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DESIGN, CONSTRUCTION AND EXECUTION OF MANUFACTURING CELLS: AN ALTERNATIVE DYNAMIC FOR TEACHING - LEARNING CONCEPTS OF CELLULAR MANUFACTURING IN PRODUCTION ENGINEERING[i]

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Abstract:
The use of experiential learning activities has now spread as a tool to support the teaching of production engineering. This article aims to discuss this reality and this need, presenting as a proposal a practical activity of design, construction, and execution of manufacturing cells. From this, it was proposed to the participants involved to create and modify a simulated factory environment, through the knowledge acquired during the cellular manufacturing course. Several topics related to Production Engineering were approached, such as: manufacturing cells, takt time, process standardization, lean manufacturing and waste disposal. As a result, it was possible to notice, among several aspects, significant improvement in the understanding and assimilation of the theoretical concepts by the participants; with the practice of the simulation it is possible to demonstrate and experience possible cases and difficulties that they will face daily in the factory environment.

Keywords: manufacturing cells; experiential learning; production engineering teaching

Resumo:
A utilização atividades de aprendizagem experiencial têm se difundido atualmente como uma ferramenta de apoio ao ensino de engenharia de produção. O presente artigo visa discutir sobre essa realidade e esta necessidade, apresentando como proposta uma atividade prática de projeto, construção e execução de células de manufatura. A partir disso foi proposto aos participantes envolvidos a criar e modificar um ambiente fabril

[i] PROJETO, CONSTRUÇÃO E EXECUÇÃO DE CÉLULAS DE MANUFATURA: UMA DINÂMICA ALTERNATIVA PARA O ENSINO – APRENDIZAGEM DOS CONCEITOS DE MANUFATURA CELULAR NA ENGENHARIA DE PRODUÇÃO

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simulado, por meio dos conhecimentos adquiridos no decorrer da disciplina de manufatura celular. Foram abordados diversos tópicos relativos à Engenharia de Produção, como: células de manufatura, takt time, padronização de processos, lean manufacturing e eliminação de desperdícios. Como resultado foi possível notar, dentre diversos aspectos, a significativa melhoria na compreensão e assimilação dos conceitos teóricos por parte dos participantes, com a prática da simulação é possível demonstrar e vivenciar possíveis casos e dificuldades que enfrentarão no dia a dia dentro do ambiente fabril.

Palavras-chave: células de manufatura; aprendizagem experiencial; ensino engenharia de produção

1. Introduction

Prince and Felder (2006) cite that the teaching of Engineering has been evolving due to the changing profile of undergraduate students, requiring a constant evolution in teaching due to the access to the technologies available today. According to Carvalho et al. (2001), the training of the engineer can not be made only by formulas and concepts; he must be prepared to make decisions, seek information and know how to apply them, possessing a systemic vision. According to Moscinski (2007), this is the great challenge of the role that the teacher must play in the process of professional training.

Due to these reasons, Prince (2004) points out that the traditional model in which the student attends class passively gives way to active learning. According to Auster and Wylie (2006), active learning is characterized by the considerable involvement of students, who usually participate in practice simulations and projects for real-world problem solving, in the development of their own knowledge.

In this context, the objective of this article is to present a didactic activity as a tool to support the teaching of production engineering and the concepts related to manufacturing cells, Lean Manufacturing and process improvement presented in the Cellular Manufacturing course, through the development and simulation of a production process composed of 4 manufacturing cells, from which one can approach several concepts related to production systems, takt time, kaizen, process improvement, layout and teamwork.

2. Experiential learning

According to Kolb (1984), experiential learning is a particular way of learning from life experience he author has developed the "Experiential Learning Model" that considers learning as a process and not as a result. Keeton and Tate (1978) cite that in the view of experiential learning, the emphasis is often on direct sensory experience and action in context as the primary source of learning. Although the model has some limitations, it has important implications for education (Erselcan, 2013).

Schanck (1997) developed the "*learning by doing*" model that opposes the conventional teaching model, arguing that students should learn by doing and receive help when they fail. Reynolds et al. (2002) points out that such suggestions require a culture of experimentation in the workplace to support this type of "*natural learning*", but in real life such situations do not usually exist.

Moreira et al. (1997) understands that learning is the process in which new information relates to the learner's cognitive structure in a non-arbitrary and substantive way, that is, learning is related to the ability to acquire and store ideas, transforming them into a psychological meaning.

