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Industry 4.0: technical qualifications for the fourth industrial revolution in Brazil

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RESUMO

Objetivo – Levantar e apresentar a forma que as qualificações técnicas necessárias para a Indústria 4.0 (I4.0) são abordadas pelos cursos de pós-graduação e pelas próprias empresas industriais no Brasil.
Quadro teórico – As novas exigências técnicas, vinculadas ao novo cenário da I4.0, implicaram na necessidade de prover formas de capacitação da mão de obra. Esta adequação passou a ser importante tanto para a supervivência dos trabalhadores no mercado de trabalho, bem como das próprias organizações no mercado empresarial.
Design/metodologia/abordagem – Foi realizada uma análise documental dos ementários e suas disciplinas de 24 cursos de pós-graduação lato sensu sobre indústria 4.0 e em 56 anúncios de vagas de emprego relativos à I4.0, caracterizando o tipo desta pesquisa como temporal e exploratória.
Resultados – Os resultados apontam que, das nove categorias tecnológicas da I4.0 levantadas, maior importância é dada às categorias Big Data (58%) e sistemas integrados (36%) por parte das empresas e para as categorias Big Data (29%), Internet das Coisas (14%), sistemas integrados (13%) e segurança da informação (12%) por parte dos cursos de pós-graduação.
Pesquisa, implicações práticas e sociais – A principal implicação prática e social relaciona-se à necessidade de as IES discutirem junto às organizações, um conjunto de conhecimentos comuns para as diferentes áreas de formação.
Originalidade/valor – A pesquisa contribui na identificação das competências necessárias aos trabalhadores na I4.0, para alertar setores de RH das organizações na capacitação destas competências, e para a necessidade de as organizações estarem conscientes da complexidade que a I4.0 representa.
Palavras-chave - Indústria 4.0; Tecnologias I4.0; Trabalho; Educação

ABSTRACT

Purpose *– To research and present the manner in which the technical qualifications needed for Industry 4.0 (I4.0) are addressed by graduate courses studied and manufacturing companies in Brazil.*
Theoretical framework *– New technical requirements linked to the new I4.0 scenario imply the need to provide new forms of training for the workforce. This requirement has become important both for workers to remain competitive in the job market, as well as for the organizations themselves within the business market.*
Design/methodology/approach *– A document review of the syllabuses and subjects of 24 lato sensu graduate courses studied and 56 job vacancies related to I4.0, which classifies this study as a time-restricted and exploratory study.*
Findings *– The results show that, of the nine technological categories of I4.0 researched, greater importance is placed on Big Data (58%) and integrated systems (36%) by companies, and in graduate courses studied, importance is placed on Big Data (29%), the Internet of Things (14%), integrated systems (13%) and information security (12%).*
Research, practical and social implications *– The main practical and social implications of this study are related to a need for HEIs to discuss a common set of knowledge with businesses regarding various areas of training.*
Originality/value *– This study contributes to the identification of the skills needed by workers in I4.0 to warn company HR departments regarding the need for training in these skills, and the need in turn for companies to be aware of the complexity that I4.0 represents.*
Keywords *- Industry 4.0; Technology I4.0; Jobs; Education.*

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1. INTRODUCTION

The term Industry 4.0 (I4.0) arose in 2011 at the Hannover Fair with the purpose of highlighting greater flexibility, productivity, and quality in the manufacturing of customized products together with shorter delivery times (ZHONG *et al.*, 2017). To make operations with these characteristics viable, integrated systems are needed which combine significant computing and physical capacity and are able to interact with human beings, termed cyber-physical systems (CPS) (MO; WAGLE; ZUBA, 2014). Based on these systems, also labeled intelligent production systems, various countries have employed methods and tools from the areas of administration and engineering to drive technological innovations and thus develop what are called aspects of I4.0 (VERMULM, 2020).

To deal with the changes in the job profiles necessary for the I4.0 job market, public and as well as private Higher Education Institutions (HEIs) have developed actions to better qualify students through an improvement in graduate *lato sensu* courses of study (FONSECA; FONSECA, 2016). These initiatives are designed, given the characteristics of graduate *lato sensu* courses of study, to direct the teaching of students and seek to deepen and improve their professional training (SAVIANI, 2000).

In this sense, there is a gap in this area in terms of the case of Brazil, that is represented by two factors which can be observed in relation to the slow pace of I4.0 implementation. First of all, Brazil's industrial park has its own characteristics, such as incomplete industrialization and the adaptations of various administrations (SARDO; FUNCK; BACH, 2021). The second is the scarcity of a specialized work force which requires the development of new competencies (TESSARINI; SALTORATO, 2018). In this sense, technological advances related to I4.0 highlight the existence of a disconnect with the competencies currently available in this country, and create a scenario in which activities are disappearing while others are being created, especially in terms of lines of production (BUHR, 2015; PEJIC-BACH *et al.*, 2020).

To diminish the gap described above, this work seeks to research and verify how the technical qualifications required by I4.0 are addressed by graduate *lato sensu* courses of study in Brazil. To accomplish this, we have employed the content analysis technique (BARDIN, 2016) in two different areas. First of all, we have used it to identify the characteristics of jobs which require knowledge of I4.0 in the areas of Business Administration (BA), Production

Engineering (PE) and Information Technology (IT) in Brazilian industrial firms. Secondly, we have used it to identify subjects covered by the graduate *lato sensu* courses of study offered in the country.

