1. Introduction

In 1976, Production Engineering was granted by Poli/USP through Decree No. 78,319 (Meirelles, 2016).

In 2010, the Production Engineering course had an exponential growth, according to data from the Synopsis of Higher Education, published annually by INEP (Institute of Educational Studies and Researches Anísio Teixeira), and which is available on the website of this Institute (INEP, 2013) and the Register of Institutions and Courses contained in the E-MEC System portal (E-MEC, 2013).

The Production Engineer is a continuous area of other Engineering and its intervention concerns not only the manufacturing industry, but also education systems, transport systems, financial institutions, etc. (Oliveira, 2012).

The success of the Production Engineering course comes from its multidisciplinary scope, a professional in the field can work either in service or in manufacturing, which requires integration, optimization and performance measurement (Pereira, 2012). For this, the Production Engineering course at universities, in general, is a desired set of knowledge, skills and competences that must be done by the professional trained in this area, even though it is one of the newest in Brazil, compared to the Engineering Course Civil (the first non-military course in Engineering in Brazil) (Telles, 1994). The course is based on integrating man, machine and technology to serve the market (Telles, 1994). Thus, there is a need to prepare students for the scope. However, in 2016 universities have been seeking to implement industry concepts 4.

Implementing Industry 4.0 in Production Engineering courses is not an easy task as it involves complex and time-consuming projects such as Learning Factory, these project-based approaches can be introduced in the early stages of a bachelor's curriculum, which predominantly serves as a period. for basic education in mathematics, physics, materials science, manufacturing and the like (Tanriogen, 2018).

Thus, the objective is to present a new structure in the pedagogical guidelines of the Production Engineering course, which will be based on the axes currently proposed by the Brazilian Association of Production Engineering (ABEPRO) and on the competencies described by the Association to be achieved. Considering the conceptual nature of the objective, this work is an observational approach of the bibliographic type (Widener et al., 2016), whose methodological trajectory is based on the exploratory and selective reading of research related to academic pedagogical guidelines in Production Engineering.

Thus, in the first section, it presents the introduction, which contextualizes the proposal of this study, the research problem, the objectives and the justification for choosing the theme. Section 2 brings the theoretical basis for further discussion, exploring in the literature concepts about the Production Engineering course in Brazil and other countries for a possible connection between Industry 4.0. Section 3 presents the methodological trajectory adopted to achieve the proposed objectives. Section 4 contemplates the analysis and interpretation of the collected data, presenting the research results and the discussion with theory. Finally, section 5 offers the research's final considerations.

The originality of this article is the presentation of the pedagogical guidelines of the Production Engineering course and its objectives in an interrelated way, measuring this integration of graph theory. As a result, an Upgrade was presented in the pedagogical guidelines of the Production Engineering course for the integration of industry 4.0. In addition, limitations were presented and the theoretical, practical and social implications of this study were explained.

2 Theoretical Framework

In the next sections, the themes will be discussed: Production Engineering Course in Brazil and other countries, application of industry 4.0 in education, as well as the integration of these two themes, using graph theory.

2.1 Production Engineering Course in Brazil

On March 11, 2002, the Production Engineering Course was instituted by the Higher Education Chamber of the National Council of Education, through the CNE/CES resolution, in which the pedagogical project of the course defines the profile of the desired graduate for a course. graduation (Junior, 2011).

The role of ABEPRO (Brazilian Association of Production Engineering) is to seek to clarify the role of the Production Engineer in society, along with government institutions that evaluate courses (MEC and INEP) and development courses (CAPES, CNPq, FINEP), supporting bodies state surveys, non-governmental organizations that deal with research, teaching and extension of engineering and private organizations, together with CREA, CONFEA, SBPC and ABENGE.

According to the Brazilian Association of Production Engineering (ABEPRO), the Production Engineering courses must contain in their modality 30% of a basic content, 15% professional and 55% specific defined by the proposed axes. The course is also divided into a sub-area of knowledge that is focused on the representation of professionals, professors and students related to the area of production engineering, which was established in 1987 (Carvalho, 2012).

