Teaching and learning of Industry 4.0: expectations, drivers, and barriers from a Knowledge Management perspective

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Abstract

This paper aimed at (*i*) identifying the expectations, drivers, and barriers for the teaching and learning in Industry 4.0 (I4.0), and (*ii*) verifying how they contribute to the knowledge management (KM) in I4.0. For that, we carried out an exploratory, qualitative study in which we collected data through semi-structured interviews with 21 graduate students who coursed an I4.0 48-hour subject in an Industrial Engineering graduate programme. In the content analysis of these data, we framed the identified commonalities according to the four main KM activities: creation, retrieval, transfer, and application. We identified four main drivers, expectations and barriers for teaching and learning I4.0. Results also indicated that those expectations, drivers, and barriers might be related to each other, concurrently affecting more than one KM activity. These results supported the formulation of four propositions for future theory testing and validation, raising the awareness of instructors and lecturers regarding those aspects. This study offers arguments to design more assertive education in I4.0, so that instructors and lecturers can anticipate their effort to meet students' expectations, reinforce drivers, and curb existing teaching and learning barriers.

Keywords: Industry 4.0, Teaching, Learning, Knowledge Management.

1. Introduction

Since its formal acknowledgement back in 2011, the Fourth Industrial Revolution (also known as Industry 4.0 - I4.0), has triggered the interests of academics, practitioners, government institutions, and society (Santos et al., 2021). As a technology-oriented approach, I4.0 is mainly characterized by the interconnectivity among products, processes, services, and people, and supported by high levels of automation (Lasi et al., 2014). The integration of I4.0 technologies and design principles into organizations and supply chains has significantly affected the way firms operate and manage their business, allowing them to overcome traditional challenges and entailing performance benefits (Dalenogare et al., 2018). Nevertheless, there are some requirements that may impair a successful I4.0 adoption, such as companies' capital expenditure capacity (Raj et al., 2020; Casillo et al., 2020), information security risks (Dotsenko et al., 2019), and lack of highly skilled labor (Grzybowska and Łupicka, 2017).

Particularly with regards to labor skills, there are some initiatives to instruct people about I4.0 concepts, methods, and practices in both industry (e.g., Paravizo et al., 2019; Casillo et al., 2020) and academia (e.g., Schuster et al., 2016; Sackey et al., 2017; Salah et al., 2020; Yoshino et al., 2020). In academia, the education in I4.0 has been more commonly led by academics from Engineering, Computer and Information Systems, and Business Management courses, at both undergraduate and graduate levels. Despite those efforts, the teaching and learning in I4.0 in academia are still at their early stages as many curricula are just starting to be revised to properly integrate I4.0's concepts, technologies, and design principles (Chong et al., 2018; Ellahi et al., 2019; Benis et al., 2020; Salah et al., 2020). I4.0 based learning factories set globally mostly focus on how smart factory operates rather than the core concepts and transformation processes applied to achieve Industry 4.0 based smart factories (Sackey et al., 2017; Salah et al., 2020). This limits the knowledge development and upgrading of student's skills to fully understand the core concepts and application of I4.0 technologies. Those incipient initiatives may raise doubts about the actual expectations, drivers, and barriers for the teaching and learning in I4.0. Such doubts are aggravated when considered from the knowledge management (KM) perspective, which relates to the creation, sharing, use and management of the knowledge and information (Nonaka, 2005).

Based on the previous arguments, two research questions arise:

RQ_1. What are the expectations, drivers, and barriers for teaching and learning of I4.0?

RQ_2. How are those expectations, drivers, and barriers associated with the knowledge management in I4.0?

To address those questions, the objective of this study is two-fold. First, we aim at identifying the expectations, drivers, and barriers for teaching and learning in I4.0. Second, we seek to verify how these expectations, drivers, and barriers contribute to the KM in I4.0. For that, we conducted exploratory, qualitative research in which data were collected through semi-structured interviews with 21 graduate students (master's and PhD candidates) from an Industrial Engineering graduate programme, who were participating in a recently developed subject on I4.0. In the content analysis of the data, we framed the identified commonalities according to the four main KM activities (Alavi and Leidner, 2001): (*i*) creation, (*ii*) retrieval, (*iii*) transfer, and (*iv*) application. The categorization of these commonalities allowed the formulation of four propositions for future theory testing and further validation. In particular, the ecological KM theory was utilized, as it approaches people, relationships, and learning communities, including interactions among individuals and organizations and the internal and external aspects that draw people together to share knowledge (Malhotra, 1999; Chang and Tan, 2013). The concept of a knowledge ecosystem is a stream of KM which fosters the dynamic evolution of knowledge interactions between entities to improve decision-making and innovation based on improved evolutionary networks of collaboration (Malhotra, 2002). Besides the theoretical contributions, our work also has implications for practice since it offers arguments to more assertively design of I4.0 teaching and learning. As formal education in I4.0

plays a crucial role in increasing knowledge and preparing students for future job opportunities (Selamat et al., 2017; Ahmad et al., 2018), our results raise the awareness of instructors and lecturers regarding those aspects. This enables the anticipation of efforts to meet graduate students' expectations, reinforce drivers, and curb the existing barriers, corroborating to a more effective KM in I4.0.

The remaining of this article is structured as follows. Section 2 highlights the background on the key concepts utilized in this work. Section 3 describes the research methods, whose results are presented and discussed in sections 4 and 5, respectively. Section 6 draws conclusions of the study and highlights its limitations and future research opportunities.

2. Background

2.1. I4.0

I4.0 is claimed to be the new production paradigm that will support organizations and supply chains to achieve superior performance results through increased data collection, sharing, and processing among products, processes, services, and people (Xu et al., 2018). I4.0 is also supposed to disrupt many existing business models, favouring the establishment of more modular and flexible systems throughout the entire value chain (Strange and Zucchella, 2017). Table 1 consolidates and describes nine of the main I4.0 technologies reported in the literature.