The development of this study is justified *a priori* from a practical view by the chance to publish the obtained results and analysis so that HEIs as well as companies can benefit from the recommendations offered at the conclusion of this work. The practical value of this research is independent of the results obtained. If the research indicates an elevated degree of adherence in the sampled companies to the technological categories of the new culture required by I4.0, this would indicate that they are on the right track. If the opposite occurs, it will be evidence of a low degree of adherence to the I4.0 culture in these companies, and the study will serve as an alert that further progress is needed in this area to obtain the benefits promised by the model. From a theoretical perspective, this study can also be easily justified by the fact that even though I4.0 is in evidence in many academic articles as well as business practice, few practical studies have been made of its adoption by industrial firms in emerging economies (VERMULM, 2020; TAUIL; MAINARDES, 2015). It is worth noting that this study is not intended to evaluate the quality of business management or the quality of the graduate *lato sensu* courses of study offered by HEIs in Brazil.

Among our main results are advances for businesses that wish to implement this type of system, especially in relation to the complexity of the knowledge required and possible training sessions for human resources departments. We will next present a brief discussion of the growing importance of I4.0 and its impact on education and work, and the concerns in the literature about adaptations that will be needed in terms of the necessary qualifications for operations management in manufacturing. This will be followed by the methodology utilized in our data collection and an analysis and discussion of the results obtained. We will conclude with our final considerations which will include the limitations of this study and possible avenues for future study.

2. THEORETICAL FOUNDATION

The Fourth Industrial Revolution, also known as I4.0, Intelligent Manufacturing, the Industrial Internet or Integrated Industry, has become a frequently discussed subject because it can have a big impact on industries by transforming the way in which products are designed, manufactured, delivered, and paid for (HOFMANN; RÜSCH, 2017). The repercussions of this subject demonstrate the evolution of technology in production processes, which has gone from embedded to cyber-physical systems, resulting in changes in production chains and business (MACDOUGALL, 2018).

Among the characteristics of I4.0 are its steering processes towards automated activities, the broad acquisition and transferal of data, and the development of new manufacturing technologies, among others (KARNIK *et al.*, 2021). These elements make it viable to develop an infrastructure which combines communications with increasingly personalized and flexible production, focusing on operational efficiency and a high degree of customization (THAMES; SCHAEFER, 2017; VIANNA; GRAEML; PEINADO, 2020). Within this scenario, machines will operate based on self-personalization and control all processes and data collection in real time, analyzing and substituting the operation of equipment for communications and guidance processes (SUNG, 2018).

In sum, we can affirm that I4.0 and its technologies have transformed and will continue to transform businesses, leading them to adopt interconnected processes increasing their production capacity and operational efficiency. However, the challenges due to the complexity of this new production arrangement need to be noted so that organizations can maximize the opportunities of the I4.0 system (KHAN; KHAN, 2018; THAMES; SHAEFER, 2017).

I4.0 is made up of various categories of technology which form the pillars needed to implement this concept (CHENG *et al.*, 2016), nine of which we will examine: Big Data, cloud computing, the Internet of Things, additive manufacturing, augmented reality, autonomous robots, information security, and integrated simulations and systems.

2.1 Big data

Factors such as technological advances, availability, and accessibility to sensors and the internet have led businesses to implement highly innovative production processes that utilize the latest generation of technology (LEE; BARGHERI; KAO, 2015; XU; DUAN, 2019). Among the results of these implementations is a large volume of data which is collected and processed which can affect an organization, which is known as Big Data (GHASEMAGHAEI, 2021). Big Data is characterized by components such as variety, volume, velocity, variability, complexity and value (KITCHIN; MCARDLE, 2016) which can help a company identify opportunities in various areas, such as marketing, management, transport, the supply chain and innovation (CHOI; WALLACE; WANG, 2018) through the acquisition, creation and management of solid databases (SAGGI; JAIN, 2018).

2.2 Cloud computing

Cloud Computing offers new business services and opportunities through scalable and virtual instruments which make it possible to improve a company's production processes (PICOTO; CRESPO; CARVALHO, 2021; ZHENG *et al.*, 2014). According to Xu, Xu and Li (2018), virtualization makes it possible to distribute and allocate resources dynamically, making it possible to load a large amount of data in cloud storage, which facilitates production. The main objective of cloud computing is using computational resources to offer Big Data apps more refined services (CHEN; MAO; LIU, 2014).

2.3 The internet of things

The Internet of Things (IoT) became popular at the end of the last decade, marking the beginning of I4.0. The term was initially related to the idea of managing the supply chain with radio frequency identification (RFID) technology (ASHTON, 2009). Recently the term IoT has come to be related to infrastructure which integrates products through embedded systems (sensors and actuators) connected by networks (ČOLAKOVIĆ; HADZIALIC, 2018), with the purpose of sharing data to make communication between objects viable (KHANNA; KAUR, 2020). In addition, at the same time that technologies are integrated with IoT systems, especially those related to information and communications technologies and cyber-physical systems (XU; XU; LI, 2018), we have observed their increased impact on our daily lives (DIAN; VAHIDNIA; RAHMATI, 2020; TAO *et al.*, 2016).

2.4 Additive manufacturing

Additive manufacturing is the process of linking materials in layers in order to create objects based on information and the application of three-dimensional (3D) printing technology (ABDULHAMEED *et al.*, 2019). This process has the capacity to transform the manufacturing and logistics of products, increasing the efficiency of on-demand production, reducing environmental impacts, permitting a high degree of personalization, reducing material waste, and decreasing stocks of raw materials and tools (FRAZIER, 2014).