2.1 Dynamics for the experiential teaching process

Struyeven (2006) points out that active and constructivist teaching methods are at the forefront of the education process Methods such as problem-based assignments, new learning styles, case-related tasks, and collaborative work assignments challenge students to construct knowledge through authentic assignments that require active involvement. In active learning, students select, interpret, and apply knowledge using case studies and solve complex problems (White, 1996, Silberman, 1996, Jacobson and Mark, 1995).

Active learning is characterized by the considerable involvement of students in the learning process (Heriot et al., 2008; Prince, 2004), improving their ability to convert theoretical concepts into practical knowledge. Snider and Balakrishnan (2013) cite that experiential learning does not require an instructor and is derived from the reflection on direct experience. Curiously, this is in direct contrast to the typical university curriculum where teachers lecture to a passive audience.

The benefits of experiential learning techniques through teaching dynamics in business education are widely published (Paul and Mukhopadhyay (2004), Cotner et al. (2004), Daly (2001), Snider and Balakrishnan (2013), Williams and Chin (2009), Braghirolli et al. Deshpande and Huang (2011)). Currently, experiential education has materialized in the classroom through interactive learning dynamics. The application of teaching-learning dynamics in the field of Production Engineering has been frequently reported in simulations and games about concepts in the area of production management. For example, Có, Có and Merigueti (2008) developed a didactic game with playing cards to teach the concept of heyjunka, one of the main practices of lean manufacturing. Lage Junior (2008), on the other hand, used LEGO® assembly blocks to explain the differences between manufacturing and remanufacturing in programming environments with the MRP I (Material Requirements Planning) and MRP II (Manufacturing Resources Planning). Vieira (2017) developed a dynamic for the teaching of Production Engineering concepts through an activity called "Signature Factory" with sheets of paper where signatures are collected to explain the concepts of production improvement and layout types. In international publications it is also possible to identify dynamics using different types of materials, such as dice games (Lambrecht et al., 2012), paper airplanes (Billington, 2004), PVC connections (Santos et al. Kart Factory (Pozzi et al., 2014), planning and control of production through balancing (Cox and Walker, 2004) and car assembly simulation with sheets of paper (Hongyi, 1998).

2.2 Manufacturing cells

According to Rother and Harris (2002), a cell is defined as an arrangement of persons, machines, materials and methods in which the steps of the process are close and occur in sequential order, whereby the parts are processed in a continuous stream. The processed components are grouped into families (similarity of shapes and / or dimensions and / or processes). The physical layout of a U-cell is best known, but many different forms are possible, such as "L", "V" or "I" (Slack et al., 1999).

For Sheridan (1990), the manufacturing cell is a powerful alternative for reducing lead time, costs, waiting times and improving product quality, which are typical goals of Lean Manufacturing. Hyer and Brown (1999) add that the manufacturing cell contributes to eye contact, displacement reduction, and greater options of allocation of operators to the workstations, facilitating the connections of information and time to the process.

3. Methodology

The lack of research on student engagement in active learning guided the choice of case study approach for the study. According to Yin (2003), the case study is adequate to understand areas with limited prior research. Also, a case study approach benefits the development of new insights about a phenomenon (Omrod, 2005).

The development of the activity of design and construction of manufacturing cells will be described in figure 1, through the exposition of the dynamizing concepts of the teaching practice employed in the methodology proposal in the discipline of Cellular Manufacture, where after access to the necessary theoretical concepts, the efficiency of the practice is verified.

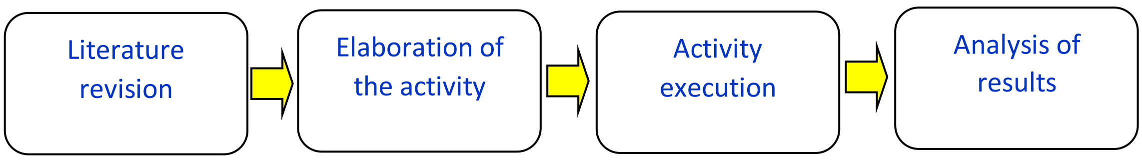


Figure 1: Activity development
(Source: Research data (2018))

In this section, the aspects related to the proposed creation of a simulated manufacturing environment will be described, in which 24 students of the Production Engineering course will be able to apply the concepts learned during the lectures on the content of cellular manufacturing and process improvement. Figure 2 shows the steps of the activity.