Some authors (e.g., Sony and Naik, 2020; Goswami and Daultani, 2021; Marcon et al., 2021) have indicated that the advent of I4.0 should be viewed as a socio-technical movement, in which both the technical (tangible) and sociocultural (non-tangible) aspects must be equally considered to ensure a successful implementation. From a technical standpoint, I4.0 technologies such as Internet-of-Things (IoT), cloud computing, big data, and machine learning, have been determining the basis on which digital applications have evolved and been integrated into organizational processes and routines (Frank et al., 2019; Narayanamurthy and Tortorella, 2021). In turn, from a sociocultural point of view, the design principles, such as interconnection, information transparency, decentralized decisions, technical assistance, service orientation, and modularity, define and guide the expected behaviours to properly support I4.0 adoption (Lu, 2017; Ghobakhloo, 2018).

Studies on I4.0 have been quite prolific and diversified in the last decade, which indicate the growing relevance of the digital transformation implied by I4.0 to academics, practitioners, government, and society. Evidence of I4.0 adoption is found in several industry sectors, such as food (Ali et al., 2021), healthcare (Rosa et al., 2021), manufacturing (Frazzon et al., 2020), retailing (Pereira and Frazzon, 2021), automotive (Lin et al., 2018), and textile and clothing (Majumdarv et al., 2021). Moreover, the application focus of I4.0 technologies has varied across organizational processes, such as scheduling and control (Frazzon et al., 2018; Rossit et al., 2019), product and services development (Benzidia et al., 2021), maintenance (Tortorella et al., 2021a), logistics (Frazzon et al., 2019), among others. Overall, those studies suggest that I4.0 implementation has been seen as a critical competitiveness factor that helps organizations meet customers' expectations more effectively and efficiently, allowing them to enter in the Fourth Industrial Revolution era.

Table 1 – Main I4.0 technologies

2.2. Teaching and learning in I4.0

The digitalization trend of I4.0 implies that conventional education in universities must be revisited to incorporate contents that refer to it. This is also applicable to the development and training of employees, especially in small and medium-sized enterprises (SMEs) (Paravizo et al., 2019; Yoshino et al., 2020). Although many I4.0 technologies (e.g., cloud computing, big data, and machine learning) were originally conceived before the formal acknowledgement of I4.0, their implementation and usage have only increased recently. This impaired their extensive adoption and delayed the development of the necessary skills and knowledge to manage them (Motta Reis et al., 2020). Nevertheless, there have been some initiatives to support the teaching and learning in I4.0, as displayed in Table 2. Those initiatives range from group activities conducted in class (Hussin, 2018), focus groups with students (Schuster et al., 2016), and board games (Paravizo et al., 2019), to more structured approaches based on the development of roadmaps (Coşkun et al., 2019) and teaching frameworks (Yoshino et al., 2020).

The focus of teaching and learning in I4.0 also varies in terms of context, i.e., industry or academia. Currently, a search for better appraising the needs of society and industry is influencing the evolution of engineering courses. Among other initiatives, placing the student at the centre of the learning process and improving the collaboration among companies, society, and educational institutions are gaining relevance. In the industry context, the concept of learning factories has been widely adopted to deal with the I4.0 implementation. For instance, Baena et al. (2017) presented a guide to change conventional workshop environments into learning factories with a focus on I4.0, while Grube et al. (2019) proposed a method, supported by digital twin modules, with which SMEs can test I4.0 technologies. Besides teaching the technological aspects of I4.0, the learning factory initiatives also covered the inherent sociocultural factors of I4.0. In the academic environment, flipped classroom (Yusuf and Nur, 2019) and problem-based learning (Zembski and Ulewicz, 2020) approaches have been adopted to teach I4.0 at both undergraduate and graduate levels. Despite the differences in the didactic and pedagogical concepts used to frame the teaching and learning in I4.0, both contexts seem to present similar challenges for the effective development of I4.0 education.

Table 2 – I4.0 teaching initiatives reported in the literature

2.3. KM

Organizational knowledge involves the creation, distribution, use and exchange of knowledge for creating value to customers and society. These processes are better comprehended based on the ecology and ecosystem metaphors (Shrivastava, 1983). The notion of knowledge ecosystem is a stream of KM that encourages the dynamic evolution of knowledge interactions among entities to enhance decision-making and innovation relying on evolutionary networks of collaboration (Bray, 2007). Knowledge ecosystems indicate that knowledge strategies should underpin more enabling self-organization in response to changing environments (Yang et al., 2009). The combination between knowledge and existing problems defines the degree of "fitness" of a knowledge ecosystem (Chen et al., 2010).

To understand knowledge ecology from a production system perspective, it is relevant to approach the knowledge ecosystem that lies at its core. Knowledge ecosystems have inputs, throughputs, and outputs operating in a constant exchange relationship with their environments (Cheng and Leong, 2017). In this context, many layers and levels of systems may be integrated to comprise the ecosystem. These systems encompass interlinked knowledge resources, databases, human experts, and artificial knowledge agents that collectively offer knowledge about the performance of organizational processes (Shrivastava, 1998).

The ecological perspective of KM has been extensively studied in the literature. For instance, Shrivastava (1998) claimed that the main elements of a knowledge ecosystem involve aspects related to technology, learning community, and organizational dimensions. Malhotra (2002) suggested that a knowledge ecology considers the human and their actions and performance.

Chen et al. (2010) proposed an ecological view for KM that comprises knowledge distribution, interaction, competition, and evolution. Chang and Tan (2013) indicated the utilization of practice and leverage of organizational knowledge as ecosystems that should be enhanced through collaborative learning. Cheng and Leong (2017) examined the KM activities (i.e., creation, retrieval, transfer, and application) from the bottom up rather than from the top down within an ecological environment.

