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Article

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Article

Adapting to Industry 4.0 in France: Essential Competencies for a Future-Ready Workforce

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Abstract: This paper identifies skills required for workers in Industry 4.0 in France and provides insights to guide the development of a future research agenda. The research draws on a bibliometric analysis of 80 papers, mapping the technical and interpersonal skills needed for professionals to adapt and thrive in the evolving industrial landscape. The results highlight the importance of a multidisciplinary approach integrating competences in information technology, automation, robotics, artificial intelligence, data analysis, project management, interpersonal skills, adaptability, and collaboration. This holistic approach to skills development reveals six major domains: Technical, Flexibility, Inter-Agency, Soft Skills, Innovation, and Information Technology. The conclusions emphasize that the interconnection between these domains is essential to prepare a workforce capable of meeting the challenges and seizing the opportunities of Industry 4.0 in France. The research shows that there is a need for a multidisciplinary and integrated approach that combines technical and interpersonal skills in Industry 4.0 activities. It provides a solid foundation for formulating talent development strategies and educational curricula aligned with the demands of Industry 4.0. By proposing a future research agenda, this study not only highlights key areas for further exploration—economic impact, public innovation policies, and curriculum adaptation—but also contributes to the evolution of human resources in the digital transformation era.

Keywords: Industry 4.0; worker; skills; competencies



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1. Introduction

Industry 4.0, also known as the Fourth Industrial Revolution, is characterized by the convergence of technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, and 3D printing, among other technologies and tools that result in highly efficient, connected, and automated production systems. According to (Waldmann et al. 2020), Industry 4.0 transforms operational efficiency and influences the quality of life in the industrial environment.

The French context provides a particularly relevant study of Industry 4.0, as the country's diverse industrial sectors—including automotive, aerospace, and information technology—face unique challenges in adapting to new technologies. Despite significant investments in digitalization and innovation, French companies encounter obstacles such as resistance to change and the need for workforce reskilling (Bocquet et al. 2017). This setting highlights the ongoing relevance of Industry 4.0 in the French economy, even as other nations begin exploring Industry 5.0, which emphasizes human-machine collaboration, sustainability, and worker well-being (Knap-Stefaniuk 2023). France's case provides valuable insights into the competencies required in this new industrial environment and the changing demands on workers. In this article, the term “workforce” generally refers

to all workers potentially suited for Industry 4.0 tasks, including both white-collar and blue-collar roles.

According to the [World Economic Forum \(2016\)](#), Industry 4.0 represents an industrial revolution driven by technological advancements and innovations in automation, digitization, and interconnection of production systems. Thus, the environment of Industry 4.0 allows significant changes in business management, and international business activities are not exempt from this transformation. For [Amarante et al. \(2023\)](#), emerging trends in Industry 4.0 also bring new challenges and opportunities, especially concerning workers' quality of life.

In this context, implementing Industry 4.0 in France has been seen as a way to increase the country's competitiveness in the global scenario. According to the French Ministry of Economy and Finance, Industry 4.0 could help companies improve their efficiency and productivity and facilitate the creation of new business models. The [European Commission \(2019\)](#) highlights the need to prepare European industries for the future in a context marked by Industry 4.0, which implies adapting to new technologies and acquiring appropriate competencies for a highly technological and interconnected economy.

As France is an EU member state, a purely national strategy cannot be conceived when facing a challenge transcending the national scope and affecting European and international competition. At the European level, the Commission introduced three strategies that had an impact on France: the 2015 digital single market strategy, the 2016 European strategy for industrial digitization, and the 2017 data economy strategy. According to the European Commission President, Europe must lead the digital transformation to ensure the competitiveness of its industry, promoting its adoption across the economy to fully benefit from new types of jobs associated with digitization. [Kovaleski and Picinin \(2020\)](#) argue that overcoming these challenges requires both "hard skills" and "soft skills", with their integration being crucial for success in Industry 4.0.

The [French Ministry of Economy, Digital Industry, and Innovation \(2021\)](#) emphasizes the Industry 4.0 Plan, which aims to contribute to the digital and technological transformation of the industrial sector in the country, thus generating a growing demand for professionals with specific skills. Furthermore, according to a McKinsey study, the digitalization of the industry could increase the French GDP by EUR 1.5 trillion by 2030.

However, the implementation of Industry 4.0 also presents challenges for French companies. A study by [Deloitte \(2018\)](#) indicated that the primary challenges French companies face in implementing Industry 4.0 are the lack of digital skills and concerns over cybersecurity. To address these issues, the French government has implemented public policies aimed at industrial digitization. According to the [Ministry of Economy and Finance \(2016\)](#), the government is investing in digital infrastructure and training programs to support companies in adapting to Industry 4.0.

According to the OECD report on transforming the labor market through technological innovation and globalization, 9% of jobs in France are likely to be eliminated in the next 10 to 20 years due to the robotization of more than 70% of the regular tasks. Another 30% could be affected by significant changes in the required skills. For these reasons, reports on the French case emphasize the need to transform the French economy into an innovation-driven economy while also strengthening the connections between companies and vocational training institutions.

However, the creation of new digitalized jobs requires a new set of skills/competencies. Law No. 2018-771 of 5 September 2018, on the freedom to choose one's professional future, promotes apprenticeship, alternating training, and long-term education opportunities that enable employees to gain new qualifications. [Sokhanvar and Çiftçioğlu \(2022\)](#) investigated the impact of R&D on employment rates specific to skills in the UK and France. The authors highlight the importance of developing innovation- and technology-related skills to boost economic growth and competitiveness in Industry 4.0.

Recent studies also highlight an emerging phase, Industry 5.0, which seeks to enhance innovation and efficiency through human and machine collaboration ([Knap-Stefaniuk 2023](#)).

Industry 5.0 emphasizes human-centered production, prioritizing employee well-being and sustainability. However, the focus remains on Industry 4.0, as many companies still face challenges in adopting its technologies (Demir et al. 2019; Knap-Stefaniuk 2023). Advancing to Industry 5.0 requires a foundation in Industry 4.0 and preparation through relevant competencies, such as critical thinking, communication, and cross-cultural collaboration (Özdemir and Hekim 2022).

While substantial progress has been made in understanding the skills required for Industry 4.0, particularly in the French context, research gaps persist. Firstly, despite comprehensive studies on technical and digital skills (Amarante et al. 2023; Kovaleski and Picinin 2020), there is limited attention paid to how these skills intersect with soft skills, such as adaptability and intercultural communication, which are becoming increasingly critical in the Industry 4.0 landscape (Demir et al. 2019). Furthermore, while some research has explored the specific challenges of industrial sectors (Bocquet et al. 2017), a holistic view encompassing different sectors and their unique skills demands is still lacking. This study addresses these gaps by examining both technical and soft skills across a range of industrial sectors and academia in France, providing a more comprehensive framework for understanding the competencies needed for Industry 4.0 (Knap-Stefaniuk 2023). The insights gained can contribute to a deeper understanding of how to prepare the workforce for the transition to Industry 5.0 and Society 5.0, where human–machine collaboration and well-being are central (Özdemir and Hekim 2022).

The transition of organizations toward a digital and multicultural work environment, in line with the principles of Society 5.0—a human-centered society aiming to enhance quality of life through technology—is essential (Jones et al. 2020). Industry 4.0 competencies thus serve as a stepping stone, preparing workers for the deeper human–machine synergy envisioned in Industry 5.0 (Stevens et al. 2008). Although Industry 5.0 focuses on the human–machine relationship, the object of study remains to assess the skill needs of the workforce in the context of Industry 4.0.

These studies provide a comprehensive view of the competencies required in Industry 4.0, particularly in France. Innovation, technology, sustainability, communication, and collaboration skills are crucial for success in this new industrial context. Therefore, investing in developing these competencies is of paramount importance to ensure the country's competitiveness and economic growth (Deloitte 2018).

Given this context, Industry 4.0 holds significant potential to benefit the French economy, though it also presents challenges. The French government is actively supporting companies in adapting to the digital landscape to enhance global competitiveness.

Understanding the competencies needed to thrive in this new environment is crucial. Therefore, this study seeks to identify the skills and competencies required of workers in Industry 4.0, as evidenced by studies conducted in France, offering valuable insights for shaping the future research agenda.

2. Industry 4.0 and the Skills for Workers

Industry 4.0 represents not only an opportunity for companies to increase their efficiency and competitiveness, but it also presents challenges that must be overcome. Companies that invest in technology and employee training are expected to be privileged to take advantage of the benefits of Industry 4.0. According to Picinin et al. (2023), the integration of sustainable practices and adaptation to new technologies are essential for companies to remain competitive in this new age of industrialization.

According to Schwab (2016) and Daugherty and Wilson (2018), the benefits brought to companies by implementing Industry 4.0 include reducing operational costs, increasing productivity, and improving product quality. Moreover, Industry 4.0 enables companies to quickly adapt to market changes and customer demands. Guerlinguer et al. (2023) highlight that the ability to adapt requires developing specific skills, such as flexibility and openness to change.

By leveraging these technologies, companies can introduce new products and services, enhance quality, productivity, and customer service, reduce costs, and ultimately adapt to market demands, increase sales, and improve operational efficiency. [Kovaleski et al. \(2022\)](#) explore the challenges associated with technology transfer in Industry 4.0, emphasizing the importance of aligning technical and interpersonal skills.