2.5 Augmented reality

Augmented reality is a technology which facilitates the interaction between users and information (FERNÁNDEZ-CARAMES *et al.*, 2018), and features elements such as cameras, tracking systems, user interfaces and visualization technology (MASOOD; EGGER, 2019). This technology is used in areas such as marketing, tourism and the games industry, and has been adopted in the factory environment (DONATO *et al.*, 2015; RAUSCHNABEL *et al.*, 2022). In this sense, it may be observed that it is possible to use augmented reality in industry as a way to combine and provide services for the production process, augmenting the security and efficiency of activities (GATTULLO *et al.*, 2019; MARINO *et al.*, 2021).

2.6 Autonomous robots

Robots are utilized in industrial production processes of the Third Industrial Revolution, acting in more complex tasks and being linked to autonomous, cooperative and flexible systems (RÜßMANN *et al.*, 2015). In addition, autonomous robots are used on three main fronts. The first is precision production line work in places that are restricted from human workers, performing tasks within programmed time frames (BAHRIN *et al.*, 2016). The second focuses on mass customization (PAWAR; LAW; MAPLE, 2016), with robots calculating the best design solutions, operational performance, energy efficiency and maintenance (DANESHMAND *et al.*, 2022; ZHU *et al.*, 2020). The third is related to the establishment of security protocols, converging on the demand for roboticized processes and the safety of human work (Ronzoni *et al.*, 2021).

2.7 Information security

In I4.0, information security leads the actions taken to prevent losses in company competitiveness, because equipment is vulnerable to cybernetic attacks, which affect the entire business model (LEZZI; LAZOI; CORALLO, 2018). According to Thames and Schaefer (2017), detecting these attacks requires layered analysis algorithms to obtain a total sweep of the system to defend against attacks and identify accesses without compromising the functionality of the system. Even though the costs of these solutions to defend against cybernetic attacks are high, they are lower than that of the damage possible when one has no security technology (KANG *et al.*, 2016).

2.8 Simulations

Computer simulations have become an important element of business systems in both the operational and strategic dimensions (RODIČ, 2017). In this sense, a simulation can be employed in various operations, including mapping decision-making and performance variables over time, seeking to prevent and solve possible problems, such as production bottlenecks (FLORESCU; BARABAS, 2020; SALAMA; ELTAWIL, 2018; SMITH, 2003). In addition, aspects such as the reduction of errors and the efficiency of layout changes can also benefit from simulations (MORENO *et al.*, 2017).

2.9 Integrated systems

Integration is an important aspect of I4.0 which requires structural changes in an organization and the management of machines and physical elements (PASZKIEWICZ *et al.*, 2020; REISCHAUER; SCHOBER, 2015). In addition, automated processes and the flow of information make it possible to develop cooperative systems between engineering, production, suppliers, marketing and the supply chain (SAUCEDO-MARTÍNEZ *et al.*, 2018). These integrated systems are constituted by ERP and CRM calls which integrate information processes within the organization which now perform more complex analyses (MARCIANO *et al.*, 2019; SILVA; GALEGALE, 2020), which are termed cyber-physical systems (TAO *et al.*, 2019). These systems present great economic and social potential, due to the increase in the efficiency of their processes and self-organization (LEE; BAGHERI; KAO, 2015; PIVOTO *et al.*, 2021). The combination of complete integration and digital automation requires the automation of communications and cooperation, mainly during the standardization process, causing an increase in the responsibility of workers in terms of understanding processes, the flow of information, and possible bottlenecks and solutions (EROL *et al.*, 2016; FOIDL; FELDERER, 2015).

2.10 Impacts of I4.0 on education and work

The fundamentals and technologies of I4.0 will influence the manufacturing of products (JABBOUR *et al.*, 2018). However, the Fourth Industrial Revolution will not only modify production systems, it will also affect work systems, substituting traditional labor with high technology machines, thus affecting work on the factory floor (KAZANCOGLU, OZKAN-OZEN, 2018). In this sense, it is possible to observe that some production tasks and work in general will diminish, while tasks such as correcting errors, solving problems, and interdisciplinary contributions will increase, establishing a new profile of a multitasking worker and a problem solver (BLAYONE; VANOOSTVEEN, 2021; SIMA *et al.*, 2020). To Kazancoglu and Ozkan-Ozen (2018), this new worker profile will come to include abilities such as self-organization, the ability to solve complex problems, and thinking about overlapping processes.

These new worker abilities in I4.0 will also affect job openings in these industries. Observed from an optimistic perspective, we see an improvement in job and working conditions. From a pessimistic perspective we assume there will be a decrease in the number of jobs due to the substitution of people with robots (PEJIC-BACH *et al.*, 2020). In developed countries like Germany assembly and production jobs will decrease by around 610 thousand, but this will be compensated for by the creation of 960 total jobs, 210 thousand of these in IT, data analysis, research and development (LORENZ *et al.*, 2015).

Thus, among the main challenges of adopting I4.0 will be a lack of the qualified labor that I4.0 requires, and there will be a need for training to deal with these circumstances, with specialization programs and graduate *lato sensu* degrees being presented as important spaces for the training of students for the job market (Erol *et al.*, 2016; KIEL; ARNOLD; VOIGT, 2020; PAIVA *et al.*, 2017).