The main focus of the insertion of the Production Engineering course in Brazil is to promote self-sustainable social development, propose and ensure the correct practice society in search of professional preparation, adding competence to act in the best way in the market, and directly contributing to obtain a fair, democratic and legal society, based on ethical and moral values (Fleury, 2018).

2.2 Production Engineering Course in other countries

Let's start by commenting on the University of Georgia in the United States (ISyE – Georgia Tech) which was recognized as the best university by the “Subject Ranking 2015-2016: engineering & technology Top 100,” in the world. The Production Engineering course at the University of Georgia in the United States aims to be as flexible as possible, be multidisciplinary and encourage critical thinking that facilitates innovative decision-making (Kennedy, 1996). In the first year, the student takes courses in the basic cycle, such as mathematics, physics and chemistry, after completing the basic cycle, the student must choose one of the following areas: operational research, quality and statistics, supply chain or economic systems and financial. To (Hotaling et al., 2012).

According to (Vaughter et al., 2016), the Production Engineering course in Canada follows a similar structure to that of the United States, with the difference that they have in their menu disciplines focused on various human factors, such as: psychology, sensory perception, human performance in specific functions, people's information processing ability and people's behavior.

In Germany, the Production Engineering course has a high performance, as the country is the largest European producer of mechanical machinery and is considered economically the strongest in Europe, and which has an extremely developed industrial sector, with large metallurgical and chemical industries. a major concern in the quality of engineering training (Germanu Trade, 2017).

In the first year of the course, the Production Engineering student has studies focused on economic sciences, mathematics and computing (Libra, 2007). After the end of this cycle, the student must choose a specific line of specialization, with a great focus on programming and on the study of different energy sources (Libra, 2007).

According to (Rodriguez et al., 1992), in the United Kingdom, the Production Engineering course is aimed at manufacturing new products, and its pedagogical guidelines tend to give its students a more objective technical training, with an emphasis on preparing the student for professional life, being the most practical course.

In Spain, the Production Engineering course focuses on the following areas: supply chain, operational research and information science (Zorio Grima et al., 2018).

In India, the Production Engineering course is offered at very few universities, as the industrial sector in India already employs more than a third of the country's entire production, being offered cheap labor and low protectionism, he says (Khare, 2015).

There are few universities that offer the Production Engineering course in China, the course is rarely offered as an undergraduate, but rather as an extension course where the student needs to be previously trained in some engineering area, with ergonomics and logistics being the main focuses of this course (Wang, 2011).

According to (Sengupta et al., 2017), universities in Japan and South Korea are focused on training students to become researchers in the field. Both countries stand out in the automotive, shipbuilding and electronics technology sectors.

In South Korea, the Production Engineering course is focused on programming and management, having been responsible since the early 1980s for the great growth of its automotive sector and numerous support tools, for example, lean manufacturing, too. known as lean manufacturing or Toyota Production System, it was together with the Kaizen philosophy of continuous improvement responsible for a great revolution in the industrial sector around the world, which had to adapt and copy the efficiency of the Japanese so that they could maintain competitiveness (Kim , 2012).

Analyzing the countries of South America, Chile and Argentina, the Production Engineering course lasts for five years, with a comprehensive menu that is very similar to the Brazilian one, with little focus on research (Tambosi et al., 2010).

2.3 Application of Industry 4.0 in education

The term 'Industry 4.0' was coined to mark the fourth industrial revolution, a new paradigm enabled by the introduction of the Internet of Things (Internet of Things) to the production and production environment (Johnson, 2018).

(Johnson, 2018) states that industry 4.0 emphasizes global machine networks in an intelligent environment, a factory capable of autonomously exchanging information and controlling any type of object.

(Weyer, 2015) confirmed four reasons why Industry 4.0 is important and is seen as revolutionary in the age of information technology and open market operations:

First, Industry 4.0 eases the burden of current challenges for manufacturers in order to make companies more flexible and responsive to business trends. These challenges include increased market volatility, shorter product lifecycles, increased complexity and global supply chains. For example, smart items will bring a stronger integration of the top floor and shop floor, hence more intelligence and flexibility for production.