The study by [Georgieva et al. \(2022\)](#) aligns with the work of [Sokhanvar and Çiftçioğlu \(2022\)](#) by addressing capacity development through the implementation of Programmable Logic Controller (PLC) training for Industry 4.0. The authors emphasize the importance of training professionals to deal with advanced technologies and automated systems in this new industrial context.

Another convergent study by [Tiwarei et al. \(2022\)](#), who conducted a bibliometric analysis on smart manufacturing and sustainability, emphasizes the need to develop skills related to environmental sustainability and the use of digital technologies in the industry, aimed at reducing the environmental impact and increasing production efficiency.

In the context of artificial intelligence, [Kallel et al. \(2023\)](#) investigated the role of exclusivity neglect in human–chatbot interactions. The study’s findings underscore the importance of developing communication and empathy skills to facilitate effective interactions between humans and AI systems.

Finally, the study by [Carayannis et al. 2000](#)) addresses the formation of strategic R&D partnerships between government, universities, and industry in France. According to the authors, it is relevant to leverage knowledge, learning, and innovation in these partnerships to drive the development of the necessary skills for Industry 4.0.

[Jerman et al. \(2020\)](#) classify the skills required for Industry 4.0 based on the model presented in Figure 1. This model identifies six main domains that encompass the essential skills for the modern worker in an advanced production context, promoting the efficient integration of new technologies and processes into operations.

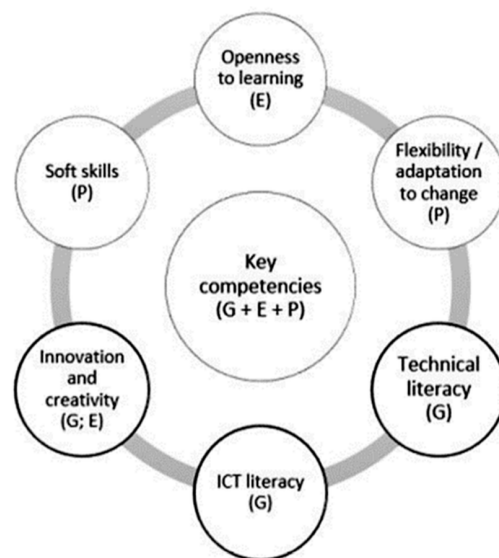


Figure 1. Conceptual key competency model. Source: [Jerman et al. \(2020, p. 75\)](#).

The six competency domains proposed by [Jerman et al. \(2020\)](#) form an essential framework for preparing workers for Industry 4.0. These domains include technical, digital, methodological, social, personal, and managerial competencies. Together, these skills help workers deal with advanced technologies, work in teams, solve complex problems, and lead innovations in a digitalized production environment.

The model proposed by [Blayone and Van Oostveen \(2021\)](#) on preparing workers for Industry 4.0, presented in Figure 2, addresses five essential dimensions that help professionals adapt to this new work environment. These dimensions emphasize the importance of integrating technologies and human skills.

#	Readiness Factor	Readiness Subfactors (KSAs)	Contextual Considerations
1	Technological	(1) Foundational digital skills (2) Advanced IT skills (3) Attitudinal orientations and intrapersonal skills supporting enthusiastic IT use skill development	Level of Industry 4.0 technological maturity Presence of adaptive augmentation systems towards Operator 4.0
2	Flexibility	(1) Multidisciplinary knowledge (2) Openness to dynamically assigned roles and tasks (3) Tolerance of environmental dynamism and emergent problems	Stubbornness of traditional (hierarchical) organisational cultures Broader socioeconomic pressures on manufacturing operations Level of Industry 4.0 technological maturity
3	Inter-agent	(1) Attitudes of openness and comfort toward human-machine partnering (2) A well-calibrated level of trust toward technological agents and automation systems (3) Knowledge and skills for modelling, communicating and calibrating trust with machine agents/robots	Availability and sophistication of collaborative robots, adaptive augmentation systems, wearable tech, expert systems and machine agents Organisational decision-making protocols
4	Interpersonal	(1) Social-networking competencies (2) Communication and negotiation skills (3) Attitudes and skills supporting digital-mediated collaboration problem-solving in dispersed, cross-cultural teams	Distribution of responsibilities among agents in cyber-physical systems Location and diversity of teams Levels of interaction, ranging from coexistence to collaboration, required to achieve objectives
5	Innovation	(1) Creative and adaptive strategic-thinking skills (2) Data-analysis knowledge and software application skills	Creative capabilities of humans and other agents Organisational culture/rules related to conservatism and innovation Level of Industry 4.0 technological maturity

Figure 2. Modelo proposto de cinco dimensões de prontidão do trabalhador para a Indústria 4.0. Source: (Blayone and Van Oostveen 2021, p. 12).

This approach is essential to ensure that workers not only become familiar with new tools, but also develop skills that promote their effectiveness and innovation in a constantly changing industrial scenario (Blayone and Van Oostveen 2021). In this research, a mixed approach of the models of Jerman et al. (2020) and Blayone and Van Oostveen (2021) is used to classify domains, as follows:

- Technical Domain: addresses the skills and abilities necessary to perform specific tasks at work, such as solving complex problems.
- Flexibility Domain: involves the ability to quickly and efficiently adapt industrial operations and processes to changes and flexible demands.
- Agent Interaction Domain: assesses the interactions and collaborations between different autonomous agents to perform tasks and achieve common goals.
- Behavioral and Subjective Skills (“soft skills”) Domain: focuses on the socio-emotional and behavioral skills valued and necessary for professional success in a highly technological and automated environment.
- Innovation Domain: covers the ability to adopt and develop advanced technological solutions, promoting a culture of innovation in processes, products, and services.
- Information Technology Domain: assesses the ability of professionals to effectively use information and communication technologies to improve productivity, efficiency, and innovation in industrial processes.

3. Materials and Methods

The underlying bibliometric analysis methodology employed in this study involved compiling a documentary corpus from documents available in the Scopus™ database up to 2023, with a focus on Industry 4.0 and worker competencies in France. A rigorous systematic review process was employed to gather relevant papers, followed by a qualitative approach to assess their contributions (Grant and Booth 2009).

The Scopus database was selected due to its predominance of high-quality, peer-reviewed journals addressing topics related to internationalization, ensuring both the academic standards and the quality of the papers published and included in this research (Jones et al. 2011). Furthermore, Scopus is one of the leading authorities among interna-

tional sources of academic work publication and one of the most extensive peer-reviewed literature abstracts and citation databases (Vieira and Gomes 2009).

In addition to its extensive coverage, factors such as its multidisciplinary scope, which spans a wide range of disciplines, the availability of advanced analytical tools, including citation analysis, collaboration networks, and impact metrics, and the rigorous selection of sources, which ensures the quality and relevance of indexed articles and journals, particularly in the fields of exact and technological sciences (Passas 2024), collectively substantiate the prioritization of the Scopus database for conducting this research.

3.1. Definition of Search Parameters

The search parameters were established to focus on articles published in the last 20 years, prioritizing those that address Industry 4.0 and the skills needed for the job market. The selection included only peer-reviewed papers, ensuring the quality and relevance of information.

The search in the Scopus database was conducted on 9 October 2023 and was limited to the category “original” and “review papers”. The keyword-based search, presented in Table 1, was designed to maximize the relevance of the results by carefully selecting terms such as “Fourth Industrial Revolution”, “Industry 4.0”, “Smart Manufacturing”, “Cyber-Physical System*”, “CPS”, “Cloud Manufacturing”, “CM”, “Big Data”, “Big Data Analytic*”, “Internet of Thing*”, “IoT”, “Artificial Intelligence”, “competence*”, “skill*”, and “France*”. The search yielded a total of 84 papers.

Table 1. Search documents.

Keywords	Total of Papers
“Fourth Industrial Revolution” OR “Industry 4.0” OR “Smart Manufacturing” OR “Cyber-Physical System” OR “CPS” OR “Cloud Manufacturing” OR “CM” OR “Big Data” OR “Big Data Analytics*” OR “Internet of Things*” OR “IoT” OR “Artificial Intelligence” OR “competence*” OR “skill*” “France*”	84

3.2. Keywords Definition

Keywords were carefully selected, including terms such as “Industry 4.0”, “professional skills”, “technology”, and “work flexibility”. Queries were structured to combine these keywords in order to maximize the relevance of the results, using Boolean operators (AND, OR, NOT) to refine the searches.

During the filtering procedures, four conference papers were eliminated. The documents were screened based on titles and abstracts when necessary.

This study aims to analyze the competencies required in the context of Industry 4.0 in France based on a comprehensive review of the existing literature.

3.3. Filtering Refinement

After the initial collection, the results were filtered based on criteria such as relevance, year of publication, and type of document. Papers that did not meet the established criteria, such as those that were abstracts or were not directly related to the topic, were excluded, resulting in 80 papers for analysis.

The papers were categorized into common areas to provide a holistic view of the necessary competencies, and that the findings can guide professionals, educational institutions, and companies interested in developing talent aligned with the demands of Industry 4.0.

As a result, 80 documents were exported from the Scopus database to a CSV file to conduct the bibliometric analysis. All these documents were considered in the study. R Studio, a free and open-source integrated development environment (IDE), was utilized for the bibliometric analysis, allowing for the execution of scripts in R and data visualization. The Biblioshiny graphical interface, which facilitates interaction with the Bibliometrix package, was employed to manage references and perform detailed analyses of the collected

data. The Bibliometrix package was utilized to configure the tool and conduct more detailed data analyses. The R and RStudio software were used to establish the environment, build it, and analyze the portfolio (Aria and Cuccurullo 2017). The specific version of RStudio used was 2024.09.0+375. After preparation, the Bibliometrix package was configured, and the data and graphs were imported using the Biblioshiny interface.