Graduate *lato sensu* degrees were created with the objective of training specialized professionals, based on the preparation of students in a given specific area (TAUIL; MAINARDES, 2015). In this sense, the versatility and agility of the responses to specific job market requirements will enable graduate *lato sensu* courses of study to be recognized as mechanisms for the dissemination of knowledge by organizations, scholars, and professionals (PILATI, 2006). In relation to the subject of I4.0, the three most correlated areas are Business Administration, Production Engineering, and Information Technology (AZEVEDO; GONTIJO, 2017; BORCHARDT *et al.*, 2009; DUQUE; DIAS; FERREIRA, 2018; LEMOS; PINTO, 2008; OTTONICAR; VALENTIM, 2019; PAIVA; FERREIRA, 2013).

3. METHODOLOGICAL PROCEDURES

3.1 Object of study

This study has been developed based on the delineation of a qualitative study, because it is based on a description of an analyzed phenomenon which involves changes in contemporary society (FLICK; VON KARDOFF; STEINKE, 2004; CHUEKE; LIMA, 2012). In this sense, the qualitative approach seeks to answer the following research question: How are the technical qualifications required for I4.0 being addressed in graduate *lato sensu* courses of study in Brazil? Thus, to research how the qualifications demanded by I4.0 are being approached by Brazilian graduate *lato sensu* degrees, we have collected data using a transversal sample, which involves collecting data from more than one case during a single period of time, together with a group of qualitative data for two or more variables which undergoes content analysis to detect association patterns (BRYMAN; BELL, 2011).

3.2 Data collection for graduate courses of study

This part of the study is designed to research technical qualifications associated with I4.0 in Brazil. Thus, we analyzed program contents and syllabuses for courses in graduate *latu sensu* majors related to I4.0 offered by Brazilian HEIs, using a similar method to that adopted by Peinado and Graeml (2014) to research subjects addressed by courses in various areas of study.

To identify the graduate majors used by the Ministry of Education's e-MEC website, which presents data for HEIs within the Federal Teaching System, or in other words, the undergraduate and graduate majors ministered in this country. Operationally, we used the "advanced consultation" option in the e-MEC database and the specifications: "Search for": "Specialized Major and Major": "Industry 4.0".

In total, we verified 82 results for graduate courses of study related to I4.0. The resulting list of majors was utilized to research program and syllabus content for the courses of each graduate major. In this process, we verified each of the HEI websites in order to ascertain and select the information necessary for the content analysis. Of the 58 majors found, we excluded those which were inactive or outside the Business Administration, Production Engineering and Information Technology areas, or majors which are part of the database, but do not appear on the institution's website or do not have related syllabuses, and these exclusions are displayed in Table 1.

Table 1 – Majors Excluded Based on the Exclusion Criteria

<table>
<tr><td colspan="2">Exclusion criteria</td><td>Number of majors</td></tr>
<tr><td colspan="2">Inactive majors</td><td>2</td></tr>
<tr><td colspan="2">Majors outside of Bus. Adm, Pr. Eng. and IT</td><td>0</td></tr>
<tr><td colspan="2">Majors which are part of the database, but do not appear on the HEI's website</td><td>14</td></tr>
<tr><td colspan="2">Majors which do not have related syllabuses</td><td>42</td></tr>
<tr><td colspan="2">Total of excluded majors</td><td>58</td></tr>
<tr><td rowspan="3">Selected majors by area</td><td>Adm.</td><td>4</td></tr>
<tr><td>Pr. Eng.</td><td>18</td></tr>
<tr><td>IT</td><td>2</td></tr>
<tr><td colspan="2">Total of selected majors (82 – 58)</td><td>24</td></tr>
</table>

Source: The Authors based on research data.

3.3 Data collection and job listings

This part of the study seeks to research whether the technical qualifications related to I4.0 are used to exercise I4.0 activities in Brazil, based on the requirements described in job listings. According to Peinado and Graeml (2014), collecting data from job listings posted by online agencies has become a data source for researchers working in a variety of areas.

To select the information and data related to these job listings, we opted to examine the Indeed.com and InfoJobs.com websites, due to their international recognition. For both websites the keyword "Industry 4.0" was used as our research filter. In total, we obtained 97 job listings related to I4.0. Of this total, 41 of them were excluded because they were internships or were outside of the areas of business administration, production engineering and information technology, or because they were repetitions found on both websites. Table 2 displays the listings that were excluded.

Table 2 – Job Listings Excluded from the Sample

Exclusion criteria	Number of positions
Internship positions	3
Listings outside of Bus. Adm., Pr. Eng. and IT	35
Repeated job listings	3
Total excluded job listings	41
Total of selected listings (97 – 41)	56

Source: The Authors based on research data.

To explore the data in the researched documentation, we used the content analysis method, which was separated into three steps: pre-analysis, codification and categorization (BARDIN, 2016).

The pre-analysis was performed and the procedures to be implemented were defined (VERGARA, 2000). We initially selected 82 documents about graduate courses of study and 97 documents about job listings. The documental analysis delimited the study's corpus to 24 graduate majors and 56 job listings related to I4.0.

After the pre-analysis, the codification step defined the units of registration for the exploration of the selected material. According to Bardin (2016), in this step we transform raw data using rules that permit the classification of the text. The registration units correspond to the words or content segments indicated as units based on the study.

The final step is categorization, when the constitutive elements of a group are classified by distinction and then grouped according to their genus, following previously defined rules, such as mutual exclusion, homogeneity, pertinence, objectivity and productivity. We utilized lexical categorization in order to classify the words according to feelings and synonyms (FRANCO, 2005).

The various technologies of I4.0 were defined by the technological categories which are formed by registration units. Table 3 presents the nine technological categories used in I4.0, with their respective frequencies based on the registration units found in the content analysis, separated into graduate courses of study and job listings.