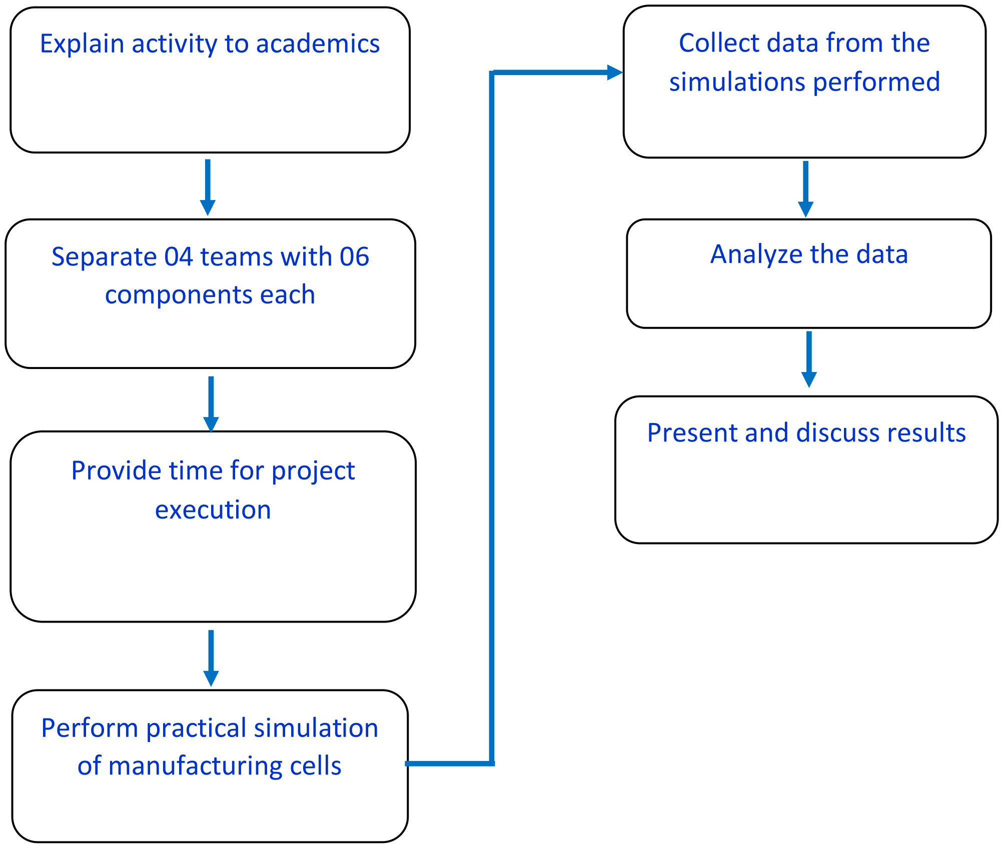


Figure 2: Sequence of activity steps
(Source: Research data (2018))

At the beginning of the dynamic, the teacher should explain to the students that the objectives of the activity are the applications of the concepts studied in the classroom on cellular manufacturing, lean manufacturing, teamwork and process improvement. The expected results in the execution of the activity are that the teams use these concepts to construct the manufacturing cells and can reconcile theory and practice. The teams must build manufacturing cells to assemble a didactic toy called "Robôcano", which was developed by Santos et al. (2013) and is composed of several PVC screw connections, as can be observed in figure 3.

This didactic toy consists of several parts of screw-on connections that can be divided into parts, which facilitates the application of the concepts of cellular manufacturing. The time for executing the assembly of the didactic toys was 5 minutes to assemble 5 robots. Each team developed its cell so that it was possible to meet these process specifications.

Figure 3: Robôcano didactic toy
(Source: Adapted from Santos et al. (2013))

This activity took place over 4 classes lasting 2 hours each, totaling 8 hours to execute the dynamic. The materials used by the students were: cardboard sheets, paper boxes, wire, glue, scissors, adhesive tape, sheets of A4 paper, tape measure and stylet.

The teams had to use the concepts of manufacturing cells, Lean Manufacturing, Kaizen, production balancing, standardized work, ergonomics, chrono-analysis and teamwork to execute the dynamic.