This study employed a variety of tools to analyze and visualize the data on Industry 4.0 research. Figures 1–3 were generated directly from the Scopus database using data mining and bibliometric analysis techniques. Figures 4–10 were created with the help of the bibliometric tool Bibliometrix, which offers advanced features for network analysis and bibliometric data visualization, including geographic maps, word clouds, cluster analysis, and temporal evolution of research themes.

Documents by year

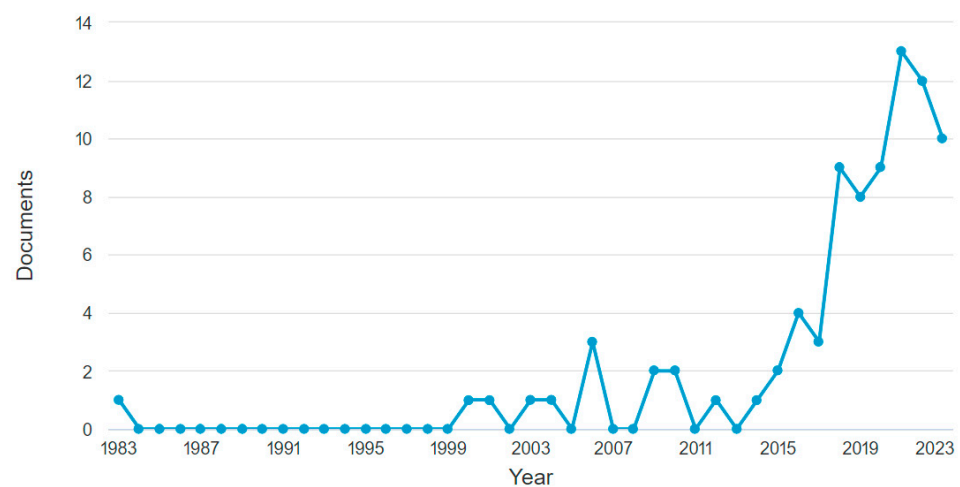


Figure 3. Number of papers published per year.

Documents by subject area

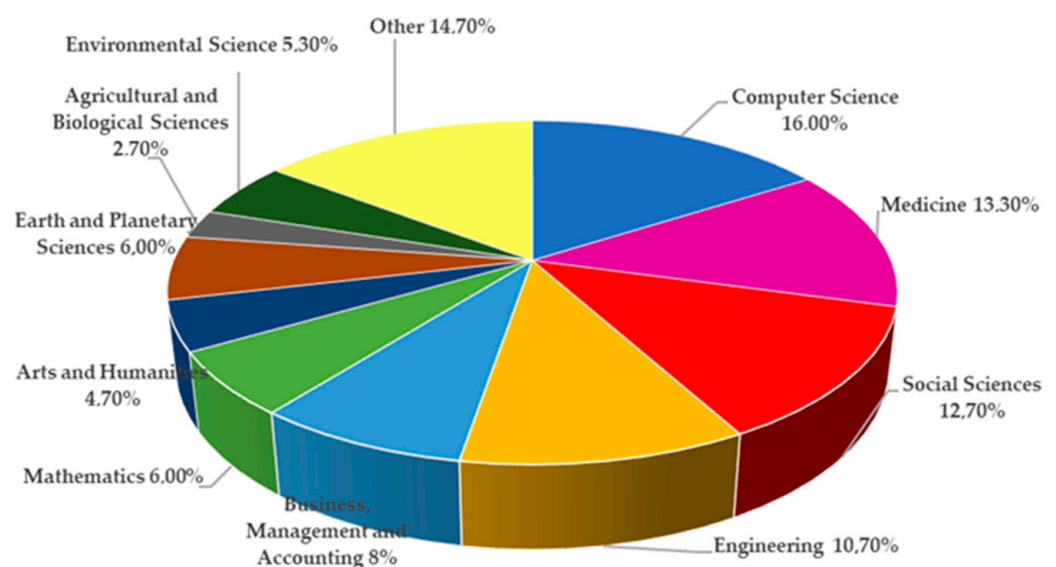


Figure 4. Scope of knowledge areas.

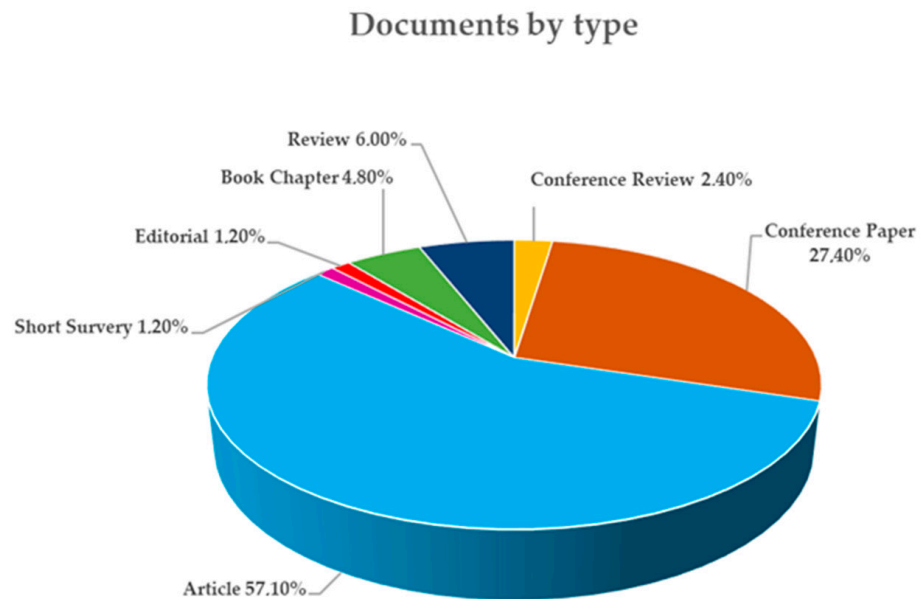


Figure 5. Types of documents.

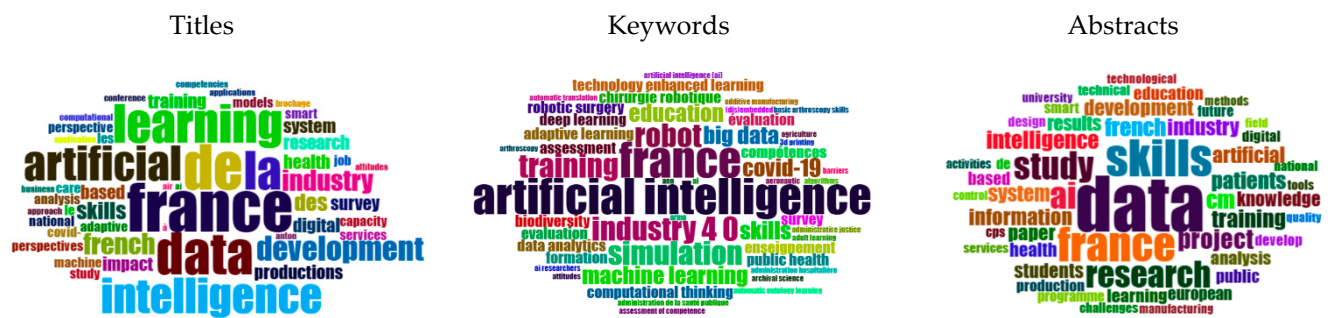


Figure 6. Shows the keyword analysis in the form of word clouds, which helps to identify the topics and focus areas of each paper.

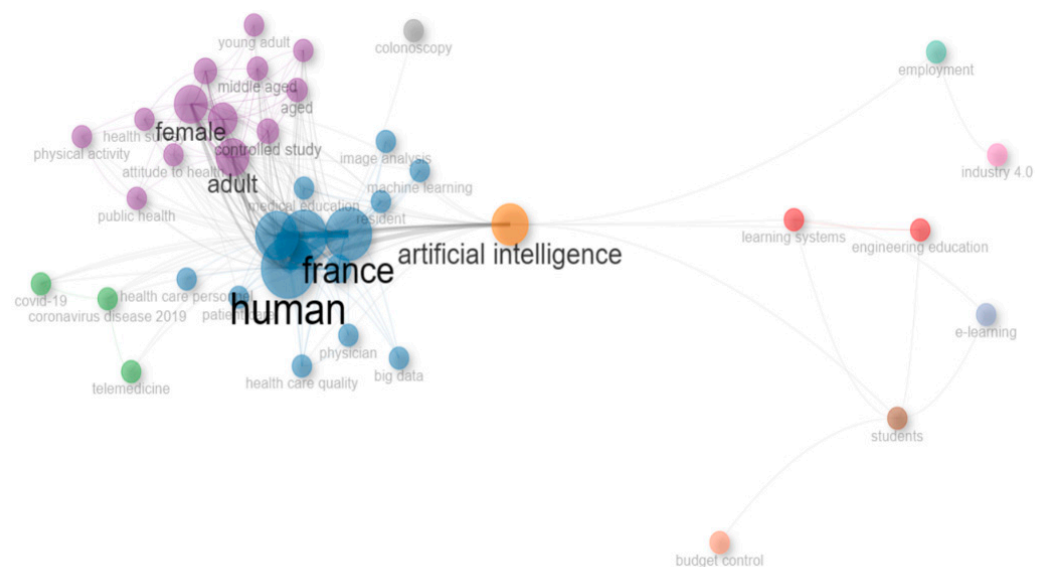
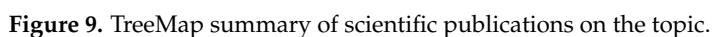


Figure 7. Keyword clusters.