2.4. KM in I4.0

The technological advances promoted by I4.0 can support the scanning and detection of meaningful pieces of information and, hence, develop more sophisticated uses of the existing knowledge (Stocker et al., 2014; de Bem Machado et al., 2021) from which might emerge new KM approaches. A few researchers (e.g., Garad and Gold, 2019; Manesh et al., 2020; Schiuma et al., 2020) highlighted the utilization of KM approaches to underpin reasoning based on the expressive amount of data collected and shared through the increased automatization and big data. Further, companies undergoing the I4.0 implementation may develop specific practices to cope with knowledge at individual, team and organisation levels, relying their decision-making processes on more accurate data (Tortorella et al., 2020a). Analogously, Li et al. (2019) mentioned that an organization implementing I4.0 must create, acquire, and adaptively transfer knowledge to handle unpredictable market conditions more quickly than competitors.

Despite the research indications on the relationship between KM and I4.0 (e.g., Waris et al., 2018; Schuh et al., 2019), there is still a paucity of studies that provide empirical validation for such a relationship. Moreover, most studies poorly approach how embodied knowledge is articulated and made manifest in practice, particularly with regards to the utilization of new I4.0 technologies that contribute to knowledge diffusion across companies (Hoffmann et al., 2019; Manesh et al., 2020). To actually benefit from I4.0 adoption, KM must embrace different kinds of information more cohesively and understandably, while assuring that the necessary information is effectively received (Mourtzis et al., 2019; Lei and Wang, 2020). This seems to be a major gap in I4.0 investigation due to the practical relevance of its technologies to KM (Ilvonen et al., 2018).

Additionally, researchers appear to disagree with their recommendations regarding the effect of I4.0 on the main KM activities. For instance, Fomunyam et al. (2020) stated that knowledge creation might be stimulated by technologies such as collaborative robots, whereas Belinski et al. (2020) emphasized the adoption of 3D printing, augmented reality and IoT for creating and organizing knowledge faster. Complementarily, Ríos et al. (2017) argued that individuals must create knowledge based on computational and simulation technologies, especially when considering project development and teamwork communication. Due to the divergences in the literature, more practical applications and empirical evidence are required to comprehend the effect of I4.0 on KM (Tortorella et al., 2020a). With the growth in the number of studies on this topic, pedagogical and management failures would become clearer, raising the attention new opportunities for enhancing the relationship between KM and I4.0.

Overall, it is worth mentioning that very few studies investigated the drivers, expectations, and barriers for teaching and learning I4.0. This gap is particularly aggravated when considering these drivers, expectations, and barriers from the ecological view of KM activities. The need for empirical studies that examine this association and raise theoretical propositions for the field is latent, hence, motivating our study.

3. Research methods

To comply with the exploratory and descriptive nature of this investigation, a qualitative approach was conducted (Voss et al., 2002; Barrat et al., 2011). We used *a priori* theorization to ground the research design (Ketokivi and Choi, 2014), providing a deeper comprehension of the teaching and learning of I4.0 at a graduate level, yielding insightful outcomes to the body of knowledge. Additionally, the analysis of these interviews from the ecological view of KM raised insights that can help to systematic improve the effectiveness of teaching and learning in I4.0.

The proposed method was composed of three main steps: (*i*) description of the study's context, (*ii*) interviews with graduate students; and (*iii*) content analysis and propositions formulation. These steps are detailed next.

3.1. Description of the study's context

The study was carried out in a graduate programme of a Brazilian public university. The graduate programme is comprised of four main areas: (*i*) operations management, (*ii*) ergonomics, (*iii*) product and process development, and (*iv*) logistics. It offers both Doctoral and Master of Philosophy, and receives approximately 200 applications per year. Regardless of the degree, graduate students are required to enrol in some subjects (48-hour courses) in addition to their thesis (6 subjects for master's students and 12 for doctoral students). These subjects are often divided into three quarters per annum, starting in March and ending in December. Each subject consists of lectures and tutorials that sum up a total of 48 hours distributed over a twelve-week period. Originally, the teaching and research in I4.0 were led by academic staff from the operations management area.

Three professors concurrently teach the subject in I4.0, and its main objective is to provide a managerial overview of the industry digital transformation promoted by I4.0 technologies and design principles. The learning outcomes, teaching content, methods, and assessments of the subject are displayed in Table 3.

Table 3 – Curriculum of the subject in I4.0

During 2021, 21 graduates (9 doctoral and 12 master's students) started their research in topics associated with I4.0 and, hence, enrolled in the I4.0 subject. Table 4 shows the profile of the students, whose characteristics were reasonably balanced. Most of them had a part-time dedication (52.4%), more than 5 years of work experience (52.4%), and about two thirds claimed to have a moderate knowledge on I4.0 previously to the subject. Since participants from different generations may be more suitable to certain practices and technologies (Tortorella et al., 2019), students were asked their year of birth. Most of them (81%) were born between 1980 and 1995, hence, being considered from generation Y or millennials. This suggested the existence of a homogeneous group of graduate students regarding their generational values, behaviours, and work style, improving the consistency of the sample.

Following the suggestions from Tortorella and Cauchick-Miguel (2018), the analysis of the data was eminently qualitative. Previous qualitative studies (e.g., Guest et al., 2006; Fugard and Potts, 2015; Braun and Clarke, 2016; Boddy, 2016) have suggested a sample size of at least twelve interviewees to achieve data saturation among a relatively homogeneous population. Thus, we argue that our sample size was large enough to explain the phenomenon of interest and address the examined research questions, avoiding repetitive data, and attaining theoretical saturation (Vasileiou et al., 2018).

Table 4 – Graduate students' profile (n = 21)

3.2. Interviews with graduate students

In contrast to the quantitative perspective, a distinctive feature of qualitative studies is the emphasis on the perspective of the individual being investigated (Taylor et al., 2015; Cauchick-Miguel and Sousa, 2018). Therefore, the focus of the interviews was to raise information about the perspective of graduate students and interpret the environment in which the phenomenon occurs. In qualitative approaches, the subjective reality of the individuals involved in the study is considered relevant and contributes to the development of the research. Such an approach tends to be less structured to capture the perspectives and interpretations of the interviewed individuals. Nevertheless, this does not mean being less rigorous, but it makes research control more critical (Miles and Huberman, 1994).