4. Results and Discussion

Initially the teams have to perform the Takt Time calculation of the activity, which is 5 minutes to assemble 5 robots.

$$Takt\ Time = \frac{available\ time}{demand}$$

$$Takt\ Time = \frac{5\ minutes}{5\ robots} = 1\ minute/robot$$

With the Takt Time information, each team can perform the balancing of the assembly operations, although no operation could exceed 1 minute. From this, the students began the assembly simulations to verify the division of the operations, recording the time of the operators. Each team was given the freedom to choose the type of manufacturing cell that was designed and executed for the robotic assembly. In Figure 4 it is possible to observe the initial operation of the teams for the construction of the manufacturing cells.

Figure 4: Initial operation for activity development
(Source: Research data (2018))

Initially, the teams carried out simulations to assemble the Robocano on laboratory benches. After the balancing simulations, the cells were designed and made. To facilitate the understanding of the work, the teams will be called A, B, C and D, where each one will be detailed in the following sections.

4.1 Team A

This team opted for an "L" shaped manufacturing cell model, which was composed of 04 operators, according to Figure 5.

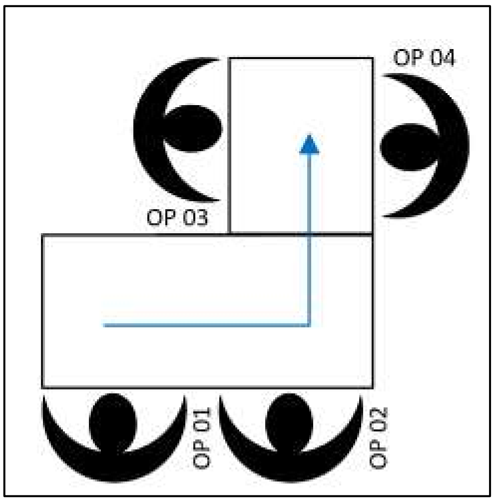


Figure 5: Team A cell layout
Source: Research Data (2018)

The division of the work of this team was performed with 04 operators, where each one performed part of the assembly of the robot, so that the time of each activity did not exceed the takt time. Working instructions were developed for each workstation, and operators were trained based on the information from that documentation. In figure 6 it is possible to visualize the configuration of the cell of team A.

Figure 6: Configuration of the manufacturing cell of team A
(Source: Research data (2018))

The total time for the assembly of the 5 robots was 3 minutes and 34 seconds, which is below the calculated 5 minutes of takt time.

4.2 Team B

This team opted for a U-shaped manufacturing cell model, which was composed of 03 operators, according to figure 7.

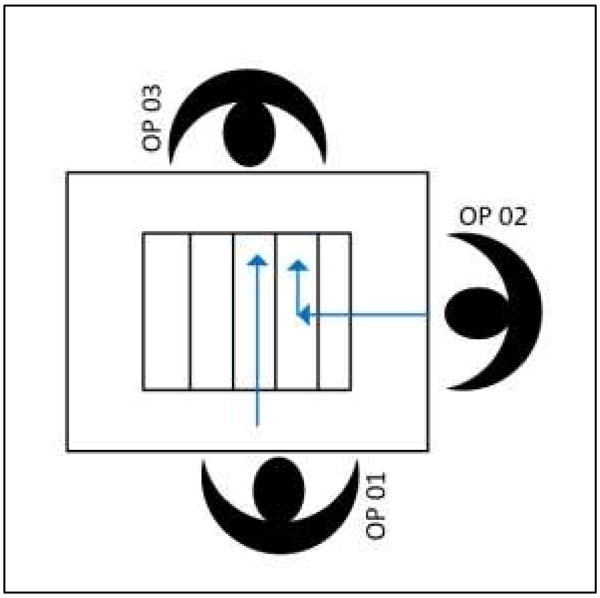


Figure 7: Team B cell layout
(Source: Research Data (2018))

The work was divided with 03 operators, where each one executed part of the assembly of the robot so that the time of each activity did not exceed the takt time. They also developed work instructions for each job, and the operators were trained based on the information of this documentation. It was possible to observe the use of troughs with the use of gravity to move the product in the cell. In figure 8, the configuration of the cell of team B can be seen.

Figure 8: Configuration of the manufacturing cell of team B
(Source: Research Data (2018))

The total time for the assembly of the 5 robots was 4 minutes and 29 seconds, which is below the calculated 5 minutes of takt time.

4.3 Team C

This team opted for a manufacturing cell model in an "I" format, which was composed by 03 operators arranged in line, according to figure 9.