- Annual publication trends: the number of papers published annually since 2016, indicating a growing interest in the field;
- Geographic collaborations: a geographic map highlighting country collaborations in research, with darker shades representing more intense collaboration;
- Publication types: the predominance of scientific papers and conference papers in the academic literature on the subject;
- Keyword analysis: keyword clouds and clusters, respectively, highlighting the most relevant themes and research areas in Industry 4.0;

- Thematic growth over time: the growth of different themes over time based on the most commonly used keywords by authors;
- TreeMap analysis: a TreeMap to show the frequency of words in the abstracts of scientific publications;
- Thematic categorization: a two-dimensional thematic map categorizing the keywords into driving, niche, emerging, or basic themes;
- Historical evolution: A view of the historical evolution of Industry 4.0 research, highlighting temporal trends and key themes identified through factor analysis. These tools enabled a comprehensive and detailed analysis of the scientific production of Industry 4.0, providing valuable insights into trends, collaborations, and areas of interest in the field;
- Qualitative domain analysis: a qualitative analysis establishes six main analysis domains, their respective competencies, and the category “others”.

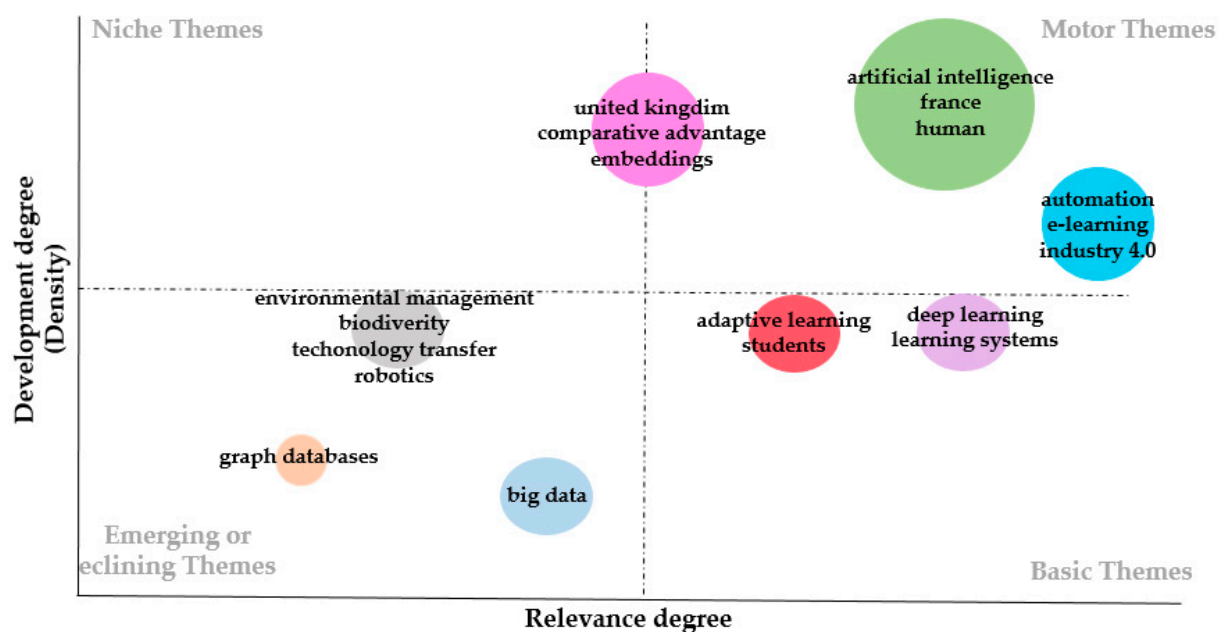


Figure 10. Thematic map of keywords. Source: Authors.

The following section presents the results in detail that were obtained from analyzing the data from the Scopus database. This analysis provides a detailed overview of the publications related to Industry 4.0 in France, highlighting trends, country collaborations, and the competencies required in the contemporary context. Subsequently, conclusions are drawn from the findings, including graphs and tables illustrating the evolution of the research and the areas of most significant interest in the academic literature on the subject.

4. Results

This section presents the results of the data analysis collected from the Scopus database, aiming to provide a comprehensive understanding of publications related to Industry 4.0 in France. The research highlights emerging trends, international collaborations, and the competencies required for workers in this new industrial context.

The study by [Boudjema et al. \(2019\)](#) identified essential competencies and skills for professionals in Industry 4.0 in France, including advanced technological knowledge, problem-solving abilities, and critical thinking. Teamwork and interaction with various fields were also emphasized, as these are considered fundamental in this dynamic environment. Additionally, the ability to work with data and conduct large-scale analyses was repeatedly mentioned in the papers.

The intensive use of big data and analytics for strategic decision making characterizes Industry 4.0 in France. [Boudjema et al. \(2019\)](#) emphasize the need for workers to develop data analysis, programming, and information management skills.

Adapting and engaging in continuous learning is another vital competency for professionals in Industry 4.0 in France. With the constant technological changes and shifts in work practices, workers must be willing to learn new skills and quickly adapt to new market demands.

Figure 3 provides an overview of the number of papers published annually over time on Industry 4.0.

According to the Scopus source, the first related paper was published in 1983, indicating the contemporaneity of the subject. The analysis revealed a significant increase in publications from 2016 to the present date. It is important to note that more papers may emerge by the end of 2023, which were not accounted for in this research.

The publication of papers in 2017, 2019, and 2020 appears to be influenced by a combination of external factors and the research filtering criteria. Prior to 2011, the concept of Industry 4.0 was not known by this specific term; related topics were studied, but not under this nomenclature. It was only after 2011 that the term began to gain traction, facilitating its spread and contributing to the increase in scientific publications.

Regarding external factors, changes in research funding policies, global events (such as the COVID-19 pandemic in 2020), and shifts in research priorities impacted the number of publications. For example, the COVID-19 pandemic diverted researchers' attention to health-related fields, reducing the focus on Industry 4.0 topics, as reported by [Boudjema et al. \(2019\)](#).

Additionally, the fluctuations observed were influenced by the filtering of papers based on specific keywords. Changes in search criteria over time led to variations in the number of identified papers. In certain years, more restrictive keywords or shifts in terminology within the literature may have contributed to lower publication counts.

Figure 4 illustrates the different fields of knowledge in which the papers on Industry 4.0 are categorized.

The distribution shows that the papers are spread across various fields, such as Computer Science, Medicine, Social Sciences, Engineering, Business, Management, and Accounting. Some documents are linked to more than one area of scope. Figure 5 presents the distribution of document types among the analyzed papers.

Most works consist of scientific papers (57.1%) and conference papers (27.4%). Other types include review articles, book chapters, conference reviews, editorials, and short surveys.

The size of the words indicates their frequency: the larger the word, the more frequently it was used in these publications. Themes such as AI, data, skills, learning, development, and France were predominant.

Figure 7 shows the clusters formed with the words used in the titles, keywords, and abstracts in the Scopus database research.

These keywords formed a network of relationships, as presented in Figure 7. This type of network is also known as a thematic network, where keywords are interconnected and form clusters divided by colors, with each cluster potentially representing a theme ([Cobo et al. 2011](#)). The size of each sphere is proportional to the number of publications that contain the respective keyword. At the same time, the thickness of each connection is proportional to the frequency with which the terms appear together in a publication.

Figure 8 represents the growth of different topics over time, as indicated by the keywords most frequently chosen by the authors.

The term "industry" has appeared almost constantly over the years, which explains the consistent emergence of this topic.

Figure 9 presents a TreeMap showing the frequency of words in the abstracts of scientific publications on Industry 4.0.

Keywords such as “Artificial Intelligence”, “France”, and “Human” were the most frequent in the abstracts, highlighting their relevance in this context.

Figure 10 represents a two-dimensional thematic map in which keywords are categorized as themes.

The quadrants indicate the relevance and development of these themes in the research, categorizing them as driving, niche, emerging, declining, or primary and general themes. In the results, the upper-right quadrant of the thematic map contains two clusters with terms such as “artificial intelligence, France, and humans” and “automation, e-learning, and Industry 4.0”, indicating that these are well explored and significant themes in this field of research. The lower-right quadrant also features two clusters with terms like “learning systems” and “adaptive learning”. Although these terms are not grouped together, they are considered basic themes—highly relevant but still underdeveloped.

The thematic evolution of the papers can be observed in Figure 11.

