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Toward Quality 4.0: Identifying trends for future studies

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Abstract. Industry 4.0 (I4.0) has driven significant changes in organizational processes for product and service development. As result, companies have created strategies and practices to implement I4.0 technologies in various areas, such as quality, occupational health and safety, and marketing. The implementation of I4.0 technologies in quality, known as Quality 4.0 (Q4.0), can improve operational performance and financial results for organizations. Q4.0 enables the identification and implementation of process, product, and service improvements, facilitates more assertive decision-making, monitors and controls defects, and improves the design and development of new products, etc. However, Q4.0 is an emerging topic, and organizations may encounter challenges in implementing it effectively. Therefore, this work aims to identify and systematize the main scientific gaps in Q4.0 to support

the development of new studies that contribute to the advancement of this research field. A literature review was conducted to select and analyze articles and scientific reviews published in the Scopus database. The scientific gaps identified were grouped into six clusters according to their affinities. Thus, this work contributes theoretically to the thickening and expansion of theory on the subject, supporting the development of new research on Q4.0. In a practical way, this study contributes to increasing customer satisfaction and the competitiveness of organizations.

Keywords: Quality 4.0; Industry 4.0; Quality management.

1. Introduction

Industry 4.0 (I4.0), also referred to as the fourth industrial revolution, emerged in 2011 and has changed the way companies develop their processes, products, and services. I4.0 aims to make organizations more autonomous, flexible, and collaborative through the intensive use of different technologies, such as the Internet of Things, big data, cloud computing, collaborative robots, and blockchain [1–3]. In this context, many organizations have sought strategies to implement these technologies in their areas, such as production, quality, environment, and human resources [4]. The use of I4.0 technologies in quality, known as Quality 4.0 (Q4.0), is the focus of this paper.

Q4.0 refers to the deployment of I4.0 technologies in quality control, quality assurance, and total quality management. It helps managers customize products, identify non-conformities, improve processes, make decisions more assertively, and reduce costs related to the waste of resources. Thus, Q4.0 helps organizations stand out from their competitors [1, 2, 5]. However, despite its benefits, many companies still have difficulties implementing these technologies in the quality area, requiring more studies on this subject [1, 3].

[6] reviewed the literature and identified the key ingredients for the implementation of Q4.0, which are: handling big data, improving prescriptive analytics, using Q4.0 for effective vertical, horizontal, and end-to-end integration, using Q4.0 for strategic advantage, leadership in Q4.0, training in Q4.0, organizational culture for Q4.0, and top management support for Q4.0. [5] identified and analyzed the organizational readiness factors that contribute to the implementation of Q4.0 through an online survey. They identified top management commitment, leadership, and organizational culture as the most important factors for effective Q4.0 implementation in organizations.

Although Q4.0 is becoming more and more the subject of research, it is still incipient and requires more studies [6–8]. According to [7], more studies should identify and analyze the challenges of Q4.0 development. Therefore, this work aims to fill the research gap by addressing the following research question: What are the major scientific gaps that need to be filled for the development of Q4.0? To answer this question, the objective of this paper is to present and discuss the main scientific gaps identified through the literature.

2. Research Method

The research method of "literature review" was employed in this work to collect relevant publications about Q4.0. This method allows for the in-depth and critical analysis of the subject studied [8]. Consequently, it was possible to identify and recommend research areas that require further studies for the development of Q4.0, referred to as scientific gaps. The steps for the development of this work are presented in Figure 1.

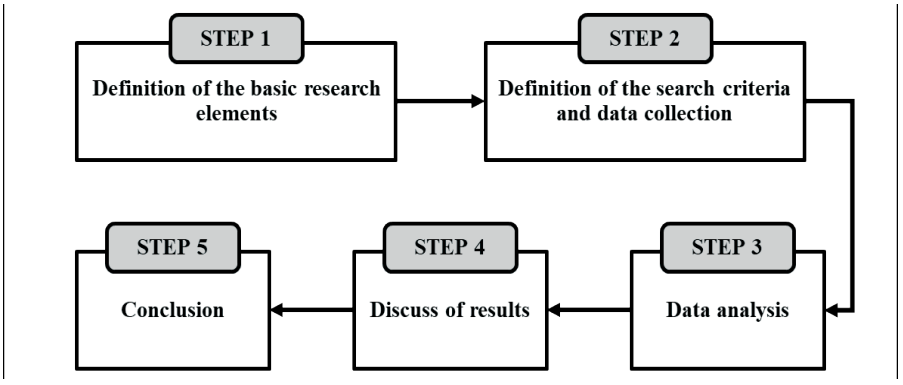

Figure 1. Methodological flow for the development of this work.