According to (Weyer, 2015), Industry 4.0 allows the transformation of the modern economy to become more innovative and increase productivity. The use of modern technologies such as digital chains, intelligent systems and the industrial Internet is expected to accelerate innovations as new business models can be implemented much faster.

Third, it highlights the consumer role as co-producer and places them at the center of all personalized product activities, it is the most important activity in the product value chain where industry 4.0 places human beings at the center of production.

The fourth reason is that industry 4.0 will enable sustainable prosperity, through the use of modern technologies, to find solutions to challenges related to energy, resources, environment and social and economic impacts. Innovative solutions can reduce energy consumption, help companies sustain their businesses, existing business models and new technologies to produce around the world (even in high-cost locations).

According to (Schepman et al., 2012), the term industry 4.0 still has some shortcomings in relation to information, standardization and conceptualization, as some technologies are abstract in relation to their application and practices, requiring good guidance and use. Thus, the author (Bildstein, 2014) mentions the term “4.0 education” which was created by Velbert Campus and Heiligenhaus (CVH) at the Bochum University of Applied Sciences, as a proposal for an educational model which prepares people for this new era of information. However, (Gilchrist, 2016) states that professionals will need to adapt to new technologies, and an effective way to start this process is through the dissemination of information and knowledge, understanding and understanding (through a playful educational content) what is industry 4.0, what it is for, and how it can be used in practice. Virgolim (2014), points out that the training and adaptation of students to industry throughout their qualification is of fundamental importance for that individual's education, as the job market is increasingly demanding and seeks people with the capacity to innovate.

For (Saccol et al., 2009), it is any type of teaching or learning that occurs when the student is not in a fixed place, or when the individual takes advantage of learning opportunities provided by mobile technologies, thus associating technological and of mobility. (Ozdamli and Cavus, 2011) approach education 4.0 as an activity that allows individuals to be more productive when consuming, creating or interacting with information, mediated by mobile and portable digital devices. Regardless of the definition adopted and any limitations of use, the use of learning systems through mobile devices brings benefits that go beyond accessibility, convenience and communication (Schepman et al., 2012).

2.4 Graph theory

Graph Theory studies the relationship between two objects of a given set (Gross, 2014). According to the same author, the Graph Theory was created to solve the Konigsberg bridge problem in 1735 (Schraven et al., 2015).

A graph can be represented by a network, such as friendships, knowledge, communication, describe the authors (Bondy & Murty, 2008). The representation of a “Graph” is a connection from one point to another (represented by vertices) through an edge (Lin et al., 2016). In a search in the Web of Science Article Base with the word "Graph Theory", 127,390 documents returned, and the first one originates from 1870 and 7,964 documents were published in 2018. Graphs represent a mathematical tool to support data structuring (Kim et al., 2012). In this article, the use of the technique is essential to visualize the links between the curriculum and knowledge. Subsequently, the connection of areas and sub-areas of knowledge to represent the systemic integration of the curriculum.

3 Methodology

RSL (Systematic Literature Review) is a research method that uses literature as the main source of data for a given topic (Sampaio & Mancini, 2007). To elaborate the methodological paths followed, the search for articles in the Web of Science database on the topic of "Pedagogical guidelines for Production Engineering courses" was used as references for this research, "Implementation of the discipline Industry 4.0 in the Production Engineering course" and "Graph Theory" to measure the degree of connectivity of industry 4.0 with the guidelines established by ABEPRO.

The nature of the research can be classified as qualitative, with an exploratory methodological approach, carried out through a systematic literature review. The methods used were: content analysis, bibliometrics of articles and reviews on the subject. The data collection procedure was structured through a string search in the Web of Science scientific articles database, which resulted in 20 articles. First you delimited the search terms to be used to search the database. Which were summarized in truncated terms by the following words: Industry 4.0, Production Engineering, Graph Theory and the interconnection between knowledge and axes. These terms were searched for in the title, abstract and also in the documents' keywords. The second cut made was the limitation of the researched journals. The third cutout refers to the researched year, which was published from 2001 to 2021, totaling documents from the last 10 years published on the subject in the researched area. The last cut was the type of document retrieved by the search terms, which were limited to only scientific articles and reviews, as these two types of documents are more relevant to serve as a basis for analysis to seek to achieve the objective of this research, which focuses on the study of the curriculum of the undergraduate course in Production Engineering in Brazil and the application of graph theory.