Table 3 – Frequency of Registration Units by Technological Category

Technological categories	Frequency of registration units			
	Graduate courses of study		Job listings	
	Quantity	%	Quantity	%
1 - Big Data	59	29.35	39	58.21
2 – Cloud computing	9	4.48	1	1.49
3 – The Internet of Things	29	14.43	3	4.48
4 – Additive manufacturing	15	7.46	0	0.00
5 – Augmented reality	7	3.48	0	0.00
6 – Autonomous robots	16	7.96	0	0.00
7 – Information security	23	11.44	0	0.00
8 – Simulations	17	8.46	0	0.00
9 – Integrated systems	26	12.94	24	35.82
Total	201	100.00	67	100.00

Source: The Authors based on research data.

To analyze the results, we will next present the data from our research in three areas: Business Administration, Production Engineering, and Information Technology.

4. RESULTS

The results for the nine technological categories found for I4.0 are presented in two steps: the first presents the research results of the categories found in the graduate courses of study in the areas of Business Administration, Production Engineering, and Information Technology. Then we will present the categories found in the job listings which will be presented in an analogous manner.

4.1 Specialization courses of study in business administration

We analyzed four courses of study linked to the area of Business Administration. The content analysis of these courses of study resulted in seven technological categories: integrated systems, the Internet of Things, augmented reality, additive manufacturing, simulations, autonomous robots and Big Data. We also observed that the predominant focuses of the implementation of I4.0 concepts are related to the areas of human resources, logistics, manufacturing and marketing. Text Table 1 presents the registration units by the technological categories found.

Text Table 1 – Registration Units per Category in the Business Administration Area

Technological categories	Registration units found
1 - Big Data	BI tools; open data; learning algorithms; informational architecture; design thinking; statistical modeling; artificial intelligence; Turing tests; data mining; and machine learning
3 – The Internet of Things	Elements of the Internet of Things; Internet of Services; and industrial sensing
4 – Additive manufacturing	Additive manufacturing and rapid prototyping
5 – Augmented reality	Applications of augmented and virtual reality
6 – Autonomous robots	Autonomous systems; and collaborative and autonomous robotics
8 – Simulations	Physical and virtual prototyping; simulation and escalation; and virtual manufacturing
9 – Integrated systems	Human-machine interfaces; CRM; ERP; SAP; integration of the value chain; integrated logistics; horizontal and vertical integration of processes and systems; digital integration of clients and suppliers; integration and security; and the integration of data, clients and intelligent solutions.

Source: The Authors based on research data.

Big Data was the technological category with the greatest recurrence in the content analysis related to the Business Administration area, with this phenomenon being related to the largest number of disciplines in the courses of study related to the area of marketing. In this sense, we observed that, of the four courses of study within the Business Administration area which were studied, three possessed disciplines related to this subject. This finding could be related to the fact that Big Data is linked to the idea of large volumes of data, which can be used to stimulate the relationship with the client, improving the results of marketing, and measuring the internal reliability of companies (LEE; BAGHERI; KAO, 2015).

Another technological category which stood out was integrated systems. The four majors offered disciplines in this category, diversified in the areas of logistics, manufacturing and human resources. The complexity of the areas that use these systems is due to the origin of Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) systems, and their capacity to consolidate information from diverse areas within the company and maintaining profitable client relationships based on the use of this type of technology. Today they are related to so-called cyber-physical systems (TAO *et al.*, 2019).

Other categories which were mentioned indirectly were the Internet of Things, augmented reality, additive manufacturing, simulations and autonomous robots in disciplines related to manufacturing under terms such as elements of the Industrial Internet of Things, industrial sensing, augmented and virtual reality applications, physical and virtual prototypes, autonomous systems, and robotics.

We also observed the concept of integrated systems which received a lot of attention mainly in the areas of manufacturing and logistics through disciplines that address the value chain, integration between clients and suppliers, and the horizontal and vertical integration of systems. These concepts are utilized to demonstrate that products, processes, data and production and managerial systems interact with each other within I4.0 (MARCIANO *et al.*, 2019).

4.2 Specialized courses of study in production engineering

Specializations related to Production Engineering, unlike the Business Administration area, are broader than the area of engineering itself, and they can include terms pertinent to management, modeling and computational language. In addition, all of the courses of study in the Production Engineering area feature the term Industry 4.0 in their titles. These courses of study presented nine technological categories as shown in Text Table 2.

Text Table 2 – Registration Units: Technology Categories in Production Engineering

Technological categories	Registration units found
1 – Big Data	Process mining; logs of events; WF-Net models; causal networks; data mining; organizational mining; R language; fundamentals of data cleaning; design thinking; understanding the principles of generating, storing, extracting and analyzing data; manipulation of data and the study of its categories (social data, enterprise data, and personal data); and neural networks
2 – Cloud computing	The architecture, security and infrastructure for cloud computing
3 – The Internet of Things	IoT infrastructure; wireless sensor networks; wireless communication networks applied to IoT; communication protocols applied to IoT; and data integration platforms for IoT
4 – Additive manufacturing	Principles of additive manufacturing; manufacturing by adding layers; classification of additive manufacturing technologies; optimization of process planning in additive manufacturing; and geometric modeling designed for additive manufacturing
5 – Augmented reality	Definition of augmented and virtual reality; and iterative tools and techniques for the development of augmented reality and virtual reality.
6 – Autonomous robots	Construction characteristics of robots and industrial applications; robot components; hardware and programming for industrial robots; autonomous robots and artificial intelligence techniques; and the dynamic modeling of a robot in an open chain
7 – Information security	Best practices in information security; norms for the security of automated systems; overall vision of information security; authentication mechanisms; physical and logical security; control of access; application protocols used for the secure transmission of data and for platforms; and auditing and security methodologies.
8 – Simulations	Simulation as a pillar of I4.0; line theory; discrete event systems modeling and analysis; development cycle of the simulation design; use of computer simulations as a tool for decision making and the evaluation of the impacts from changes related to the implementation of I4.0; improvements in the factory layout; the formation of product families and a reduction in stocks; the classification of simulation models; the description of a methodology for the development of simulation designs; the conceptual definition of stochastic processes; the concept of discrete and continuous random variables and their respective distributions of probabilities associated with the simulation; and methods to generate random numbers and their importance for the development of the simulation area.
9 – Integrated systems	Machine-to-machine; the integration of digital manufacturing with I4.0 technologies, automated systems and MES; integrated management systems and ERPs; the integration of business processes