The interviews followed a semi-structured protocol with open-ended questions (see Appendix). Questions were divided into four main parts. Firstly, we asked students about their background so that we could characterize the study sample. Hence, information about their knowledge on I4.0 previously to the subject, work experience, application degree, etc., was collected. Secondly, we assessed their expectations with respect to the I4.0 subject. Then, questions on the reasons and drivers for studying the I4.0 subject were formulated. The final part aimed at verifying graduate students' perceptions on the barriers to teaching and learning I4.0.

Data was collected through online interviews with graduate students between September and November 2021, as the subject was being taught. Nevertheless, as informed in Table 4, 14 students claimed to have previous knowledge about I4.0 at moderate levels. Thus, most of our sample has previously received some kind of training or already experienced some digitalization initiative. Interviews were audio-recorded and conducted using the same semi-structured protocol, lasting from 30 to 45 minutes. No ideas from previous interviews were incorporated into subsequent ones, as suggested by Guest et al. (2017). Each interview was attended by at least two of the authors, so that our ability to handle contextual information confidently was enhanced (Dubé and Paré, 2003).

3.3. Content analysis and propositions formulation

To enable the development of a chain of evidence that supports the formulation of propositions (Carter et al., 2014), we analysed the content of the information gathered during the semi-structured interviews with graduate students. The content analysis occurred in November and part of December 2021. Interview coding, cross-interview analysis, and fact-checking were used to interpret data. Two of the authors were individually in charge of these activities. Whenever they disagreed on a specific point, a third author was engaged to untie the decision (Kubota et al., 2021), increasing the reliability of the analysis and minimizing bias. In addition, idiosyncratic responses were disregarded to focus the analysis on the prevailing patterns among interviewees. We transcribed and assessed the data from interviews, resulting in summaries that were later merged after authors reached consensus (Miles and Huberman, 1994).

To better organize and code the data, we used words and short phrases as labels, which also helped in the identification of different elements and their relationship (Hsieh and Shannon, 2005). We divided these codes into groups based on how different and related they were. This generated a narrative made up of the transcriptions plus ideas and insights, helping to organize findings into meaningful information blocks, as suggested by Tortorella et al. (2021b). Moreover, to mitigate any bias existing in the graduate students' perceptions about the expectations, drivers, and barriers for teaching and learning of I4.0, we cross compared their responses based on their respective characteristics (i.e., application degree, dedication, work experience, and previous knowledge on I4.0). Arguments that were equally mentioned by graduate students from the same group were regarded, and the ones that were loosely cited within each group were neglected.

Insights from this analysis were then consolidated and checked for commonalities among graduate students. Expectations, drivers, and barriers mentioned by graduate students from at least two different groups of graduate students were distributed according to their KM orientation (Alavi and Leidner, 2001), namely: (*i*) knowledge creation, (*ii*) knowledge retrieval, (*iii*) knowledge transfer, and (*iv*) knowledge application. Those identified commonalities were then categorized in two classes: 'briefly mentioned' and 'extensively mentioned'. To underpin this classification, we revisited the transcripts and narratives (e.g., details in examples given, arguments provided, and observed aspects), including all comments, ideas, and insights (Narasimhan, 2014). The emphasis classification of the expectations, drivers, and barriers allowed the formulation of broad propositions related to teaching and learning of I4.0 from a KM perspective.

4. Results

We now report the results from the semi-structured interviews with the graduate students, which were consolidated in Table 5 and helped respond RQ_1. Firstly, the expectations related to the teaching and learning of I4.0 seemed to be quite consistent among the interviewees. Most graduate students mentioned that they expected to better understand the relationship between theory and practice in I4.0, as commented by G_2 and G_7, respectively:

> "*To understand the connection between theory and practice on I4.0 (i.e., how to apply I4.0).*"

"*Possibility of linking the latest research to the practical aspects of the industry; understand what academia is developing to ensure that new industrial projects follow the most coherent path towards I4.0*."

Another expectation that was often mentioned was the integration of I4.0 into current management approaches. The benefits from I4.0 have been more evident when companies combine its technologies with existing management practices and routines (Narayanamurthy and Tortorella, 2021). In the same vein, graduate students seem to acknowledge that and, hence, expect that they could visualise such integration through the teaching and learning of I4.0. The comprehension of the state-of the-art in I4.0 was also an expectation fairly indicated by graduate students. Finally, interviewees raised the expectation to develop a systemic view of I4.0 through formal teaching at the university. This was particularly observed by part-time graduate students who have been working in the industry while doing their doctoral and master's degrees. Hence, those students expect to not only use the acquired knowledge to conduct their research, but also to implement it in their companies. An example of this was evidenced by G_{17}:

"(…) *being able to have a holistic view of the possibilities of I4.0, apply it to improve processes and products in my company.*"

Regarding the main drivers for teaching and learning I4.0, graduate students agreed that knowledge increase is one of the main benefits from formal education in I4.0. Moreover, they highlighted the pervasiveness of the adoption of I4.0 technologies across several industry sectors. This may increase their interest in the topic, as they can benefit from such knowledge regardless of the industry sector in which they are inserted. This was emphatically commented by G_4 and G_{20}, respectively:

> “*The topic is timely and is under investigation in all over the world. I wanted to know more about the technologies and the advantages they provide to industries and other organizations.*”

> “*The versatility of I4.0 technologies is huge. I plan to use the obtained knowledge in the coordination of industrial projects, such as plant training, process automation, use of data for decision making and application of information in production.*”