Therefore, this article proposes the application of the theory of graphs, in order to interconnect the proposed areas of the Production Engineering curriculum. For the application of graph theory, an analytical study was also carried out in a Brazilian university, to seek the guidelines of the pedagogical course and to present a systemic simplification using graph theory in order to measure connectivity within the curriculum. Proposing simplification and integration with Industry 4.0 axes (Xu, 2018).

4 Analysis of results

Based on section 2.2 Production Engineering Courses in other countries, a summary comparison was made between the compositions of Production Engineering courses in different countries. Table 01 will present this comparison between the Production Engineering courses in different countries.

Table 01: Comparison between Production Engineering courses

	Engineering areas													
	DU ST	SCM	CI	YOU	FAI TH	PS	EC	MAT	DDP	AL	TH U	*LM*	ER	LO
countries														
1-Spain	*	*	*											
2-Brazil								*	*			*		*
3-United States				*	*									
4-Canada				*		*								
5-Germany			*		*		*	*						
6-United Kingdom									*					
7-Switzerland										*	*			
8-Japan												*		
9-South Korea												*		
10-China													*	*
11-Chile														
12 Argentina								*	*			*		*

Note: PO= Operational Research SCM=Supply Chain CI= Information Science TI= Programming FE= Energy Sources PS=Psychological CE=Economic Sciences MAT=Mathematics DDP= New Product Design AL=Food QU= Chemistry LM=Lean manufacturingE=Ergonomics LO=Logistics

Table 01 shows the countries which were presented in section 2.2, based on exploratory analysis it was possible to assemble the areas in which the Production Engineering course focuses on studies, namely: Operational research, Supply chain, Information Science, Mathematics, New Product Design, Food, Chemistry, Lean Manufacturing, Ergonomics and Logistics. Each country has an engineering knowledge area that is its focal point, in table 01 it was possible to identify these areas of Production Engineering, based on the literature review carried out in section 2.2

However, the scope of a curricular matrix helps to focus the course. In order to visualize the integration of the different areas of Production Engineering, we are going to apply in this article the graphical and matrix method in the form of a graph through a literature review. Finally, quantify the method in order to get valid results.

4. 1 Analyze to the axes that guide the Production Engineering course in Brazil

The objective of this section is to present a new proposal to the axes that guide Production Engineering, with the objective of interconnecting areas of knowledge to optimize academic results, in addition to simplifying the model, through the use of graph theory (Boundy, 2008).

According to (Gross et al., 2014), Graph Theory uses a technique that graphically conjugates the link with vertices and areas. For the construction of the graph in this article we will adopt the following divisions: between objectives (vertices) and knowledge (edges) for practical purposes will be using the subareas with the knowledge to interconnect. Being (a, b, c, d...) the subjects of the curricula, that is, the subjects and (1, 2, 3...) the knowledge objectives, that is, the course syllabus. Vertices that do not have links are subjects or axes that do not communicate with the curriculum. The graph method will prove whether there is connectivity or not (Gross et al., 2014).

Table 2 shows the vertices (goals = disciplines) and edges (knowledge = course syllabus), based on a study carried out at a Brazilian university.

Table 02: Vertex and edges of the Production Engineering course

Vertices (Subjects)		Edge (Course Menu)	
		1	Planning
The	*production management*	two	Materials Management
		3	Product outputs
		4	Inventory
B	*Product development*	5	Design
		6	Materials
		7	ERP
		8	MRP (materials requirements planning)
ç	*Planning and production control*	9	Number of products to be produced
		10	manufacturing process
		11	Demand forecast
		12	Aggregate Production Planning (PAP)
		13	Production control
		14	Quality management
d	*Quality*	15	Audit
		16	Quality tools
and	*Operational Research*	17	decision making
		18	Problems solution
f	*Workplace safety*	19	Protection of the worker
		20	Work safety NR
g	*Production Strategies*	21	competitive strategy
H	*Production Costs*	22	Economy
		23	market management

Graph theory is the method to prove whether there is a connectivity or not. In order for objectives to be linked to knowledge, it will be necessary to include an incidence matrix (Bondy, 2008). Below, in Figure 01, an example of an incidence matrix.