In Step 1, the basic elements of research, such as topic, research question, research gap, and research method, were defined. In Step 2, the search criteria for documents were established. The term "Quality 4.0" was searched within the titles of articles and scientific reviews in the Scopus database. This database was chosen due to its extensive coverage and relevance to the subject under study. The search was limited to articles and scientific reviews, as they are a more reliable source of information. Furthermore, only publications in English were selected, as it is the most widely used language in scientific literature [9]. It is worth emphasizing that quotation marks

were employed to identify documents that are more trustworthy and related to the researched topic (Q4.0). This search was conducted in September 2022, resulting in the discovery and collection of 35 scientific publications.

In Step 3, the authors began the reading and detailed analysis of the publications collected to identify their scientific gaps. In Step 4, the 35 scientific gaps were grouped into six clusters according to their similarities. These clusters are presented and discussed in Section 3. In Step 5, the conclusion was elaborated, presenting the theoretical and practical contributions of this work.

3. Results and Discussion

This section presents the 35 scientific gaps in Q4.0 identified in articles and reviews collected from the Scopus database. They were categorized into six clusters based on their similarities. In other words, these clusters are comprised of scientific gaps that exhibit common characteristics (Table 1). The clusters represent crucial areas for further research to advance and improve Q4.0. They provide significant recommendations for future studies.

As shown in Table 1, the proposed clusters are: Implementation of Q4.0, Implications of Q4.0, Expansion of Q4.0, Skills and Competencies for Q4.0, Empirical Studies in Q4.0, and Q4.0 and Quality Management System.

Table 1. Clusters of scientific gaps in Q4.0.

Cluster	Scientific gaps	Articles
Implementation of Q4.0	Create models and strategies to assist in the implementation of I4.0 technologies in the quality management system	[10]
	Map strategies for the development and maintenance of Q4.0 in organizations from different countries	[3]
	Propose models and strategies to assist in the successful development of Q4.0 in organizations	[7]
	Create strategies to evaluate the quality management system of companies after the integration of I4.0 technologies	[11]
	Develop strategies and tools for integrating Q4.0 with the dimensions of organizational performance	[12]
	Create strategies to align Q4.0 with sustainability	[13]

Cluster	Scientific gaps	Articles
Implications of Q4.0	Identify and categorize the investments required to implement Q4.0 in organizations	[14]
	Identify, empirically, the main motivations, difficulties, and solutions that companies have encountered when implementing Q4.0	[5]
	Identify the barriers that hinder the implementation of Lean Six Sigma using Q4.0	[15]
	Analyze the influences of Q4.0 on organizational performance dimensions (financial performance, customer value proposition, internal business processes, environmental performance, and social performance)	[1]
	Conduct empirical studies to identify the main motivations, difficulties, and solutions that companies from different sectors have when implementing Q4.0	[2]
	Analyze and measure economically the costs and investments required to implement Q4.0	[16]
	Propose metrics to measure the impacts of Q4.0 on organizations	[4]
	Determine and analyze the different types of resources needed to implement Q4.0 in organizations	[17]
	Propose solutions to major Q4.0 barriers, such as data privacy	[18]
	Analyze and determine the impact of using different types of leadership on Q4.0	[19]
Expansion of Q4.0	Develop instruments for assessing cultural readiness in the implementation of Q4.0 in small, medium, and large enterprises	[6]
	Map strategies for the development and maintenance of Q4.0 in organizations from different countries	[3]
	Identify and analyze the success factors that contribute to the effective implementation of Q4.0 in organizations of different sizes and segments	[20]
	Propose metrics to assess the development of Q4.0 in companies and schools	[21]
	Propose solutions for small industrial companies to implement Q4.0	[22]
	Identify and propose guidelines for the implementation of Q4.0 in project-based industries through empirical studies	[23]
	Propose guidelines for developing Q4.0 in industrial organizations	[24]
	Propose approaches for implementing Q4.0 in the service sector	[25]
	Identify how the I4.0 technologies can help the quality of food companies	[26]
	Create metrics to evaluate the implementation of Q4.0 in different organizational sectors	[27]
	Develop frameworks to assist in the implementation of Q4.0 in medicine	[28]
	Develop frameworks and recommendations for companies to implement I4.0 concepts and technologies in process control	[29]