Another driver that was considerably raised was related to the provision of a technical basis for developing their research activities. Specifically, students who have a full-time dedication, such as G_{10} and G_{19}, were more emphatic about this benefit. In opposition, students who present a part-time dedication as they are currently working in industry emphasized the relevance of the teaching and learning in I4.0 for the development of the required skills for future jobs. Many graduate students acknowledged that the knowledge on I4.0 is fundamental for their future employability and, hence, they see this learning opportunity as a means to enhance their skills and be aligned with both industry’s and academia’s needs. This driver was particularly cited by G_6 and G_{15}, respectively, as follows:

> “*I intend to use this knowledge throughout my professional and academic journey.*”

> “*I think the teaching and learning of I4.0 can level the scientific knowledge and understanding of some technologies necessary for my self-development as a researcher and practitioner.*”

With respect to the barriers, the most prominent one was related to the scarcity of companies fully embracing I4.0 technologies. I4.0 is claimed to be a new production paradigm, whose adoption is supposed to allow companies to achieve superior performance levels. However, different from other management approaches such as Lean Manufacturing and Six Sigma, which had iconic companies (e.g., Toyota and Motorola, respectively) leading the way so that others could follow their best practices and learn from them, I4.0 is at early stages and most companies are still struggling with its concepts and implementation (Rossini et al., 2019). Therefore, the lack of a company (or companies) widely acknowledged for its I4.0 implementation somewhat impairs benchmarking I4.0 technologies more extensively. Graduate students perceived this fact as a barrier for the teaching and learning in I4.0, as most application examples are scattered among several firms and no single company seems to provide the whole picture. Another barrier that potentially aggravates such benchmarking activities is the intellectual property of many I4.0 solutions. Due to the digital frenzy implied by I4.0, technology providers have been facing high levels of competitiveness, which has led them to protect their products and services to ensure quality and market niche (Kreydenko et al., 2020). A third barrier that might also be correlated with both previous ones is the tailored digital applications to very specific issues. Hence, if companies do have some structured digital initiatives towards I4.0 and those are not protected by intellectual property agreements, their utilization as part of the teaching and learning of I4.0 may be limited due to their narrow application focus. As G_1 stated:

> "*It becomes hard to expand the benefits from certain I4.0 technologies to other contexts and applications. There are I4.0 technologies, such as blockchain, that their applications are still very narrow. This limits our understanding of its potential benefits.*"

In a similar sense, G_{11} also mentioned:

> "*Sometimes the customization of technology solutions to companies is so specific that undermines a broader view. As expected, companies tend to combine technologies as they see fit for their processes and issues.*

However, this impairs the understanding of how each technology can actually favour another process in a different context."

Finally, graduate students claimed that most examples of I4.0 adoption are in manufacturing environment. With the relevance growth of the service industries worldwide, I4.0 technologies may find a fruitful field for application (Bonamigo et al., 2021). In this sense, it becomes paramount to better balance the reports and case studies found in the literature between manufacturing and service industries.

Table 5 – Consolidation of main expectations, drivers and barriers for teaching and learning of I4.0

5. Discussion

Table 6 summarizes the commonalities for expectations, drivers, and barriers among graduate students and categorizes them according to the main KM activities, answering RQ_2. The emphasis of five of those common elements was also classified as 'extensively mentioned', while the remaining ones were indicated as 'briefly mentioned' due to the differences in the arguments, examples, and frequency of mention.

From a knowledge creation perspective, the main expectation related to teaching and learning of I4.0 seems to be the comprehension of the state-of-the-art in I4.0, which is intrinsically associated with the driver 'increase knowledge in I4.0'. Both elements refer to the need to expand graduate students understanding of the main concepts, technologies, and design principles from I4.0. According to Motta Reis et al. (2020) and Yoshino et al. (2020), despite the growing teaching initiatives, the incorporation of I4.0 into most engineering and business management curricula is still rare. This undermines the knowledge in I4.0, which justifies the expectations and drivers from graduate students found in our investigation. In terms of barriers, the 'unbalanced evidence between manufacturing and service industries', briefly mentioned by interviewees, appears to impair the knowledge creation in I4.0. As most of the application evidence is reported in the manufacturing environment, the teaching and learning in I4.0 is negatively affected due to the limitations in examples and knowledge accrued. Nevertheless, it is worth highlighting that even in the manufacturing context, companies from different sectors (e.g., automotive, footwear and clothing, among others) may present completely different conditions for I4.0 adoption. This reduces the breadth of knowledge creation in I4.0. Thus, the following proposition is developed:

Proposition 1. The knowledge creation through the teaching and learning in I4.0 is expected to have the state-of-the-art comprehended, be driven by knowledge increase, and impaired by the unbalanced evidence between manufacturing and service industries.

Regarding knowledge retrieval, the 'integration of I4.0 into current management approaches' (e.g., Total Quality Assurance, and Total Productive Maintenance) was categorized as the most prominent expectation. As organizations adopt I4.0, the data collection and information sharing tend to significantly increase through sensing and communication technologies (Tortorella et al., 2020b). The availability of real-time information may support more assertive decision-making activities in those organizations. Nevertheless, to fully achieve the benefits from these technologies, I4.0 adoption must be properly integrated to retrieve the information in a structured form consistent with the existing management approaches (Agostini and Filippini, 2019). The interviewed graduate students acknowledge and expect to learn it in the university. The 'provision of a technical basis for research development' was the driver categorized under knowledge retrieval. As many of the interviewed graduate students are doing their master's or doctorate's research in topics associated with I4.0, they are seeking to know more about the ongoing research in I4.0. Hence, they tend to perceive the teaching and learning in I4.0 at a graduate level as an opportunity to distil the body of knowledge more comprehensively, establishing a starting point for their studies. Finally, as pointed by Kolberg et al. (2017), most of the I4.0 solutions are tailored applications that were developed for very specific issues. Our results corroborated this, raising concerns about its implications for knowledge retrieval for teaching and learning of I4.0. Based on these arguments, we formulate the following proposition:

Proposition 2. The knowledge retrieval through the teaching and learning in I4.0 is expected to integrate I4.0 into current management approaches, be driven by the provision of a technical basis for research development, and impaired by tailored applications to very specific issues.