	V1	**V2**	**V3**	**V4**	**V5**	**Sum**
THE	1	0	1	0	1	3
B	1	0	0	0	0	1
Ç	0	1	0	1	0	two
D	0	0	0	0	0	0
Sum	two	1	1	1	1	**Index %**

Note: V=Vertex (Subjects); A= Edge (Menu)
Figure 01: Incidence Matrix
Source: Adapted from (**Scheinerman, 2010**)

An incidence matrix computationally represents a fork through a two-dimensional matrix, where one of the dimensions is vertices and the other dimension are edges. Table 03 shows the relationship of the Production Engineering course guidelines with the knowledge menus indicated by ABEPRO.

Table 03- Incidence matrix of the axes of knowledge objectives indicated by ABEPRO

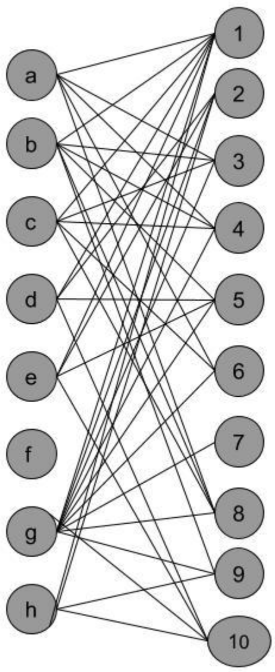
		Knowledge indicated by ABEPRO										
		1	two	3	4	5	6	7	8	9	10	Sum
The	production management	*		*	*		*		*			5
B	Product development	*		*	*	*			*	*		6
ç	Planning and production control	*		*	*		*		*			5
d	Quality	*	*			*					*	4
and	Operational Research	*	*			*					*	4
f	Workplace safety											0
g	Production Strategies	*	*	*	*	*	*	*	*	*	*	10
H	Production Costs	*	*							*	*	two
											Nominal connectivity degree of the graph	**0.42 or 42.2 %**

Note: 1= Integrate physical, human and financial resources in order to efficiently produce the lowest cost, considering the possibility of continuous improvement. 2= Make use of mathematics and statistics to model production systems that aid decision making. 3= Improve, design and implement systems and products taking into account the limitations and characteristics of the communities involved. 4= Predict and analyze demands, through scientific and technological knowledge, designing products or improving their features and functionality. 5= Quality techniques throughout the production system, both in technological and organizational aspects, improving products and processes, producing standards and control and auditing procedures. 6= Predict the evolution of production scenarios, realizing the interaction between organizations and their aspects of competitiveness. 7=Follow up technological advances, organizing and serving the demands of companies and society. 8= Understand the interrelationship of production systems with the environment, both with regard to scarce resources and the final disposal of waste and tailings, paying attention to the requirement for sustainability. 9= Use performance indicators, costing systems to assess the economic and financial feasibility of projects 10= Manage and optimize the information flow in companies using appropriate technologies. 8= Understand the interrelationship of production systems with the environment, both with regard to scarce resources and the final disposal of waste and tailings, paying attention to the requirement for sustainability. 9= Use performance indicators, costing systems to assess the economic and financial feasibility of projects 10= Manage and optimize the information flow in companies using appropriate technologies. 8= Understand the interrelationship of production systems with the environment, both with regard to scarce resources and the final disposal of waste and tailings, paying attention to the requirement for sustainability. 9= Use performance indicators, costing systems to assess the economic and financial feasibility of projects 10= Manage and optimize the information flow in companies using appropriate technologies.

To perform the calculation of the nominal connectivity degree of the graph, the recommendations of (Bondy, 2008) were followed, where the sum of the vertex degrees divided by the maximum sum of the number of vertices v minus one (subtraction of one unit is due to vertical of the matrix always equal to zero), giving a degree i = 0.42 or 42% of the objective matrix with knowledge is interconnected.

In figure 2, the connection of the menu offered by the Brazilian university vs what is expected by ABEPRO will be represented in graph form.