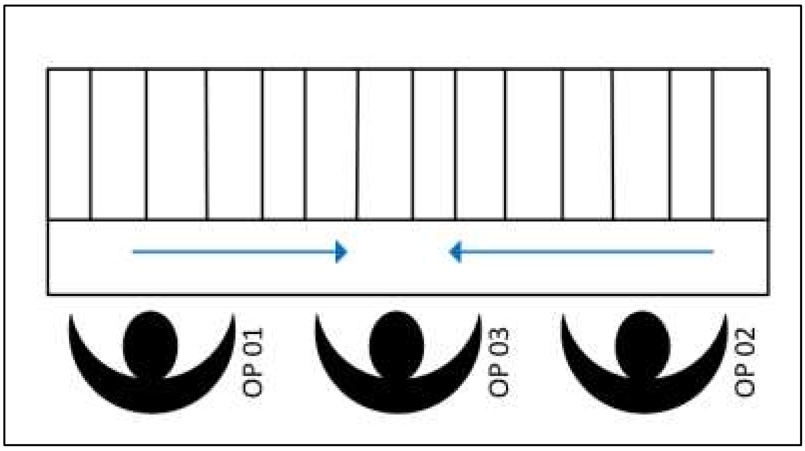


Figure 9: Team C cell layout
(Source: Research Data (2018))

The work was divided with 03 operators, where the assembly of the parts was started at the sides and ended in the central part of the cell. Each operator executed part of the assembly of the robot, so that the time of each activity did not exceed the takt time. They also developed work instructions for each work station, and the operators were trained based on the information of this documentation. It was possible to observe the use of troughs with the use of gravity and a supply in the back of the cell for movement of the product in the cell. In figure 10, the configuration of the cell of team C can be visualized.

Figure 10: Configuration of the manufacturing cell of team C
(Source: Research Data (2018))

The total time for the assembly of the 5 robots was 3 minutes and 57 seconds, which is below the calculated 5 minutes of takt time.

4.4 Team D

This team opted for an "L" shaped manufacturing cell model, which was composed of 02 operators arranged in line, according to figure 11.

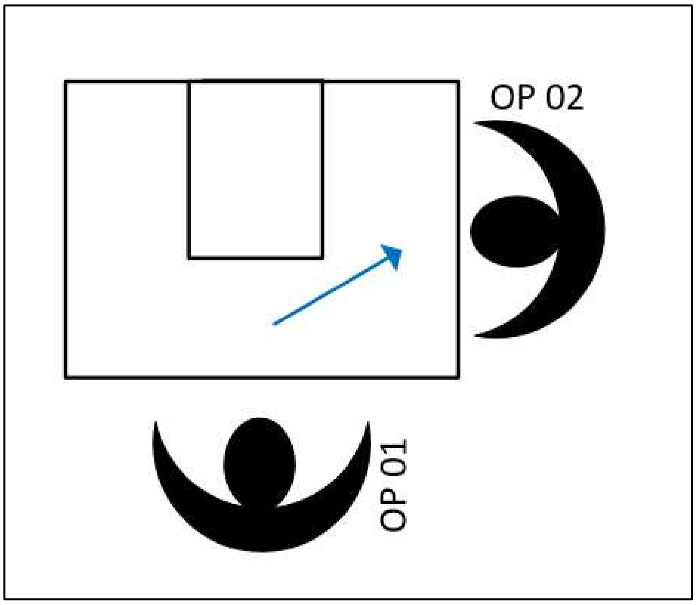


Figure 11: Team D cell layout
(Source: Research Data (2018))

This team divided the work with 02 operators, where each one executed part of the assembly of the robot. They also developed work instructions for each job, and the operators were trained based on the information in this documentation. In figure 12 it is possible to visualize the configuration of the cell of team D.