Table 6 – Emphasis of expectations, drivers and barriers for the teaching and learning in I4.0 according to KM activities

In terms of knowledge transfer through the teaching and learning of I4.0, graduate students mentioned the expectation to better understand the link between theory and practice on I4.0. Like other management approaches (Slack et al., 2004; Tracy and Knight, 2008), knowledge on I4.0 is developed through concurrent initiatives in academia and industry. Since its formal acknowledgement in 2011, the implementation of I4.0 has been extensively evidenced in scientific articles (e.g., Xu et al., 2018; Dalenogare et al., 2018) and industry reports (e.g., McKinsey & Company, 2020; Forbes, 2021), reinforcing the concomitant efforts. Nevertheless, the exchange of knowledge between theory and practice is not always clear. In light of this issue, such expectation on the teaching and learning of I4.0 is quite reasonable. Further, the versatility of I4.0 technologies characterizes another driver for the teaching and learning in I4.0. Graduate students seem to realize this fact and perceive the formal education in I4.0 as a means to utilize and transfer knowledge across different industry sectors.

Intellectual property agreements stood out among the barriers to knowledge transfer through the teaching and learning of I4.0. Those agreements may impair the exchange of knowledge between organizations, culminating in poor or shallow evidence to be shared in class. Against this backdrop, we formulate the following proposition:

Proposition 3. The knowledge transfer through the teaching and learning in I4.0 is expected to link the theory and practice on I4.0, be driven by the pervasiveness of I4.0 across sectors, and impaired by the intellectual property of many I4.0 solutions.

With regards to knowledge application, the teaching and learning of I4.0 are expected to help students visualize the systematic implementation of I4.0 in companies and supply chains, i.e., sequential, logical, and interrelated guidelines for I4.0 adoption. Companies often adopt a one-off trial-and-error approach to implementing improvements, which undermines a holistic view of its implications across the organization and its supply chain (Netland, 2013). This feature is no different when considering I4.0 implementation. Thus, formal education in I4.0 may provide this overall understanding of the required steps to successfully apply the knowledge in I4.0. In terms of drivers, graduate students claim that their future employability will rely on the skills related to I4.0. This job requirement has also been raised by Fareri et al. (2020), which emphasized that I4.0 technologies will highly impact managerial roles. In the same vein, Grzybowska and Łupicka (2017) highlighted the shift in the required competencies implied by I4.0. Our results converge to these arguments, and teaching and learning in I4.0 might be a key driver for knowledge application. Concerning the barriers, the scarcity of companies that have fully implemented I4.0 undermines the establishment of an iconic reference to which others can refer. For instance, Toyota plays this role and establishes the reference for the teaching and learning in Lean Manufacturing (Tortorella and Cauchick-Miguel, 2017). Despite the solid initiatives and efforts from some companies, a similar situation is not found when considering

I4.0, which impairs knowledge application through teaching and learning. These arguments give rise to the following proposition:

Proposition 4. The knowledge application through the teaching and learning in I4.0 is expected to guide the systematic implementation of I4.0 in companies and supply chains, be driven by the development of the required skills for future employability in industry, and impaired by the scarcity of reference companies.

Our study propositions are consolidated in Table 7 according to KM activities.

Table 7 – Consolidation of study propositions according to KM activities

6. Conclusions

In this research, we examined the expectations, drivers, and barriers for teaching and learning of I4.0 at a graduate level, and how they contribute to the KM in I4.0. We performed an exploratory qualitative study in which we collected data through semi-structured interviews with graduate students of an Industrial Engineering graduate programme. The content analysis of this data allowed the identification of commonalities among interviewees, establishing a chain of evidence that supported the formulation of four propositions for future research. Our findings present relevant contributions to both theory and practice, as pointed out next.

6.1. Theoretical implications

With respect to theoretical implications, this study provided a better understanding of how the teaching and learning in I4.0 might be associated with KM activities. The empirical evidence collected and analysed here indicated that each KM activity may be favoured or impaired by different expectations, drivers and barriers related to the teaching and learning in I4.0.

Moreover, those expectations, drivers and barriers might be correlated, causing a concurrent impact on more than one KM activity. The formulation of the four propositions, originated from an inductive approach, allows the testing and further verification of the identified relationships, adding to the body of knowledge on the topic. These propositions may lead to more cohesiveness between what is taught in class and what is observed in practice, resulting in a more effective knowledge ecosystem for teaching and learning I4.0. In other words, a more effective interaction between these elements (i.e., expectations, drivers and barriers related to the teaching and learning in I4.0) promotes a healthier ecosystem. This may lead to a more assertive KM, especially in terms of creation, retrieval, transfer, and application of knowledge on this highly relevant topic (I4.0). To the best of our knowledge, there is no similar study in the literature. Thus, we argue that this is an original contribution to the existing body of knowledge.

6.2. Contributions to practice

Concerning the practical contributions, our research offers insightful findings to support the design of more assertive teaching and learning in I4.0. As observed, formal education in I4.0 plays a crucial role since it increases graduate students' knowledge and prepares them for future job opportunities. In this sense, our results raise the awareness of instructors and lecturers with regards to those aspects, allowing them to anticipate efforts to meet graduate students' expectations, reinforce drivers, and curb the existing barriers. These indications may be applicable, up to a certain extent, to instructors and lecturers who teach I4.0 at other educational levels as well, such as undergraduate and technical courses.

6.3. Limitations and future research

Some study limitations are worth mentioning. Firstly, being a qualitative study, the data collection and analysis are often a point of concern. Although we carefully addressed all the recommended countermeasures, there is always a certain level of subjectivity in the assessment. Thus, further studies with other data collection and analysis methods, e.g., survey, focus groups, secondary data collection, etc., would provide more evidence to complement our findings. Secondly, due to the inductive approach conducted in this study, the generalization of our results might be limited. Future research could encompass the teaching and learning of I4.0 at different levels, courses, institutions, and socioeconomic contexts. This would offer a broader view of the role played by formal education in I4.0. Finally, our investigation only involved the opinion of students, who are the upcoming workforce in organizations. Even though this is a valid perception, it would be interesting to compare these opinions about teaching and learning in I4.0 with industry leaders and managers, who are the ones that are actually in charge of I4.0 implementation and will hire those graduate students later on. The confrontation of both perceptions (students' and industry leaders') would allow the identification of commonalities and divergences that could be used to mitigate the existing gaps in the formal education in I4.0.