Source: The Authors based on research data.

As we have already seen, integrated systems such as Manufacturing Execution Systems (MESs) and ERP systems, are essential tools for the union of various processes within a company. Therefore, graduate courses of study in Production Engineering also cover these tools, in addition to the integration of digital manufacturing with I4.0 technologies. This makes it possible to have flexible and reconfigurable manufacturing systems through intelligent machines, thus forming a self-organized system which can be dynamically reconfigured to adapt to different types of products (FOIDL; FELDERER, 2015).

Meanwhile the teaching of Big Data in graduate production engineering majors has a differentiated focus, with it being predominantly related to aspects such as decision making based on neural nets, programming using the R language, and process and data mining. According to Lee, Bagheri and Kao (2015), Big Data can facilitate layouts, process indicators, maintenance management, and the alteration and improvement of products and providing services.

In terms of the Internet of Things, graduate courses focus their attention on infrastructure (sensors) and communication protocols for IoT, as well as data integration platforms. This technological category utilizes the collection, processing and analysis of data produced by IoT sensors, which are integrated through flexible systems used to track processes and products, in addition to their making for more agile decision making (ČOLAKOVIĆ; HADZIALIC, 2018).

In simulations, graduate courses of study are based on the modeling and analysis of systems with discrete random variables and decision-making tools and the evaluation of impacts from changes related to the implementation of I4.0. To accomplish this, real or imaginary models are utilized to understand the behavior of the manufacturing process, which can reproduce the basic structure of the factory model, offering information such as its layout, resources and physical structure, as well as details of its processes, volumes and production times (RODIČ, 2017).

Another focus of teaching in the analyzed graduate courses of study is information security. According to Lezzi, Lazoi and Corallo, (2018) industrial installations are vulnerable due to their high level of automation and their connections with external networks. Thus, we observe a concern in these majors with learning the security norms for automated systems, authentication mechanisms, physical and logical security, application protocols for the secure transmission of data, and auditing and security platforms and methodologies.

In addition to these technological categories, the others appear in graduate courses through the architecture and infrastructure of cloud computing, the principles and classifications of additive manufacturing, the definitions, tools, and techniques of augmented reality and the construction characteristics and applications of autonomous robots.

4.3 Specialized courses of study in information technology

Graduate courses of study in Information Technology provide all the support necessary to learn the processes and operations of I4.0. To accomplish this, the two courses of study present nine technological categories which are displayed in Text Table 3.

Text Table 3 – Registration Units per Technological Category in Information Technology

Technological categories	Registration units found
1 - Big Data	Artificial intelligence; design thinking; definition and fundamentals of BI; structured and unstructured data analysis; ETL processes (extract, transform and load); statistic modeling; data mining; data lake; data warehouse; OLAP (online analytical processing); tools for constructing dashboards; data science; data analytics; artificial feedforward neural networks; convolutional and recurrent artificial neural networks; *Python* (variables, datatypes, functions, conditions, iterations) and *Python* libraries (*NumPy*, *Pandas*, *Matplotlib*, *Seaborn*, *PyTorch*, *TensorFlow*)
2 – Cloud computing	Financial analyses and risks of migrating to a cloud; objective evaluations for the definition of new cloud implementations; cloud council requirements; *Gartner's* 5Rs; and the impact on business and IT processes (ITIL, COBIT, ISO 27001) of transitioning to a cloud
3 -The Internet of Things	Definition of the fundamentals of IoT; concept of ubiquitous computing; wireless sensor networks; digital twins; sensors and data collection; development of IoT platforms; OSI layer model; and combined protocols (SOAP, MQTT and OPC-UA)
4 – Additive manufacturing	Fundamentals of material sciences in industry; modern materials in I4.0; composite materials; 3D printing and rapid prototyping; types of rapid prototyping technologies; the application of additive manufacturing in industry (production, maintenance and distribution); and mass customization
5 – Augmented reality	Concepts and fundamentals of virtual and augmented reality and the management of assets with virtual and augmented reality.
6 – Autonomous robots	Principles of robotics and autonomous systems; robotic applications; UAVs (drones); and robotic inspections, exoskeletons, and autonomous vehicles.
7 – Information security	Fundamentals and applications of blockchains; cryptography; digital signatures; nodes and wallets; block transactions and structure; mining; fundamentals of cybernetic security; risk analysis and security policies; evaluation of existing security systems; support techniques and solutions and security supervision systems; and access port security.
8 – Simulations	Optimization in production through the use of simulations.

9 – Integrated systems	Fundamentals of cyber-physical systems.

Source: The Authors based on research data.