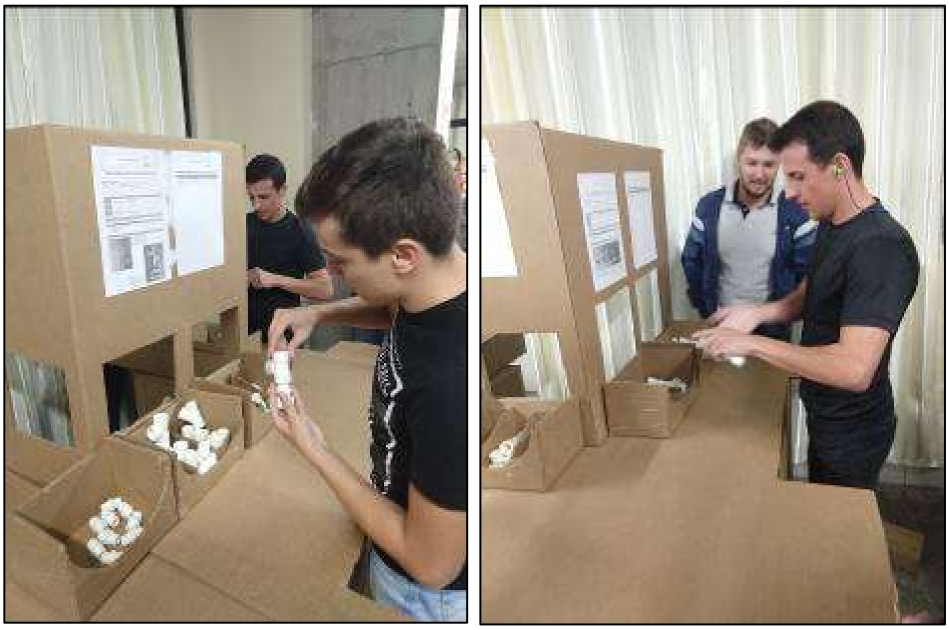
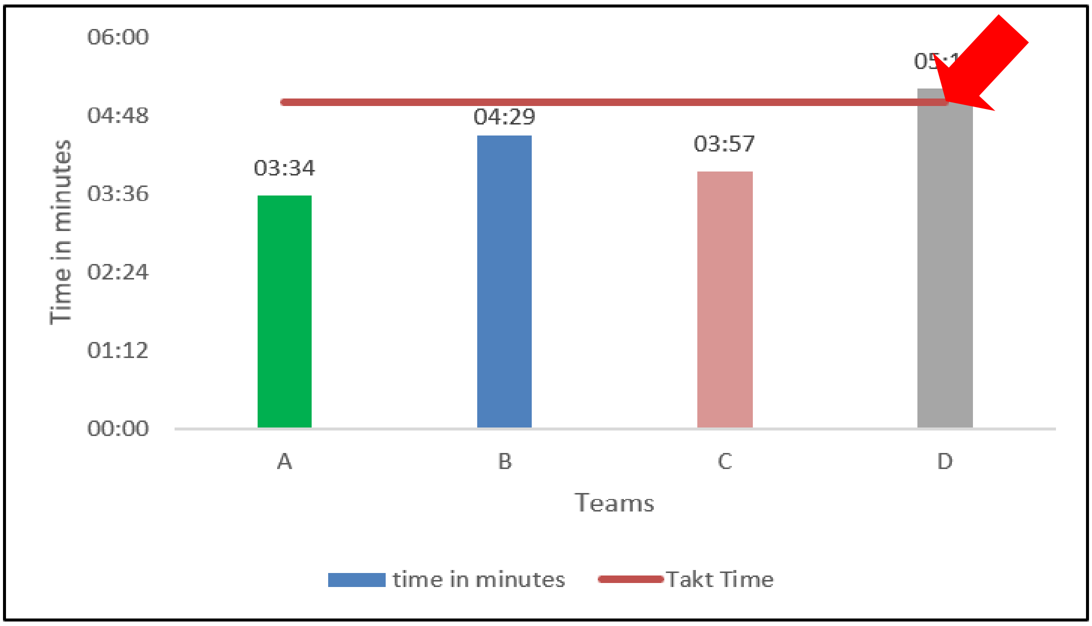


Figure 12: Configuration of the manufacturing cell of team D
(Source: Research Data (2018))

The total time for the assembly of the 5 robots was 5 minutes and 12 seconds, which is above the calculated 5 minutes of takt time.

4.5 Analysis of results

After the completion of the dynamic by all the teams, a closing meeting was held to analyze the performance of each production cell and to verify if the proposed goals were reached. In graph 1 it is possible to visualize the result of the activity.