Figure 02: Linking goals with knowledge



A vertex of disconnected g-Work Safety was found, which aims to present to the student worker protection items and the NR's of work safety. In summary, the graph has 8 vertices and 1 disconnected with a degree less than 0.40 or 40% connectivity.

4.2 Proposed axis: Industry 4.0

In this section, a new matrix will be developed combining the objectives integrating with oi (Industry 4.0), based on the concepts presented in section 4 of this article, it was possible to analyze the connection of the menu offered by the Brazilian university vs what is expected by ABEPRO.

In the course offered by SENAI (National Service for Industrial Learning), the menu offered for the discipline industry 4.0, has the following purpose: "to enable professionals for the Management of contemporary Industrial Productive Systems, developing skills, abilities and attitudes for the application of techniques, procedures and work methods related to systems integration, data science, internet of things and technologies enabling Industry 4.0 to optimize production processes, following technical, environmental, quality and occupational health and safety standards”. Based on this, it was possible to make the connection with the menu expected by ABEPRO. According to table 04.

Table 04: Insertion of the Industry 4.0 shaft

		Knowledge indicated by ABEPRO										
		1	two	3	4	5	6	7	8	9	10	Sum
The	production management	*		*	*		*		*			5
B	Product development	*		*	*	*			*	*		6
ç	Planning and production control	*		*	*		*		*			5
d	Quality	*	*			*					*	4
and	Operational Research	*	*			*					*	4
f	Workplace safety											0
g	Production Strategies	*	*	*	*	*	*	*	*	*	*	10
H	Production Costs	*	*							*	*	two
i	**Industry 4.0**	*	*	*	*	*	*	*	*		*	10
											Nominal connectivity degree of the graph	**0.50 or 50%**

In this table, an analysis of the syllabus of the subject -Industry 4.0- offered by SENAI (National Service for Industrial Learning) was carried out, and we added the pedagogical guidelines already existing in the Production Engineering course at a Brazilian University. Finally, we compared what is expected by ABEPRO and added the discipline - Industry 4.0-. Thus, it was possible to identify whether to insert the 4.0 industry axis in the pedagogical guidelines of the Production Engineering course, the degree of connectivity between the course guidelines vs. ABEPRO, we can observe an 8% nominal increase in the graph. In order to reach approximately 100% connectivity we would have to insert some industry 4.0 technologies separately, since most elements of the Fourth Industrial Revolution are already present in the market and have the potential to increase profitability, several countries have encouraged the development of industry 4.0 in their territory (Xu, 2018). The curriculum of Production Engineering courses needs to meet not only the world scenario, but also local realities. The presence of complementary sub-areas or in a curriculum represented as elective subjects.

5 Final considerations

The aim of this article was to present a new structure in the pedagogical guidelines of the Production Engineering course, which was based on the axes currently proposed by the Brazilian Association of Production Engineering (ABEPRO) and on the competences described by the Association to be achieved. In order to comply with it, the inclusion of the subject "Industry 4.0" in the Production Engineering course and measure its degree of nominal connectivity with the other subjects already included in the Engineering course. The sample of this article consisted of 20 groups from the Production Engineering course at a Brazilian University. The data show that the pedagogical guidelines adopted in the study in question, it has a connectivity with the menu proposed by ABEPRO of 42% and that among the 8 specific subjects of the course, only 1 is disconnected from what is proposed by ABEPRO. In addition, it was discovered if we insert the subject "Industry 4.0" in the guidelines of the Production Engineering course, the degree of connectivity with the knowledge menu will have an 8% increase in its degree of connectivity, if we study all the concepts of the industry 4.0 in only one discipline, if the enabling technologies of industry 4.0 are studied in separate disciplines, we can reach a degree of connectivity close to 100%. During the analysis, some limitations were found regarding the collection of data to use the theory of graphs to measure connectivity as a whole. it was not a relevant conditioner to assess the study's conclusions. As future work, it intends to expand to: validate engineering knowledge or skills; integrate the curriculum with other enabling technologies of industry 4.0 with a qualitative training; structure interconnected practices in a systemic way.

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