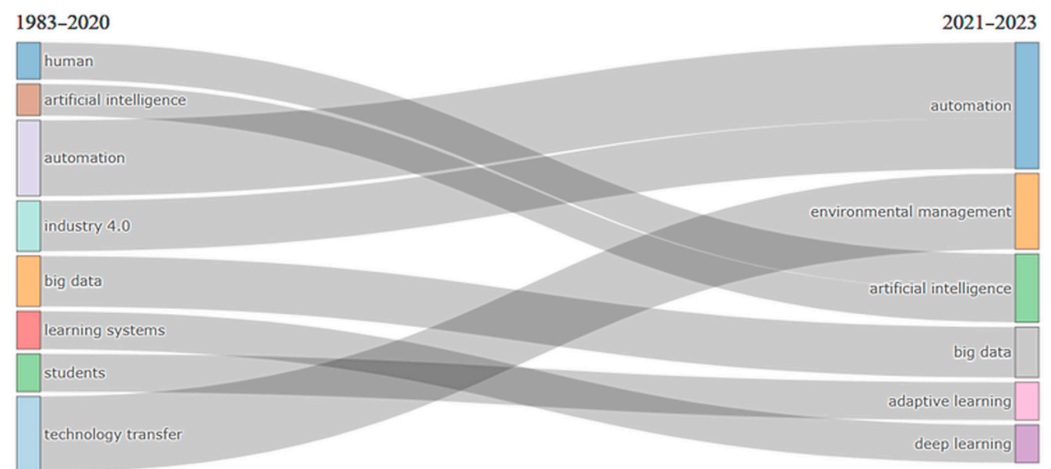


Figure 11. Historical evolution of research on Industry 4.0.

The graph was generated through factor analysis, taking into account “Keywords Plus”, 250 words, and the frequency distribution across eight clusters.

With technological advancements and the widespread adoption of Industry 4.0, substantial changes have occurred in the labor market, requiring the acquisition of new competencies by professionals (Brynjolfsson and McAfee 2014; Schwab 2017). In this scenario, it is crucial to understand the labor market’s needs concerning workers’ competencies to ensure adaptation and professional success.

The analysis of the portfolio’s results from the 80 papers identified six main domains for further examination, along with their respective skills, and an additional category “others”, as shown in Table 2.

Table 2. Domains and skills identified.

Domain/Number of Papers	Authors/Year	Skills
Technical Domain (11 papers)	(Colin et al. 2023); (Pilc et al. 2022); (Santos et al. 2018); (Bonnaud 2019); (Kallel et al. 2023); (Georgieva et al. 2022); (Caruso 2017); (Heiwy 2016); (Candille 2006); (Carayannis et al. 2000); (Bonnaud 2019)	Medical knowledge and clinical procedures; Climate modeling and weather forecasting; Diagnostic medicine and early disease detection; Paleontology and botanical studies; Training in the electronics industry is essential, focusing on the technical and adaptive skills necessary for the sector’s recovery.

Table 2. Cont.

Domain/Number of Papers	Authors/Year	Skills
Flexibility Domain (14 papers)	(Justy et al. 2023); (Bergdahl et al. 2023); (Peterson et al. 2023); (Ranchon et al. 2023); (Zwetsloot et al. 2021) (Bimonte et al. 2021); (Marxer et al. 2021); (Chabin 2020); (De la Sierra 2020); (Matuchansky 2019); (Waymel et al. 2019); (Diebolt et al. 2019); (Custers et al. 2018); (Le Tallec and Joulia 2009)	Skill in adapting teaching and learning practices; Development of frameworks or methodologies for data analysis; Change management and organizational adaptability; Skill in utilizing AI in the medical field.
Inter-agency Domain (7 papers)	(Julia et al. 2023); (Melchior et al. 2022); (Ferriot et al. 2021); (Chevalier-Cottin et al. 2023); (Mori et al. 2020); (Bobbia et al. 2019); (Kontaxakis et al. 2006)	Collaboration and teamwork; Organization of public health activities; Co-construction of climate services; Integration of experimental research approaches in ecology.
Behavioral and Subjective Skills Domain (Soft Skills) (5 papers)	(Pirbhai 2023); (Fejzic et al. 2022); (Sa et al. 2021); (Karoui et al. 2022); (Semet et al. 2019)	Health communication; Communication skills and understanding of social context; Skill in conducting qualitative studies to understand the experiences and perspectives of doctoral students; Problem-solving skills and critical thinking.
Innovation Domain (7 papers)	(Fister et al. 2023); (Fokaides et al. 2022); (Tiwari et al. 2022); (Dumas et al. 2023); (Clobert et al. 2018); (Porras et al. 2016); (Alphandery and Fortier 2015)	Innovation and creative thinking; Exploration of the ethical and social implications of artificial intelligence; Development of an adaptive language learning platform; Application of nature-inspired models.
Information Technology Domain (19 papers)	(Hubert et al. 2019); (Perrier et al. 2022); (Boursicot et al. 2023) (Sokhanvar and Çiftçioğlu 2022); (Giabelli et al. 2021); (Seveso et al. 2021); (Giabelli et al. 2022); (El Mawas et al. 2020); (Carter et al. 2021); (Walbron et al. 2022); (Beagon et al. 2020); (O'Brien et al. 2019); (Alfonso-Hermelo et al. 2019); (Kim and Kim 2018); (Messaadia et al. 2018); (Dunai et al. 2017); (Ben Othman et al. 2016); (Ederer et al. 2015); (François and Lanthony 2014)	Data analysis and trend identification; Development of technological skills; Knowledge and application of telemedicine technologies; Artificial intelligence applied to filtering systems.
Others (17 papers)	(Rozelot and Singh 2022); (Chambonnière et al. 2021); (Marzi 2021); (Laanani et al. 2019); (Fouilloy et al. 2018); (Batté et al. 2018); (Romano et al. 2018); (Hedir and Haddad 2017); (Mele 2017); (Mazin et al. 2016); (Bostyn and Cayol 2012); (Durbec et al. 2010); (Vojtěchovský 2010); (Zoppi et al. 2006); (Gob et al. 2003); (Monnier-Cholley et al. 2001); (Grauvogel-Stamm and Duranteer 1983)	Spectrographic observation and analysis; Knowledge in public health and social impact; Neural machine translation and linguistic analysis; Medical knowledge and clinical procedures; Climate modeling and weather forecasting; Knowledge in reproductive health; Artificial intelligence applied to filtering systems; Artistic analysis and interpretation; Archaeology and geology; Ecology, environmental studies, and analysis techniques; Diagnostic medicine and early disease detection; Paleontology and botanical studies.

This list includes a diverse range of specialized skills and knowledge areas, encompassing key domains such as public health, artificial intelligence, and climate modeling. Each area contributes uniquely to the broader understanding and application of knowledge in its respective fields, underscoring the interdisciplinary nature of modern research and of the respective professionals in Industry 4.0 and human resources management in France.

5. Discussion

5.1. Industry 4.0 Competences in Technical Domain France

The 11 papers in the Technical Domain provide a comprehensive and diverse view of the skills and abilities required to perform specific work-related tasks, including solving complex problems. Each of these works offers valuable perspectives, concentrating on specific aspects of this continually evolving scenario. This focus is crucial for driving technological and organizational advancement, as it enables a deeper understanding of the dynamic interplay between innovation and the changing demands of industries and workplaces (Colin et al. 2023; Pilc et al. 2022; Santos et al. 2018; Bonnaud 2019; Kallel et al. 2023; Georgieva et al. 2022; Caruso 2017; Heiwy 2016; Candille 2006; Carayannis et al. 2000; Bonnaud 2019).

Pilc et al. (2022) highlight the diversity of opinions regarding Industry 4.0, addressing everything from positive views on increased efficiency and productivity to concerns and criticisms. Bonnaud (2019) analyzes technological evolution in France, specifically in the context of ULSI (Ultra Large-Scale Integration) technologies and thin-film semiconductors, emphasizing the importance of partnerships between companies and academic institutions in promoting innovation. In addition to the previously mentioned contributions, Bonnaud (2021) underscores the significance of training in the electronics industry in France. They also highlight that a national recovery plan should incorporate strong training strategies to support the industry's growth and competitiveness. The skills identified in this study include specific technical skills related to electronics and adaptive skills that enable workers to adjust to rapid technological changes.

The literature also included discussions on human–chatbot interaction (Kallel et al. 2023), noting that despite the increasing use of chatbots across areas, they often overlook the individual characteristics of users. Training in Programmable Logic Controllers (PLCs) for industrial automation is addressed by Georgieva et al. (2022), highlighting the importance of these systems in facing the challenges of Industry 4.0. Heiwy (2016) offers design guidelines for the Internet of Things (IoT), emphasizing the importance of user focus, security, and multidisciplinary collaboration. Candille (2006) explores the benefits of automation for efficiency and quality in industrial processes. Carayannis et al. (2000) discuss collaboration between government, universities, and industry to promote innovation and economic growth.

The paper by Santos et al. (2018) discusses the emergence of new business models based on fabrication laboratories, exploring innovation and experimentation in these spaces to develop products and services, both for tech startups and traditional companies adapting to Industry 4.0.

Authors such as Colin et al. (2023) and Georgieva et al. (2022) stress the importance of human resource training in keeping pace with rapid technological advancements. They highlight the need for developing new skills to maintain competitiveness and foster innovation within organizations. Caruso (2017) analyzes the social impact of digital innovation and Industry 4.0 in various sectors of society, addressing profound changes in how people live, work, and interact.

Together, these papers highlight the complexity within the Technical Domain, addressing everything from technical aspects and innovations to socioeconomic issues, emphasizing the importance of adaptation, collaboration, and continuous skill development to thrive in this constantly evolving environment.