In the disciplines related to the Internet of Things, communication protocols between machines like MQTT (Message Queuing Telemetry Transport), SOAP (Simple Object Access Protocol) and OPC-UA (Open Platform Communications Unified Architecture), the infrastructure of networks and sensors and digital twins are their main characteristics. These attributes lead to network infrastructure based on communication protocols which attribute intelligent interfaces and physical and virtual instruments, perfectly integrating themselves with information networks (TAO *et al.*, 2016).

In relation to cloud computing, graduate courses of study highlight its financial implications, technology, and the risks in migrating data. According to Picoto, Crespo and Carvalho (2021), suppliers are more concerned about computational power and reductions in costs, while IT professionals are more cautious in terms of the compatibility of the cloud and their information systems and corporate needs, and they are also not certain about the security and standardization of the services that cloud computing can offer.

In the additive manufacturing category, the fundamentals and characteristics of materials, the types of technologies for prototyping and their application in industry are the main aspects observed. The importance placed on additive manufacturing is due to the fact that it has a process which links materials in layers like 3D printing, increasing production efficiency (ABDULHAMEED *et al.*, 2019).

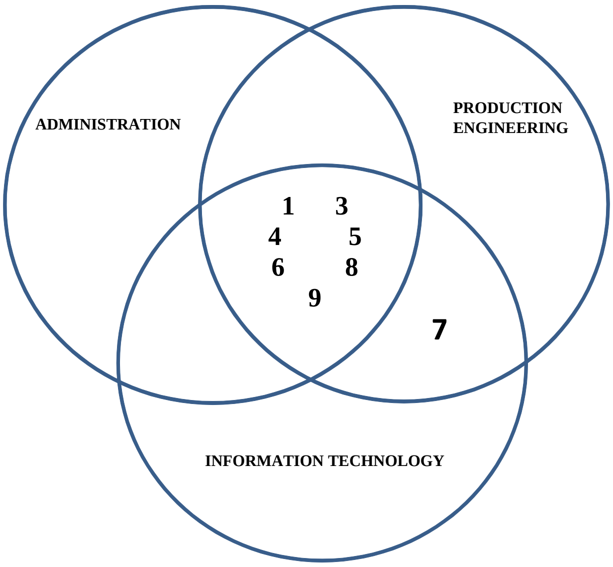
Information security is observed in course syllabuses through blockchains, cryptography, and cybernetic security policies. Its presence is due to, among other factors, the vulnerability of connected computational systems (LEZZI; LAOZI; CORALLO, 2018), which requires complex systems to cover the entire network to verify threats (THAMES; SCHAEFER, 2017).

Autonomous robots are also covered in these courses of study and they stand out in terms of the demand for knowledge about robotics applications and principles mainly in drones and autonomous vehicles. Its importance is due, among other factors, to the versatility of the application of these concepts, including everything from greater precision in production processes to demands for mass customization (BAHRIN *et al.*, 2016; PAWAR; LAW; MAPLE, 2016).

In terms of the Big Data category in IT courses of study, BI (Business Intelligence) tools, structured and unstructured data analysis, data analytics, neural nets, and Python programming dominate in terms of frequency of appearance. This technological category offers great opportunities in various sectors, but also presents an unprecedented challenge in terms of handling ever growing volumes of data, in which the advanced analysis of data is essential to understanding the relationships between resources and information (GHASEMAGHAEI, 2021). In terms of the disciplines linked to the fundamentals of Big Data, integration appears in one of the graduate courses of study in IT, through the integration of the supply chain and manufacturing systems. Due to the increase in client services, supply chain management requires the integration of processes as well as operational excellence in corporations (CHOI; WALLACE; WANG, 2018).

Figure 1 summarizes one of the study's interesting findings, showing clearly that all the graduate courses of study in the three areas contemplated by this study feature all of the I4.0 technological categories with the exception of information security (Category 7).

Figure 1 – Technological categories and areas of knowledge in graduate courses of study



Source: The Authors based on research data.

4.4 Job Listings in the area of business administration

In relation to job listings in Business Administration, seven of them cited I4.0 in a general way, without specifying the technological category used. They are job listings which only specify that the candidate needs to have knowledge of I4.0. Two companies cite the SAP ERP as a necessary qualification to fill this position, and another company mentions MESs (Manufacturing Execution Systems), as presented in Text Table 2. Even though the positions are more generic in relation to knowledge, we can see the importance attached to knowledge of integrated systems like ERPs in these companies, which are the base for understanding more complex cyber-physical systems (MARCIANO *et al.*, 2019).

Text Table 2 – Result of Business Administration Job Listings

Technological categories	Registration units found
9 – Integrated systems	SAP and MESs

Source: The Authors based on research data.

To sum up, we have observed that specialized courses of study pay more attention to Big Data and integrated systems, with the latter being the most recurrent requisite in the analyzed job listings. This is in keeping with the function of an administrator, which is often based on the need for a holistic view of analyses and factual decisions based on data.

4.5 Job listings in the area of production engineering

In respect to job listings in Production Engineering, companies seek people with abilities in programming, data analysis, integrated management systems, and knowledge of automated systems, as displayed in Text Table 4. It is possible to relate a greater complexity of knowledge required of candidates in the Production Engineering area with interdisciplinary characteristics which have to do with the role of problem solvers in production processes (BLAYONE; VANOOSTVEEN, 2021; SIMA *et al.*, 2020) which are more and more permeated by new technologies.

