents a significant barrier to integration with global industry trends (Kodama et al., 2019; Pasqualeto, 2023).

However, some initiatives have shown potential to reduce this gap, such as partnerships between universities, companies, and educational institutions, and the implementation of hybrid training models (Click Petróleo e Gás, 2025). These initiatives have helped to empower workers for Industry 4.0, integrating emerging technologies and enabling learning without interrupting work (Tessarini; Saltorato, 2018). The implementation of public policies focused on modernizing technical education and continuous qualification is also crucial for workforce adaptation (Pasqualeto, 2023; Do Amaral Aires; Moreira; De Sá Freire, 2017).

A comparison between available skills and the demands of Industry 4.0 reveals a mismatch that could compromise the sustainable growth of the Northeastern industrial sector unless effective measures are adopted for educational reform, technical training, and the development of digital skills (Canavarro, 2019; National Confederation of Industry, 2025).

International comparison and training gaps

Training for Industry 4.0 presents structural challenges, varying according to the level of technological maturity of each country. Countries such as Germany, the United States, and Japan have implemented effective policies to align vocational training with the needs of digital manufacturing, while Brazil still faces difficulties in adapting its educational and technical models (Andrade Lucena; Eduardo Roselino; Carlos Diegues, 2020). Germany, a global benchmark, adopts a dual education system, integrating theoretical learning with practical experience in companies, which ensures that its workforce is prepared for Industry 4.0 (Arbix et al., 2017; Habekost, 2019). In the United States, training is decentralized, with partnerships between companies and universities, preparing professionals for a highly digitalized environment (Ottonicar et al., 2021). Japan combines the dual system with a strong focus on continuous retraining (Sakurai; Zuchi, 2018).

In Brazil, technical training still focuses on traditional processes, with little emphasis on skills essential for Industry 4.0, such as programming, automation, and data analysis, creating a shortage of qualified professionals (Ottonicar et al., 2021; Furtado et al., 2017). The lack of integration between companies, universities, and government also hinders the adaptation of the workforce to digitized manufacturing (Andrade Lucena; Eduardo Roselino; Carlos Diegues,

2020). Limited educational infrastructure and a lack of incentives for continuing education are other obstacles to the effective implementation of training programs (Silva et al., 2020). To reduce these gaps, it is necessary to adopt structural changes in teaching models, including the adoption of a dual education system and partnerships between universities and companies to offer courses focused on Industry 4.0 (Habekost, 2019). In addition, public policies to encourage continuing education, such as those adopted in Japan, are essential to allow workers to update themselves in the face of rapid technological changes (Sakurai; Zuchi, 2018). Compared to advanced economies, Brazil still needs to make significant changes to align its workforce with the demands of Industry 4.0 and ensure the competitiveness of national industry (Furtado et al., 2017).

Conclusion

The review points to opportunities to mitigate the identified challenges. Strengthening partnerships between universities, companies, and innovation centers can align academic training with market needs. Educational models inspired by the German dual system and the encouragement of continuous learning, as in Japan, can contribute to reducing skills gaps. The use of educational technologies—such as distance learning platforms and augmented reality simulators—also expands access to professional training.

This research contributes to consolidating evidence on the gap between the skills demanded by Industry 4.0 and the training offered by technical and higher education institutions in Brazil, particularly in the Northeast region. The study integrates perspectives on hard skills and soft skills, linking education, public policies, and technological innovation—aspects that are still underexplored in the national literature. By synthesizing these findings, the work provides support for the design of training policies and programs aligned with ongoing productive transformations.

The results confirm the hypothesis that there is a mismatch between vocational training and the demands of Industry 4.0, but also reveal promising paths to overcome this, especially through structured public policies and the integration of education and the productive sector. To keep pace with digital transformation, Brazil needs to invest in professional retraining, updating technical education, and strengthening behavioral skills. The review emphasizes the need for an integrated approach between government, the productive sector, and educational

institutions so that the country can overcome structural barriers and remain competitive on the global stage. In short, the study reaffirms the strategic role of technological education and innovation as pillars for sustainable development and the consolidation of Industry 4.0 in Brazil.

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