5.2. Industry 4.0 Competences in Flexibility Domain in France

In the Flexibility Domain, 14 studies were associated (Justy et al. 2023; Bergdahl et al. 2023; Peterson et al. 2023; Ranchon et al. 2023; Zwetsloot et al. 2021; Bimonte et al. 2021; Marxer et al. 2021; Chabin 2020; De la Sierra 2020; Matuchansky 2019; Waymel et al. 2019; Diebolt et al. 2019; Custers et al. 2018; Le Tallec and Joulia 2009) that explore the ability to adapt operations and industrial processes quickly and efficiently to changing and variable demands. Organizations must be able to adapt in order to remain responsive and

competitive in a world where technology is constantly evolving and consumer demands are continuously shifting. These studies offer various perspectives on integrating data and AI technologies in this context. [Justy et al. \(2023\)](#) examine the barriers and drivers for adopting data analytics in Small and Medium Enterprises (SMEs), underscoring the importance of these tools for strategic decision making. [Bergdahl et al. \(2023\)](#) investigate global attitudes toward AI, emphasizing cultural and individual influences and highlighting self-determination as crucial.

[Peterson et al. \(2023\)](#) propose a typology of managerial approaches to data analysis, considering organizational resources and strategies. [Ranchon et al. \(2023\)](#) explore data linkage techniques to analyze the use of health products and care trajectories, highlighting their utility in health data analysis.

[Zwetsloot et al. \(2021\)](#) examine the immigration preferences of AI researchers, while [Bimonte et al. \(2021\)](#) present a framework for collecting and analyzing agro-biodiversity data in a participatory context. [Marxer et al. \(2021\)](#) address advances in intelligent robotics, highlighting their applications in maritime contexts.

[Chabin \(2020\)](#) discusses the collaboration between AI and archival science, focusing on processing data from the French national debate. [De la Sierra \(2020\)](#) explores the relationship between AI and administrative justice, examining the role of judicial review in this context. [Matuchansky \(2019\)](#) explores AI in the medical field, highlighting the clinician's role in decision making. [Waymel et al. \(2019\)](#) investigate the impact of AI on radiology, while [Diebolt et al. \(2019\)](#) explore AI in clinical research with regard to AI's impact on the quality of medical care.

[Custers et al. \(2018\)](#) compare European Union (EU) data protection policies, emphasizing the need for harmonization for a practical approach. Finally, [Le Tallec and Joulia \(2009\)](#) discuss the MAVDEM project, which refers to the Micro Aerial Vehicle and Digital Elevation Model, highlighting the feasibility of miniature aerial systems in various applications.

These studies within the Flexibility Domain offer a broad and in-depth overview of the implications, challenges, and advances in the convergence of data analysis and artificial intelligence, providing valuable resources for professionals, researchers, and policymakers in this constantly evolving field.

5.3. Industry 4.0 Competences in Inter-Agency Domain in France

The constant advancement of technology has played a fundamental role in transforming healthcare. Seven papers were found on the Inter-Agency Domain ([Julia et al. 2023](#); [Melchior et al. 2022](#); [Ferriot et al. 2021](#); [Chevalier-Cottin et al. 2023](#); [Mori et al. 2020](#); [Bobbia et al. 2019](#); [Kontaxakis et al. 2006](#)), which address the environment in which autonomous agents interact and collaborate to perform tasks and achieve common goals. These papers provide a broad view of the innovations influencing this field and the relevant issues being explored by researchers and professionals in this area.

As discussed by [Julia et al. \(2023\)](#), expanding vaccination competencies for community pharmacists not only increase access to human papillomavirus (HPV) vaccination but also underscores the need for adequate training and effective communication to ensure the safety and quality of the process. This initiative marks a significant step in broadening healthcare services provided by pharmacists and enhancing vaccine efforts.

Contrary, [Melchior et al. \(2022\)](#) reveal how the COVID-19 pandemic negatively impacted chronic pain patients, resulting in increased pain intensity and reduced access to treatments and healthcare services. The authors stress the urgent need to develop strategies to ensure patients with chronic conditions receive continuous care, even during public health crises.

Additionally, [Ferriot et al. \(2021\)](#) address the organization of public health activities in university hospitals in France, highlighting challenges in integration and efficiency. Addressing these challenges and proposing strategies to improve the coordination of activities highlight the critical need for a more integrated approach to delivering public health services. Furthermore, by ensuring more effective resource allocation, improved

cross-sector collaboration, and improved responsiveness to the intricate and changing demands of public health, this approach eventually improves population outcomes and service delivery.

[Chevalier-Cottin et al. \(2023\)](#) reinforce the relevance of clear communication about the benefits of vaccines, aiming to prevent infectious diseases and overcome misinformation and skepticism. This approach is crucial for increasing public trust and ensuring high immunization rates.

Studies by [Mori et al. \(2020\)](#), [Bobbia et al. \(2019\)](#), and [Kontaxakis et al. \(2006\)](#) explore specific advances in medical technologies, such as artificial intelligence in endoscopy, bedside ultrasound in emergency medicine, and telemedicine applications for veterinary oncology. These advances offer significant benefits, such as more accurate diagnoses, real-time monitoring, reduced waiting times for treatment, and improved patient care quality.

Collectively, these studies within the Inter-Agency Domain illustrate the growing importance of technology in healthcare, from enhancements in clinical care to more effective organization of healthcare services. The papers highlight not only technological advancements but also the challenges faced in implementing and communicating these innovations, emphasizing the ongoing need for interdisciplinary research and collaboration to promote better outcomes in healthcare.

5.4. Industry 4.0 Competences in Behavioral and Subjective Skills Domain (Soft Skills) in France

The Behavioral and Subjective Skills Domain (Soft Skills) ([Pirbhai 2023](#); [Fejzic et al. 2022](#); [Sa et al. 2021](#); [Karoui et al. 2022](#); [Semet et al. 2019](#)) encompasses a range of socio-emotional and behavioral skills that are highly valued and essential for professional success in an increasingly technological and automated work environment. These competencies highlight specific and significant facets of emotional intelligence, communication, and adaptability—all of which are essential for succeeding in today's businesses.

[Pirbhai \(2023\)](#) conducted a qualitative study on the training of PhD candidates in French Studies, focusing on the experiences of doctoral candidates in Mauritius and France. This study demonstrates the need to adapt the training of PhD candidates in French Studies to enhance student experiences and better prepare them for the job market.

[Karoui et al. \(2022\)](#) explored the development of an automated and adaptive language-learning platform. By emphasizing the importance of personalization in language teaching, this study points to the relevance of more individualized approaches in the learning process, aiming to improve students' language skills.

[Sa et al. \(2021\)](#) shared valuable lessons from the Smart Machines-CTIC-UNI program, which refers to the Information and Communication Technology Center of the National University of Engineering (UNI), emphasizing the importance of developing capacities in intelligent technologies for university students in Peru. This paper offers insights into the challenges and opportunities in the specific context of capacity building in technology-related areas.

In the context of the pandemic, [Fejzic et al. \(2022\)](#) highlighted the challenges faced by veterinary education institutions in the Mediterranean region. Their paper provides a detailed account of the strategies employed to maintain the educational quality during this challenging period, emphasizing the critical adaptations required to ensure the continuity of teaching.

Finally, [Semet et al. \(2019\)](#) explore the application of Ant Colony Optimization (ACO) concepts to develop an adaptive rewards system in serious games. The research is part of the European H2020 In Life project (a project funded by the European Union under the Horizon 2020 (H2020) program), which aims to integrate modern technologies into education using severe games, connected objects (IoT), and artificial intelligence. The research suggests that applying algorithms inspired by ant colonies can offer an innovative approach to personalizing and optimizing learning experiences in educational environments. The study is based on swarm intelligence principles, where the collective behavior of simple entities

(such as ants) is used to solve complex problems. The system uses success and failure pheromones to guide the adaptation of rewards.

In addition to highlighting the need for PhD training in French Studies to adjust for better student experiences and job market preparation, the main findings of the studies related within the Behavioral and Subjective Skills Domain (Soft Skills) highlight the significance of emotional intelligence, communication, and adaptability, in today's technologically advanced work environment. Additional insights from studies on individualized language learning, capacity building in intelligent technologies, maintaining educational quality during crises, and the creative application of swarm intelligence in educational platforms are also included.

5.5. Industry 4.0 Competences in Innovation Domain in France

Seven studies were analyzed in the Innovation Domain (Fister et al. 2023; Fokaides et al. 2022; Tiwari et al. 2022; Dumas et al. 2023; Clobert et al. 2018; Porras et al. 2016; Alphandery and Fortier 2015) that discuss the ability of individuals to adopt and develop advanced technological solutions and foster a culture of constant innovation in their processes, products, and services. These studies address essential aspects of using technology to promote environmental sustainability in various areas.

Fister et al. (2023) mark the importance of using machine learning models and data reduction techniques in accurately forecasting air temperature over the long term. The authors emphasize the limitations of traditional forecasting approaches, highlighting the relevance of these methods for urban, agricultural, and natural resource management applications.

Fokaides et al. (2022) focus on using "digital twins" to drive research in intelligent and carbon-neutral built environments. These models can optimize the performance of buildings and infrastructure, aimed at energy efficiency and sustainability, contributing to a more innovative and lower environmental impact built environment.

Tiwari et al. (2022) conducted a bibliometric analysis on the intersection between smart manufacturing and sustainability, identifying trends and the growing importance of integrating these concepts in the industry, underscoring the need for sustainable approaches in manufacturing and emphasizing the crucial role of technology in this process.

Dumas et al. (2023) explore the co-construction of climate services based on networks of weather stations. This approach can offer valuable insights into local climate conditions, helping to support informed decision making across various sectors.

Clobert et al. (2018) discuss integrating experimental research approaches in ecological and environmental studies, using the AnaEE (Analysis and Experimentation on Ecosystems) France research infrastructure as an example to facilitate experiments in ecology.