Graph 1: Results of team times
(Source: Research Data (2018))

The only team that passed the 5-minute takt time was team D, reaching 5 minutes and 12 seconds and thus failing to meet the activity goal. The rest of the teams managed to achieve the proposed goal by efficiently balancing the activities. One factor that contributed to team D being over the time takt was the inadequate balancing of work, since they only worked with 02 employees, generating a work overload for them. At the end of the analysis of the results, participants should be allocated a time slot so that they can see new improvements that could still be made in the process. Lastly, the dynamics mediator should encourage participants to comment on the lessons learned and their contribution to the training provided by the activity.

4.6 Evaluation of the dynamic

After the analysis, a questionnaire was distributed in order to obtain feedback from the students about the activity performed. The questionnaires were answered anonymously, and were composed of 04 questions regarding learning, motivation and involvement, perception of practice and importance:

- Learning: Did your participation in the dynamic facilitate your learning of the theoretical concepts of the discipline?
- Motivation and involvement: Did applying the learning dynamic make the class more interesting and motivate you to participate more in the discipline?
- Perception of practice: Did the learning dynamic allow you to identify the types of cell layouts that exist in the processes more easily in real situations?
- Importance and continuity: Do you think it is essential that this dynamic is always used in the discipline of Cellular Manufacturing?

The result of the questionnaire applied is shown in Table 1:

1. Learning: Did your participation in the dynamics facilitate your learning of theoretical concepts of the discipline?	I totally agree	75%
	I agree	25%
	Neither agree nor disagree	0%
	Disagree	0%
	Strongly disagree	0%
2. Motivation and involvement: Did the application of the dynamics of learning make the class more interesting and motivate you to participate more in the discipline?	I totally agree	88%
	I agree	12%
	Neither agree nor disagree	0%
	Disagree	0%
	Strongly disagree	0%
3. Practice of Perception: Did the dynamics of learning allow you to identify the types of existing layouts in the processes more easily in real situations?	I totally agree	67%
	I agree	25%
	Neither agree nor disagree	8%
	Disagree	0%
	Strongly disagree	0%
4. Importance and continuity: Do you think it is fundamental that this dynamic is always used in the discipline of Plant Layout and Design?	I totally agree	92%
	I agree	8%
	Neither agree nor disagree	0%
	Disagree	0%
	Strongly disagree	0%

Table 1: Result of the activity evaluation questionnaire
(Source: Research Data (2018))

As can be seen in Table 1, the activity was well accepted by students. Analyzing the effects of the application qualitatively, the teacher noticed a significant increase in motivation in the students after the participation in the dynamic, because through it, the students were able to "get their hands dirty" and build a production cell from design to execution. According to Hofstede (1983), it is extremely important for any professional to reconcile theory with practice. According to the classification made by Snider and Balakrishnan (2013), the presented activity fits into the active learning dynamic in the semistructured experiential form.

5. Conclusion

This work described a teaching dynamic used to understand the concepts of manufacturing cells, continuous improvement, teamwork, process improvement, production balancing, standardized work and waste disposal. The activity followed the philosophy of active learning, stimulating students to experience situations that would allow them to consolidate theoretical concepts and build their own knowledge. According to Felder et al. (2000), to ensure the future of engineering, it will be necessary to teach more about "real world" engineering projects and operations by offering more and better instruction in oral and written communication skills, teamwork skills, creative thinking, and problem-solving methods.

The application of the activity of manufacturing cells with the undergraduate students in the Production Engineering course has proved quite interesting. This dynamic has become an additional resource for the teaching of Production Engineering. The concepts of manufacturing cells, Kaizen, Takt Time, Production Balancing, and teamwork are easily passed on to students, in addition to making the class much more attractive from the didactic point of view.

The experiential learning (through didactic games) makes the main role of the teaching-learning process shift to the student, who becomes the center of the process, unlike traditional teaching that focuses on the role of the teacher. This facilitates greater involvement by the desire to seek competitive and cooperative learning. The group work prevails over the presentation and individual presentation of the teacher.

As for the results, the students emphasize the change imposed by the execution of the dynamic and the breaking of the routine of theoretical classes. They emphasize that topics often only worked out theoretically can be experienced in practice, demonstrating possible cases and difficulties they will face in the manufacturing environment. The answers of the evaluation questionnaire, applied soon after the dynamic was accomplished, confirmed the wide acceptance that it had among the students.

The use of this activity enabled the generation of a model that adequately came close to reality. The good results obtained stimulate the continuation of the studies, with possibility of unfolding to other disciplines in the area of Production Engineering, such as: Production Planning and Control; Quality Management, Industrial Organization, Lean Production and Ergonomics.

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