Cluster	Scientific gaps	Articles
Skills and Competencies for Q4.0	Assess the influence of I4.0 technologies on the development and training of employees in Q4.0 areas	[30]
	Map the main skills and competencies required for the successful implementation of Q4.0 by conducting empirical studies, such as case studies, surveys, and interviews	[31]
	Map the skills and competencies required for the formation and training of professionals capable of operating in Q4.0 environments	[32]
	Map the skills and competencies needed from managers related to Q4.0	[33]
Empirical Studies in Q4.0	Analyze, empirically, the influences of I4.0 technologies on the EFQM model	[34]
	Identify, empirically, the main motivations, difficulties, and solutions that companies have encountered when implementing Q4.0	[5]
	Identify and propose guidelines for the implementation of Q4.0 in project-based industries through empirical studies	[23]
	Map the main skills and competencies required for the successful implementation of Q4.0 by conducting empirical studies, such as case studies, surveys, and interviews	[31]
	Conduct empirical studies to identify the main motivations, difficulties, and solutions that companies from different sectors have when implementing Q4.0	[2]
Q4.0 and Quality Management System	Create models and strategies to assist in the implementation of I4.0 technologies in the quality management system	[10]
	Propose strategies to mitigate the risks that the I4.0 technologies can bring to the quality management system	[8]
	Analyze the impacts of Q4.0 and its relationship with ISO 9001	[35]
	Create strategies to evaluate the quality management system of companies after the integration of I4.0 technologies	[11]
	Create metrics to evaluate the quality management system after the integration of I4.0 technologies	[36]

In the cluster “Q4.0 Implementation”, it is suggested that further research be conducted to support the implementation and development of Q4.0. This requires the creation and proposition of strategies, models, and tools that help organizations implement I4.0 principles and technologies in quality management [7, 10]. Also, [13] emphasize the importance of conducting studies that identify the relationship between Q4.0 and sustainability and analyze the contributions of Q4.0 to sustainable development.

In the cluster “Implications of Q4.0”, it is recommended to analyze the benefits and difficulties of Q4.0. It is important to identify and evaluate the human, fi-

nancial, and material resources necessary for the development of Q4.0 [7, 17]. According to [16], it is necessary to measure the investments required and the returns that can be provided to the organizations that implement Q4.0 [14]. Furthermore, future studies should propose solutions for the main challenges faced in the use of I4.0 technologies in quality management [5, 18].

In the cluster "Expansion of Q4.0", it is proposed to conduct further research on the development of Q4.0 in organizations from different countries, sizes, and segments. Small and medium-sized enterprises need solutions for Q4.0 implementation that are appropriate to their realities and characteristics [6, 20, 22]. Also, it is recommended that Q4.0 continue to be applied and studied in areas beyond industrial organizations, such as in medicine [28] and education [21], as it can provide benefits and competitive advantages.

In the cluster "Skills and Competencies for Q4.0", it is recommended that work be conducted to develop the skills and competencies required for Q4.0. In the face of I4.0, new technologies are being implemented in organizations, thus intensifying the need for increasingly skilled and qualified employees to work in this new scenario [30–32]. To this end, it is necessary to conduct further studies related to the theme, such as evaluating the influence of I4.0 technologies on the development and training of employees in areas related to Q4.0 [30] and mapping the skills and competencies required for the education and training of professionals capable of working in Q4.0 environments [32].

In the cluster "Empirical studies in Q4.0", it is emphasized that after the analysis of the literature on the subject, it is then necessary to conduct practical studies (surveys, case studies, etc.) to understand the reality of companies facing Q4.0 [31, 34]. In light of this, it is necessary to empirically analyze the influences of I4.0 technologies on the EFQM model [34]. Furthermore, future studies should empirically identify the main motivations, difficulties, and solutions that companies encountered when implementing Q4.0 [5, 25].

In the cluster "Q4.0 and Quality Management System", it is recommended to conduct more research related to the implementation of I4.0 technologies in the quality management system to increase the competitiveness of the organization over its competitors. To this end, it is necessary to develop models and strategies to assist in the implementation of I4.0 technologies in the quality management system [10]. Other study opportunities are to propose strategies to mitigate the risks that I4.0 technologies can bring to the quality management system [8] and to analyze the impacts of Q4.0 and its relationship with ISO 9001 [35].

4. Conclusion

Although Q4.0 is a recent topic and requires further study, many companies have developed strategies to implement it and excel in the global market. The objective of this work has been achieved through the identification and systematization of the key scientific gaps in Q4.0, which support the development of new studies in this research field. Therefore, the research question has been addressed, and the following are the key gaps that need to be addressed to contribute to the development of Q4.0: Implementation of Q4.0, Implications of Q4.0, Expansion of Q4.0, Skills and Competencies for Q4.0, Empirical Studies in Q4.0, and Q4.0 and Quality Management System.

The main theoretical contribution of this work is the expansion and deepening of the theory on the impact of I4.0 technologies on quality management. This will serve as a foundation for the development of new studies on Q4.0. The main practical contribution is to increase customer satisfaction and the competitiveness of organizations by improving the quality of their processes, products, and services. To advance the understanding of Q4.0, it is recommended that future studies investigate and address the scientific gaps identified in this work, particularly through empirical studies which propose implementation guidelines tailored to enterprises across different sizes.

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