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Table 1 – Main I4.0 technologies

Technology	Description	Reference
Internet-of-Things	Describes physical objects (or groups of such objects), that are embedded with sensors, processing ability, software, and other technologies, and that connect and exchange data with other devices and systems over the Internet or other communications networks.	Lasi et al. (2014); Liao et al. (2017); Lu (2017); Xu et al. (2018); Frank et al. (2019); Raj et al. (2020); Narayanamurthy and Tortorella (2021); Santos et al. (2021).
Cloud computing	Cloud computing is the on-demand availability of computer system resources, especially data storage (cloud storage) and computing power, without direct active management by the user.	
Big data	Big data is a field that treats ways to analyze, systematically extract information from, or otherwise deal with data sets that are too large or complex to be dealt with by traditional data-processing application software.	
Machine learning	Machine learning is the study of computer algorithms that can improve automatically through experience and by the use of data. It is seen as a part of artificial intelligence.	
Augmented reality	Interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, utilizing multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory.	
3D printing	Refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object, with material being added together layer-by-layer.	
Wireless sensors	Devices that collect the data and allow further functionality from self-monitoring and self-configuration to condition monitoring of complex processes.	
Collaborative robots	Intended for direct human robot interaction within a shared space, or where humans and robots are in close proximity.	
Remote control or monitoring	Designed to control large or complex facilities such as factories, power plants, network operations centres, airports, and spacecraft, with some degree of automation.	

Table 2 – I4.0 teaching initiatives reported in the literature

Reference	Objective	Method	Findings
Schuster et al. (2016)	To investigate the preferred kinds of virtual learning environments for higher education context.	Focus groups were carried out to collect information, which was used as a basis for creating a collaborative virtual learning environment within the open world fame Minecraft.	First screenings of the video material of the study indicate a connection between communicational behaviour and successful collaborative problem solving in virtual environments.
Hussin (2018)	To identify the trends of Education 4.0, preferences and skills of the 21st century learners, and share some ideas on how to implement Education 4.0 in the classroom.	Based on the utilization of group activities in classroom and collect students' feedback.	The changes that take place in Education 4.0 describe the learning preference of the Gen Z students. Integrating more technologies will make the instructors more creative in designing their lessons, thus making the learning in I4.0 more interesting.
Coşkun et al. (2019)	To introduce a roadmap to be conducted in the areas of curriculum development, lab concept, and student club activities in I4.0.	It was determined new study modules and changes to the existing ones. Further, it was designed two main labs to address the changes in the curricula.	Results showed that it was feasible to apply the framework and the adopted underlying theory of Kolb to adapt engineering education to I4.0.
Terkowsky et al. (2019)	To identify potentials for future-oriented teaching and learning in the light of the required competences for "Working 4.0" in a remote laboratory at a German university.	Current scientific studies and industry agendas about Working 4.0 competences were identified, connected learning objectives were derived, and the focused remote laboratory was linked to these objectives.	The educational setting had the potential to reflect the complexity of Working 4.0. However, results indicated that the examined laboratory has only addressed some of the competences from I4.0.
Paravizo et al. (2019)	To develop and pilot testing of a board game for education and training in I4.0.	The development of the board game was divided into three steps: content, game development, and testing.	Participants indicated the game is successful in improving their understanding of the link between I4.0 principles and company's objectives as well as of the I4.0-related technologies.
Bartelt et al. (2020)	To presents an approach that segments an automated production system into modules.	The complexity of the system can be varied depending on the needs of the students or participants. With this, classical automation topics as well as state-of-the-art topics can be touched and trained.	The concept is designed so that it is applicable in university education and that individual topics can be taught in half-day or one-day seminars with appropriate previous experience.
Yoshino et al. (2020)	To present an efficient model to teach I4.0 technologies in undergraduate engineering courses.	First, it was identified the skills required for an I4.0 practitioner and how those are taught worldwide. Then, a multicriteria model was created to identify the appropriate teaching strategy.	A framework for studying I4.0-related subjects was proposed. Its application indicated effective outcomes, becoming part of the engineering curricula.
Motta Reis et al. (2020)	To identify research gaps in the education of I4.0, as well as to group associated themes.	A literature review using the Scopus database was carried out.	Based on the identified gaps, five groups with similar characteristics in Education 4.0 were proposed.

Table 3 – Curriculum of the subject in I4.0

Learning outcomes	Module contents	Teaching methods	Assessments and weights (%)
Understand the conceptual and practical foundations of advanced manufacturing and supply chains through I4.0 adoption	History of industrial revolutions, characterization, and conceptual definition of I4.0	-Classroom lectures (12 hours) -Tutorials (12 hours) -Guest lectures from industry and academic experts (6 hours) -Videos discussion (2 hours) -Group discussion (6 hours) -Teaching case studies (4 hours) -Individual projects guidelines and supervision (6 hours)	Group activities (10%) Individual exercises (10%) Research seminars (10%) Individual project (70%)
Understand the various paths for the digital transformation of businesses and companies	Integration of advanced technologies and methods to support decision-making in operations and supply chain management		
Identify the different benefits and challenges intrinsic to the adoption of disruptive technologies from I4.0	I4.0 association with organizational areas (e.g., quality, product development, and maintenance)		
Understand both the technical and sociocultural implications of digital transformation	Implications of industry digital transformation to processes, products, services, and people		

Table 4 – Graduate students' profile (n = 21)