Text Table 4 – Results of the Job Listings for Production Engineering

Technological categories	Registration Units Found
1 – Big Data	C#; *MSSQL*; data analytics*; Tableau; Power BI;* interfaces between databases and dashboards; *Qlik Sense; Minitab;* data collection and acquisition; JSON; and XML.
9 – Integrated systems	Mapping of processes and work flows; integration with equipment and industrial peripherals; ERPs; knowledge of industrial system architecture and harmonization with corporate systems; and knowledge of integration with an automated layer.

Source: The Authors based on research data.

Thus, we can see that the Production Engineering area focuses on computational and mathematical systems which are more aligned with quantitative analyses, with it being possible to also observe this tendency in the disciplines of IoT which value knowledge of sensors and communication protocols. This knowledge is also aligned with probabilistic tools and controlling processes.

4.6 Job Listings in the area of information technology

The job listings were concentrated in the categories of Big Data, the Internet of Things, cloud computing, and integrated systems, especially software as can be seen in Text Table 6. This knowledge is expected in the IT area, but it also combines traditional knowledge in the area like ERPs, with more complex knowledge related to intelligent manufacturing like MESs (Manufacturing Execution Systems) (MOHAMMED *et al.*, 2018).

Text Table 6 – Results of the Job Listings for Information Technology.

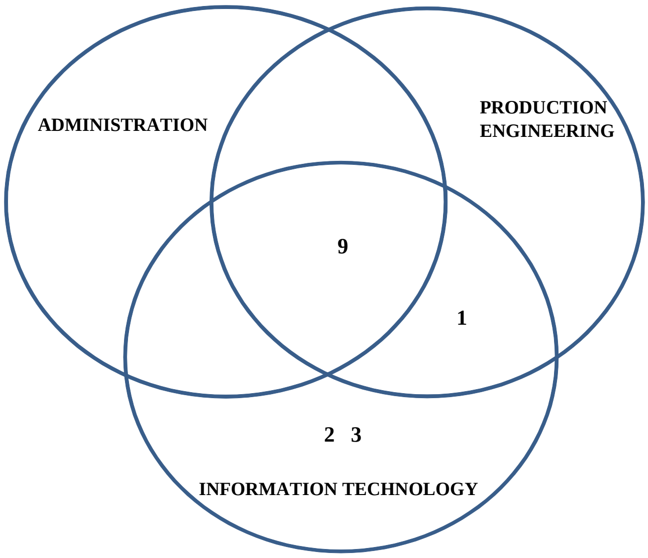
Technological categories	Registration Units Found
1 - Big Data	*MySQL*; *Java*; *Python*; *CSS*; HTML; experience with data visualization tools; *Power BI*; extraction, transformation and loading of data; *Oracle* databases; C#; *devops;* and *PostgreeSQL*
2 – Cloud computing	Experience with *Amazon Web Services*
3 – The Internet of Things	LPWAN Networks and SOA
9 – Integrated systems	System integration; MES; CRM; ERP; *Jira*; and MRP

Source: The Authors based on research data.

To sum up, we can see that the IT area is more pragmatic, for example, with additive manufacturing processes more aligned to prototyping; as well as a strong concern about information security and the possible vulnerabilities of systems. This is corroborated by the analysis of the job listings, which require advanced knowledge of manufacturing but also specific experience such as *Amazon Web Services*.

Figure 2 summarizes another interesting finding which shows that companies appear to be far from applying the precepts proposed by I4.0

Figure 2 – Technological categories and areas of knowledge in job listings



Source: The Authors based on research data.

5. CONCLUSIONS

With the new technical demands linked to changes in the work world, there is now a need to adapt workers to the new scenario of I4.0. This adjustment is important to establish the worker in the job market through the knowledge required by businesses (KHAN; KHAN, 2018; THAMES; SCHAEFER, 2017).

On one hand, the content analysis of job listings demonstrated that companies in general are looking for professionals with experience linked to the technological categories Big Data and integrated systems. Due to the great quantity of information data processed in the I4.0 environment, these two technological categories are restricted to specific types of software, or in other words, companies are interested in candidates with expertise in certain programs. On the other hand, the content analysis of the disciplines demonstrated that all of the nine technological categories of I4.0 are covered by graduate courses of study in these three areas (Business Administration, Production Engineering, and Information Technology).

Content analysis of the job listings also shows that the specifications of knowledge relating to these nine I4.0 categories are superficial when they occur, which could indicate that some companies lack a multifaceted vision of I4.0.

The main contribution of this work, in the opinion of the authors, is an alert for production organizations to be conscious of the complexity of I4.0 systems and the gamut of combined knowledge that these arrangements require. This study indicates a need for HEIs and the governmental bodies that support them to meet with businesses to discuss the body of common knowledge in several areas to arrive at a taxonomy of shared attributes.

Despite the interesting results we have obtained, this study has a few limitations which reduce how generally they can be applied. The two main limitations in the authors' view are related to the difficulty of access to syllabuses in HEIs, due to a lack of information on their portals. The second limitation is related to the reduced number of job listings due to its division into three areas as defined by the scope of this study.

Despite (and as a result) of these limitations, we believe that our discussion of the technical qualifications needed for I4.0 is important not just due to the results which it can obtain, but also to stimulate a debate about teaching interests and business practices in the areas of Business Administration, Production Engineering and Information Technology, providing an added opportunity to reflect on the potential of I4.0 in the training of future professionals and their roles in the job market.

Future studies can explore the reasons why certain companies believe that a lack of trained labor is one of the barriers to Brazilian companies' adoption of I4.0, despite the great variety of content available in graduate courses of study. It is possible that this narrative carries little weight in the justifications for the large number of unemployed workers as well as the technological backwardness that afflicts developing countries.

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