Porras et al. (2016) present a master's program on pervasive computing and communications for sustainable development. The authors emphasize the training of professionals capable of applying technology sustainably in different sectors, recognizing the importance of a responsible and sustainable approach.

Alphandery and Fortier (2015) discuss the challenges of transparency in collecting and using naturalist data, highlighting ethical, privacy, and security issues and demonstrating how projects using these data contribute to a better understanding of biodiversity and ecosystems.

These seven studies within the Innovation Domain offer a comprehensive perspective on how technology can be applied sustainably in various contexts, from accurate climate forecasting to training professionals and ethics in data collection, playing critical roles in promoting technological sustainability.

5.6. Industry 4.0 Competences in Technology Domain in France

In the Information Technology Domain, 19 papers were analyzed (Hubert et al. 2019; Perrier et al. 2022; Boursicot et al. 2023; Sokhanvar and Çiftçioğlu 2022; Giabelli et al. 2021; Seveso et al. 2021; Giabelli et al. 2022; El Mawas et al. 2020; Carter et al. 2021; Walbron et al. 2022; Beagon et al. 2020; O'Brien et al. 2019; Alfonso-Hermelo et al. 2019; Kim and Kim

2018; Messaadia et al. 2018; Dunai et al. 2017; Ben Othman et al. 2016; Ederer et al. 2015; François and Lanthony 2014). These studies are essential to understanding and addressing the demands of Industry 4.0 in France. They provide insights into how professionals can effectively use and leverage available information and communication technologies to improve productivity, efficiency, and innovation in industrial processes.

While Perrier et al. (2022) and Hubert et al. (2019) highlight the growing importance of artificial intelligence in medicine and healthcare, emphasizing the need to understand how professionals in pediatrics perceive and apply this technology in their practices, others like Boursicot et al. (2023) and Carter et al. (2021) focus on competency assessment, addressing training models to enable individuals to contribute to the Sustainable Development Goals (SDGs) and discussing the future of competency assessment in medical education and other health-related areas.

Sokhanvar and Çiftçioglu (2022) research analyzes the impact of Research and Development (R&D) investment on employment rates across different skills, highlighting the relationship between innovation and job creation in specific sectors. The systems presented by Giabelli et al. (2021) and Seveso et al. (2021)—Skills2Graph and Skills2Job—address the matching of candidates' skills with job opportunities, using graph databases to tackle skill mismatches in the labor market.

El Mawas et al. (2020) explore the use of adaptive educational games to foster computational thinking skills in adults. Beagon et al. (2020) focus on developing a framework aimed at stimulating creative and innovative skills in engineering students.

Studies such as those by Alfonso-Hermelo et al. (2019), O'Brien et al. (2019), Messaadia et al. (2018), and Dunai et al. (2017) focus on technology-driven learning systems, project-based learning, and specific skill analysis to promote professional and economic growth.

Authors like Kim and Kim (2018), Ben Othman et al. (2016), Ederer et al. (2015), and François and Lanthony (2014) highlight essential skills such as computational thinking, problem solving, and collaboration, applicable to teacher training, human resource management, and systems engineering. These authors provide a multifaceted view on the fundamental skills and innovations needed to thrive in Industry 4.0 in France, emphasizing the importance of continuously adapting technical and non-technical skills for success in a rapidly changing environment.

5.7. Industry 4.0 Competences in Others Categories

The set of papers by various authors (Rozelot and Singh 2022; Chambonnière et al. 2021; Marzi 2021; Laanani et al. 2019; Fouilloy et al. 2018; Batté et al. 2018; Romano et al. 2018; Hedir and Haddad 2017; Mele 2017; Mazin et al. 2016; Bostyn and Cayol 2012; Durbec et al. 2010; Vojtěchovský 2010; Zoppi et al. 2006; Gob et al. 2003; Monnier-Cholley et al. 2001; Grauvogel-Stamm and Duranteer 1983) cover various topics unrelated to the core focus of Industry 4.0 in France and human resources. These papers delve into technologies like the Internet of Things (IoT), artificial intelligence, automation, advanced manufacturing, and digital interconnection in industrial production. While their contributions are valuable within their specific fields, they present limitations when applied to this particular research focus.

Among these works, there are investigations on topics such as the spectroscopy of coronal emissions (Rozelot and Singh 2022), side effects of COVID-19 restrictions on children (Chambonnière et al. 2021), impact of machine translation on gender language (Marzi 2021), risk factors in colonoscopies (Laanani et al. 2019), solar forecasting through machine learning (Fouilloy et al. 2018), heatwave prediction in Africa (Batté et al. 2018), post-surgical fertility (Romano et al. 2018), automatic filtering of radar echoes (Hedir and Haddad 2017), mathematical techniques (Mele 2017), archaeological sites (Mazin et al. 2016), production techniques, geographical distribution, and cultural significance of these specialized productions (Bostyn and Cayol 2012), early melanoma diagnosis (Durbec et al. 2010), political biographies (Vojtěchovský 2010), research investigating the properties and characteristics of this hematite (Zoppi et al. 2006), applying the lichenometry technique

to study the historical and recent dynamics and sediment transport of the Figarella River in Corsica (Gob et al. 2003), based on a French experience, discussing the challenges in early diagnosis and its impact on treatment efficacy (Monnier-Cholley et al. 2001), and the importance of species in the evolutionary history of plants (Grauvogel-Stamm and Duranteer 1983).

The Information Technology Domain studies offer important insights into the role of ICTs in France's Industry 4.0, with a focus on the use of AI, adaptive learning environments, R&D effects on employment, and creative systems like Skills2Graph and Skills2Job that use graph databases to solve skill mismatches in the labor market. All of these point to the necessity of ongoing adaptation of both soft and hard skills in a rapidly changing industrial environment.

However, it is important to recognize that Industry 4.0 in France extends beyond technology to encompass social, environmental, and cultural dimensions. As such, these studies may offer complementary perspectives, providing valuable insights into interdisciplinary issues that shape the Industry 4.0 era. By exploring these broader contexts, the research can help illuminate the challenges and opportunities that arise, enhancing our understanding of the multifaceted impacts of technological advancements on society and the environment.

The analysis of the six domains, along with the "Other" category, established in the portfolio of 80 articles related to Industry 4.0 and competencies in France, highlights the significance of a multidisciplinary and comprehensive approach to addressing the challenges and opportunities presented by this technological transformation.

Among the six domains evaluated, the Technical Domain is pivotal, as it directly engages with the concepts, technologies, and impacts of Industry 4.0. It covers critical topics such as automation, the Internet of Things (IoT), big data, cloud computing, augmented reality, among others. This category is fundamental to understanding the changes in the workplace, the digitization of production processes, and the emerging demand for new skills.

Each of the analyzed domains plays an essential role in understanding and implementing Industry 4.0 in France, as well as in fostering the competencies required for success in this context. These domains address various aspects of technological transformation, ranging from core concepts and technologies to social, environmental, and educational issues. Given the diversity of these domains, an integrated and holistic approach is crucial for effectively tackling the challenges and maximizing the opportunities offered by Industry 4.0.

5.8. Theoretical Implications of the Study

The theoretical implications of this study have enhanced the understanding of capabilities in Industry 4.0 and their constant evolution. Santos et al. (2018) and Caruso (2017) explored how digital transformation has shaped innovation theories, introducing new paradigms on how companies and workers adapt to technological changes. Carayannis et al. (2000) further expanded this discussion by highlighting the triple helix model of collaboration between government, industry, and academia as a key theoretical framework for fostering innovation. This theoretical understanding served as a basis for research that explored the interaction between the public and private sectors in the promotion of core capabilities. Peterson et al. (2023) contributed theoretically by proposing a typology for the analysis of organizational data, which explored different managerial approaches and helped to understand how companies could align their data strategies with internal capabilities. This typology provided a conceptual foundation for studies on data analysis and information management strategies in Industry 4.0. Custers et al. (2018), in their study on data protection policies in the European Union, highlighted the importance of regulatory harmonization to ensure that privacy and security were managed uniformly, bringing relevant theoretical implications for AI governance.

The study by [Julia et al. \(2023\)](#) on the expansion of the role of pharmacists in vaccination brought theoretical implications for the flexibilization of professional competencies in health. This change suggested a new model of pharmaceutical practice that combined specialized training with a focus on communication, expanding the scope of pharmacists' work and questioning the traditional division of responsibilities in the health system. [Melchior et al. \(2022\)](#) introduced theoretical questions about the vulnerability of chronic patients during public health crises, encouraging reflection on how health policies and systems could be adapted to ensure more resilient and equitable care.

[Pirbhai \(2023\)](#) and [Karoui et al. \(2022\)](#) highlighted the importance of adapting educational programs to increasingly globalized contexts and aligning them with labor market needs, contributing to the theory of adaptive and personalized education. [Sa et al. \(2021\)](#) emphasized the value of training students in advanced technologies, supporting theories that advocate for the role of digital skills in contemporary education. Research by [Fejzic et al. \(2022\)](#) in the context of the COVID-19 pandemic reinforced theories on educational resilience and the adaptability of teaching methods during crises.