Interviewee	Degree	Dedication	Work experience	Previous knowledge about I4.0	Generation (year of birth)
G_1	Master	Part time	≤ 5 years	Basic	Ys (1980 – 1995)
G_2	Master	Part time	≤ 5 years	Basic	Ys (1980 – 1995)
G_3	Master	Part time	> 5 years	Moderate	Xs (1965 - 1979)
G_4	Master	Part time	> 5 years	Moderate	Xs (1965 - 1979)
G_5	Master	Part time	> 5 years	Moderate	Ys (1980 – 1995)
G_6	Master	Part time	> 5 years	Moderate	Ys (1980 – 1995)
G_7	Master	Full time	≤ 5 years	Basic	Ys (1980 – 1995)
G_8	Master	Full time	≤ 5 years	Moderate	Ys (1980 – 1995)
G_9	Master	Full time	≤ 5 years	Moderate	Ys (1980 – 1995)
G_{10}	Master	Full time	> 5 years	Basic	Ys (1980 – 1995)
G_{11}	Master	Full time	> 5 years	Moderate	Ys (1980 – 1995)
G_{12}	Master	Full time	> 5 years	Moderate	Ys (1980 – 1995)
G_{13}	Doctoral	Part time	≤ 5 years	Basic	Xs (1965 - 1979)
G_{14}	Doctoral	Part time	≤ 5 years	Moderate	Ys (1980 – 1995)
G_{15}	Doctoral	Part time	> 5 years	Moderate	Xs (1965 - 1979)
G_{16}	Doctoral	Part time	> 5 years	Moderate	Ys (1980 – 1995)
G_{17}	Doctoral	Part time	> 5 years	Moderate	Ys (1980 – 1995)
G_{18}	Doctoral	Full time	≤ 5 years	Basic	Ys (1980 – 1995)
G_{19}	Doctoral	Full time	≤ 5 years	Basic	Ys (1980 – 1995)
G_{20}	Doctoral	Full time	≤ 5 years	Moderate	Ys (1980 – 1995)
G_{21}	Doctoral	Full time	> 5 years	Moderate	Ys (1980 – 1995)

Table 5 – Consolidation of main expectations, drivers and barriers for teaching and learning of I4.0

Elements		Master's students	Doctoral students	Part time students	Full time students	Inexperienced students	Experienced students	Basic knowledge	Moderate knowledge	Citation frequency across groups
Expectations	Understand link between theory and practice on I4.0	√	√	√	√	√	√	√	√	100.0%
	Integration of I4.0 into current management approaches		√	√	√		√	√		62.5%
	Systematic implementation of I4.0 in companies and supply chains	√		√		√		√		50.0%
	Comprehend the state-of-the-art in I4.0	√			√	√			√	50.0%
Drivers	Increase knowledge in I4.0	√	√	√	√	√	√	√	√	100.0%
	Pervasiveness of I4.0 across sectors		√	√	√		√		√	62.5%
	Preparation for future employability in industry	√		√		√		√		50.0%
	Provision of a technical basis for research development		√		√	√		√		50.0%
Barriers	Scarcity of reference companies	√	√	√	√	√	√	√	√	100.0%
	Intellectual property of many I4.0 solutions		√	√		√			√	50.0%
	Unbalanced evidence between manufacturing and service industries	√		√			√	√		50.0%
	Tailored applications to very specific issues				√		√		√	37.5%

Note: '√' indicates the element was cited by the corresponding group of graduate students

Table 6 – Emphasis of expectations, drivers and barriers for the teaching and learning in I4.0 according to KM activities

Dimensions	Knowledge creation		Knowledge retrieval		Knowledge transfer		Knowledge application	
	Element	Emphasis	Element	Emphasis	Element	Emphasis	Element	Emphasis
Expectations	Comprehend the state-of-the-art in I4.0	+	Integration of I4.0 into current management approaches	++	Understand link between theory and practice on I4.0	++	Systematic implementation of I4.0 in companies and supply chains	+
Drivers	Increase knowledge in I4.0	++	Provision of a technical basis for research development	+	Pervasiveness of I4.0 across sectors	++	Preparation for future employability in industry	+
Barriers	Unbalanced evidence between manufacturing and service industries	+	Tailored applications to very specific issues	+	Intellectual property of many I4.0 solutions	+	Scarcity of reference companies	++

Note: '+' = briefly mentioned; '++' = extensively mentioned.

Table 7 – Consolidation of study propositions according to KM activities

Knowledge creation	Knowledge retrieval	Knowledge transfer	Knowledge application
The knowledge creation through the teaching and learning in I4.0 is expected to have the state-of-the-art comprehended, be driven by knowledge increase, and impaired by the unbalanced evidence between manufacturing and service industries.	The knowledge retrieval through the teaching and learning in I4.0 is expected to integrate I4.0 into current management approaches, be driven by the provision of a technical basis for research development, and impaired by tailored applications to very specific issues.	The knowledge transfer through the teaching and learning in I4.0 is expected to link the theory and practice on I4.0, be driven by the pervasiveness of I4.0 across sectors, and impaired by the intellectual property of many I4.0 solutions.	The knowledge application through the teaching and learning in I4.0 is expected to guide the systematic implementation of I4.0 in companies and supply chains, be driven by the development of the required skills for future employability in industry, and impaired by the scarcity of reference companies.

Appendix – Semi-structured interview protocol

1. Please, tell us a little more about yourself (e.g., year of birth, application degree, and dedication) and your background (e.g., previous knowledge about I4.0 and work experience).

2. Please, let us know about your expectations with respect to the I4.0 subject. Please, justify your answer and give examples.

3. Please, tell us about your reasons for coursing the I4.0 subject.

(a) What were the drivers for coursing this subject?

(b) How do you intend to use the knowledge learned in this subject?

(c) How does this knowledge may complement your skills?

Please, justify your answer and give examples.

4. Concerning the teaching and learning of I4.0, what barriers do you think may exist? Please, justify your answer and give examples.