Regarding the theoretical implications on skills–job matches, [Giabelli et al. \(2021\)](#), ([Giabelli et al. 2022](#)) and [Seveso et al. \(2021\)](#) with the Skills2Graph and Skills2Job systems highlighted the relevance of graph-based methodologies in the analysis of skills mismatches in the labor market. These studies suggest that using databases and complex algorithms for skills matching is a promising area, particularly with the application of artificial intelligence in job and skill analysis and recommendation. Additionally, [Beagon et al. \(2020\)](#) developed frameworks for fostering innovation and creativity, essential elements in the professional training of engineers. Each study provides new perspectives and valuable contributions to the field of skills in Industry 4.0.

[Fister et al. \(2023\)](#) contributed to the understanding of how machine learning methods overcame the limitations of traditional approaches in climate prediction. [Fokaides et al. \(2022\)](#) expanded the understanding of the use of digital twins in the development of smart built environments, proposing a new focus on efficiency.

These theoretical contributions provide a more comprehensive and well-founded perspective on the skills required for Industry 4.0, encouraging the development of new approaches and insights for both academia and the productive sectors.

5.9. Practical Implications of the Study

The practical implications of the studies analyzed underscore the importance of implementing policies and programs for the qualification and requalification of workers. [Georgieva et al. \(2022\)](#) emphasized that training in Programmable Logic Controllers (PLCs) is essential for addressing the challenges of automation, enabling organizations to optimize their production processes. [Bonnaud \(2019, 2021\)](#), in turn, highlighted the need for a national recovery plan with robust training strategies, deemed crucial for sustaining the growth in the electronics industry.

[Heiwy \(2016\)](#) addressed guidelines for IoT design, emphasizing the importance of practices focused on security and usability, which was considered crucial for the acceptance of new technologies. The collaboration between government, universities, and companies, discussed by [Carayannis et al. \(2000\)](#), highlighted the relevance of an integrated approach to develop skills that sustain innovation in the industrial sector, promoting technological advancement.

[Marxer et al. \(2021\)](#) demonstrated the practical potential of intelligent robotics by exploring its applications in the maritime sector, an environment characterized by physical and operational challenges. The study highlighted how robotics could optimize operations in hard-to-reach locations, representing a practical solution to logistical and safety issues. [Ranchon et al. \(2023\)](#) analyzed the use of data linkage techniques in healthcare to monitor care pathways, an approach that favors more integrated and efficient public health policies, especially in high-demand contexts.

In the healthcare field, [Matuchansky \(2019\)](#) investigated the use of AI to support diagnostics and treatments, reinforcing the importance of the active participation of healthcare professionals to ensure effective and ethical implementation. [Julia et al. \(2023\)](#) highlighted the expansion of pharmacists' roles, suggesting that this practice could improve vaccination coverage and access to services in areas with a shortage of professionals, especially if accompanied by training programs.

In the educational field, studies underscore the importance of behavioral and emotional skills. [Pirbhai \(2023\)](#) suggested that doctoral programs should include training in emotional intelligence and adaptability to better prepare students for the job market. The work of [Karoui et al. \(2022\)](#) offered practical insights for the design of personalized educational platforms, while [Sa et al. \(2021\)](#) reinforced the need for partnerships with educational institutions to develop relevant technological capabilities.

Finally, the practical implications for sustainability were also stressed. [Fister et al. \(2023\)](#) suggested that machine learning models applied to climate prediction could benefit sectors dependent on accurate forecasts, such as agriculture. [Fokaides et al. \(2022\)](#) discussed the applicability of digital twins in optimizing energy efficiency, while [Tiwari et al. \(2022\)](#) pointed to the importance of policies to encourage the adoption of green practices in the industrial sector.

The practical implications, therefore, emphasize that Industry 4.0 requires not only technological upgrades but also structural changes, training, and incentive policies to support its effective implementation.

Thus, based on the findings of previous articles, the practical implications could include the following: (i) developing technical training programs in specific areas (e.g., programming, data analysis, cybersecurity) and integrating this knowledge into the daily operations of workers; (ii) establishing partnerships with universities to develop joint training programs and seeking government incentives for technological innovation programs; (iii) implementing customized training programs for different employee profiles, based on their experience, previous skills, and functions in the company; (iv) developing interpersonal skills, such as leadership, teamwork, and negotiation and communication skills, to improve collaboration between different departments and companies; (v) encouraging innovation, improvement suggestion programs, and the creation of environments that stimulate the exchange of experiences; and (vi) training on global digital culture, adaptability to different markets, and management of international teams, in addition to promoting language learning and intercultural skills.

5.10. Limitations of the Research

One limitation of this research is its reliance solely on documents from the Scopus database, which may restrict the diversity of perspectives and exclude relevant research not indexed on this platform. Additionally, the qualitative approach may not capture the complexity of skills required in Industry 4.0.

These limitations suggest the need for a more comprehensive approach that incorporates multiple data sources and methodologies, contributing to a more robust theory on Industry 4.0 skills. Such an approach could lead to a deeper understanding of the interactions between technology, economy, and society.

In summary, these limitations highlight the need for more integrated and adaptable approaches that support a broader, more effective application of Industry 4.0 technologies and skills, taking into account the specific needs of different sectors and regions.

5.11. Future Research Agenda for Industry 4.0 in France

With the advancement of Industry 4.0, research must delve into various areas to understand its impact and potential on the French economy. Authors like Klaus [Schwab \(2016\)](#), in "The Fourth Industrial Revolution", and other experts have highlighted the importance of exploring the interactions between technology, economy, and society. Below

is a proposed future research agenda to contribute to a broader understanding of the skills and challenges in Industry 4.0.

Based on the discussion in the paper, we suggest the following future research directions:

1. **Impact of Industry 4.0 on the French Economy:** Investigate more deeply how the implementation of Industry 4.0 in France is influencing the French economy, considering both the benefits and challenges companies face. Authors like [Brynjolfsson and McAfee \(2014\)](#), in “The Second Machine Age”, discuss how automation and digitization are transforming business models and productivity, which can be applied to the French context to understand the economic implications.
2. **Development of Interpersonal Skills in Industry 4.0 in France:** Explore the importance of interpersonal skills, such as communication, teamwork, and leadership, for professionals working in Industry 4.0 in France and how these skills can be developed and enhanced. [Goleman \(1995\)](#), in his work on emotional intelligence, emphasizes the relevance of interpersonal skills in the workplace, which is crucial for collaboration in multidisciplinary teams in Industry 4.0 in France.
3. **Public Policies and Innovation in Industry 4.0 in France:** Analyze the role of public policies in promoting innovation and the digitalization of the French industry, identifying best practices and potential improvements to support the transition to Industry 4.0 in France. Authors like [Porter and Heppelmann \(2014\)](#), in “How Smart, Connected Products Are Transforming Competition”, discuss how public policies can influence industry competitiveness, suggesting that a favorable regulatory environment is essential for innovation.
4. **Curriculum Adaptation and Professional Training:** Evaluate the adequacy of educational curricula and professional training programs to the demands of Industry 4.0, identifying opportunities for updating and enhancing them to prepare workers for future challenges. The research by [Boudjema et al. \(2019\)](#) highlights the need to integrate technical and interpersonal skills into curricula, emphasizing the importance of training that meets the demands of the contemporary labor market.
5. **A Comparison Across Different Social Levels Regarding Skills in Industry 4.0 in France:** This future research agenda can contribute to a more comprehensive understanding of the skills required for workers in Industry 4.0 in France. Authors like [Sen \(1999\)](#), in his work on human development, argue that social inequalities can impact access to education and training, which is crucial to understanding how different social groups adapt to the new demands of Industry 4.0 in France.

The future research agenda could enhance the understanding of the skills required for workers in Industry 4.0 in France, facilitating the development of effective strategies for adaptation and innovation in the continuously evolving industrial environment.

6. Conclusions

The transition to Industry 4.0 in France is redefining the global industrial landscape, and France is adapting to this technological revolution. Based on the analysis of 80 papers on the skills required in Industry 4.0, this study highlights the crucial importance of multi-disciplinary skills in addressing the challenges and seize the opportunities of this evolving environment. This paper aimed to identify the skills required of workers in Industry 4.0 through studies conducted in France, providing valuable insights for developing a future research agenda.

By mapping the technical and interpersonal skills required, the research provides significant guidance for training professionals who can adapt and thrive in Industry 4.0 in France. Thus, it contributes to the development of a future research agenda that seeks to deepen the understanding of the impact of Industry 4.0 on France’s economy and professional training practices, preparing a more innovative and resilient workforce.

The essential skills for success in Industry 4.0 in France involve proficiency in information technology, automation, robotics, artificial intelligence, data analysis, project management, and interpersonal skills. Adaptability and collaboration are equally crucial

for this new industrial era. Furthermore, the analysis of the six domains identified in the study—Technical Domain, Flexibility, Inter-Agency, Soft Skills, Innovation, and Information Technology—reveals the need for an integrated and holistic approach to developing skills in Industry 4.0 in France.

These domains address different aspects of technological transformation and its implications in the workplace. Understanding and interconnecting them is fundamental to ensuring that professionals are equipped to meet emerging challenges and take advantage of the opportunities that Industry 4.0 offers in France, thereby promoting sustainable and competitive development in the industrial sector. This study provides a comprehensive overview of the skills required in Industry 4.0, guiding professionals, educational institutions, and companies in preparing talent aligned with emerging demands.

The importance of international collaboration, technologies such as artificial intelligence and data analysis, and the need for sustainable practices in the industry are also highlighted. These findings contribute to advancing knowledge in this area and offer valuable recommendations for strategic decisions and policies related to Industry 4.0. With investment in advanced technologies and professional training, France is well positioned to thrive in this new industrial era.

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