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Active Learning "Factory of Boxes" in the Teaching-Learning Processes in Engineering and Entrepreneurship

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Abstract:"Factory of Boxes" is an Active Learning (AL) where concepts related to Industrial Engineering, Mechanics, Mechatronics, Electrotechnics and Entrepreneurial Management can be cultivated. The interconnection of these concepts offers the possibility of developing occupational related skills in the most diverse areas of knowledge. It is the use of AL, simulating the method of a factory which produces cardboard boxes in different layouts and production systems, namely: (a) Classic Taylorist-Fordist Model; (b) Positions' Enrichment Volvo Model; (c) cell production Toyota Model; and (d) automated line Taylorist-Fordist Classic Model. Data collection was based on observation, counting and recording production in a simulated test at two Universities (UFPB – Brazil and UBI – Portugal) involving master students in Industrial Engineering. The data were analysed from the aspects of productivity and cycle-time. The results showed: (a) It is an economically viable AL since it uses low-cost materials (except for simulating with automated posts which requires some investment) and (b) the Classic Model has the highest cycle-time and the Toyota Model has higher productivity, although these results derive from simulations with a teaching-learning aim and cannot be generalized. With the involvement of students-apprentices, knowledge was absorbed through layout-sharing and analysis of work organisation models' dynamics, involving activities using Engineering, Industrial Management and Entrepreneurship tools and concepts.

Keywords: Active learning, factory of boxes, industrial engineering, apprenticeship, TVET, entrepreneurship

1. Introduction

Digital technologies, combined with communication, computer and connectivity technologies (Bharadwaj et al., 2013), change the actors, structures, practices, and values, transforming the organizational game rules (Hinings et al., 2018). In this context, organizational uncertainties are being changed and how individuals must deal with uncertainty (Nambisan, 2017). In fact, according to Araujo et al. (2020), the skills needed by professional workers in order to succeed in industrial practice are (a) the ability to communicate effectively, (b) to apply mathematical, scientific and engineering knowledge, (c) to work in multidisciplinary teams, (d) to understand the impacts of engineering and technical solutions in global and social contexts, (e) to demonstrate lifelong learning and leadership, and (f) to recognise and adapt to change. In this sense, the education and learning systems adapt, requiring a new vision of entrepreneurial-professional training, especially in higher education, as well as befitting technical and vocational education training (TVET).

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Therefore, new pedagogical needs for learning arise. Changing the way, style, teaching technique is beneficial to the existence of many experiences being performed, for example, Alzaghoul et al., (2020) used the comparison between video-class and lego serious strategies for the students of engineering, technology, and vocational discipline. This perception and the need for new teaching styles are shared by Mancha and Shankaranarayanan (2020), who emphasize the imminent need for training capable of properly developing individuals to undertake and compete in a digital economy. The authors suggest that future research should test the role of experimental learning in the increasing level of digital innovation. In fact, the field of studies involving contemporary trends in engineering entrepreneurship education is growing (Reis et al., 2019). The main learning theories presented by Educational Psychology are Behaviourist, Psychogenetic, and Socio-Historical. According to the Behaviourist theory, learning is an individual's relationship with the antecedent (stimuli) and consequent (responses) events that produce changes in their behaviour.

There is a difference between the Psychogenetic theory and Socio-Historical theory. Psychogenetics considers learning as an active knowledge-building process rather than passive reception of information, while Scio-Historical theory considers the milieu as an active agent of learning, i.e., the process by which the individual acquires skills, attitudes and values from their interaction with the environment and with people (Alvarenga, 2018). Thereby, the pedagogic theories that explain learning consider: the "subject" who learns; the "object"; and the "mediation" between the subject and the object, which takes place in the interaction within a society (Lima, 2017). The traditional methodologies and processes of Teaching-Learning focus on the oral transmission of some content. The negative aspect of these methodologies may be summarised in the sentence by Mark Twain, which is often quoted in the literature: "A lesson is a process in which the teacher's notes go straight to the students' notes, without passing through the brains of either" (Mohamad et al., 2021; Konopka et al., 2015). A contemporary pedagogical tendency consists of replacing the technique of the master presenting content orally, expecting the knowledge emanating verbally to be absorbed by the apprentice, with another more itinerant, participative and active one. For example, the environmentalist theory focuses on the "object", represented by contents to be learned. The teacher's role is valued in it, and it is believed that learning occurs through information transmission.

Another option would be the innatist theory which elaborates and generates reflection and critical skills and attention to the student's needs. According to Lima (2017), the innatist theory values the "subject" and learning is attributed to each individual's hereditary and maturational factors. Indeed, learners are different, they have different learning styles and approach tasks differently. Some learners require more help than others. Some are more motivated and have clearer academic and career goals than others (Baldwin & Sabry, 2003). Notwithstanding, it corresponds to a non-directive pedagogy that considers that the differences among individuals are insuperable, as they are biologically established. Besides the environmentalist theory and innatist theory, the interactionist or social-interactionist theory emerges, which has promoted a re-reading of the explanations, which is antagonistic, about what is acquired and what is innate. It focuses on the "mediation" that occurs in the interaction between "subject" and "object", both present in Active Learning.

Active Learning (AL) is a method involving students in class by TVET. It is an educational concept that encourages critical-reflexive teaching-learning processes, in which students participate and are committed to their learning (Sobral & Campos, 2012). It takes them beyond the role of a passive listener and note-taker, allowing the students to take some direction and initiative. So, the role of the teacher is to facilitate and guide them towards capturing the object (knowledge) to be acquired and absorbed. AL can encompass various techniques that include small group discussion, role-playing, hands-on projects and teacher-driven questioning (Lorenzen, 2001). In fact, the method proposes the elaboration of teaching situations that promote the students' critical thinking regarding the reality; a reflection about problems that generate curiosity and pose challenges; the provision of resources to research problems and solutions; the identification and organization of the most appropriate hypothetical solutions to the given situation, and the application of those solutions (Sobral & Campos, 2012).

According to Mulongo (2013), strategies that promote active learning have five common characteristics: (i) Students are involved in class beyond listening, (ii) less emphasis is placed on transmitting information and more emphasis is placed on developing the students' skills, (iii) The students are involved in order thinking, such as analyzing, synthesizing and evaluating, (iv) The students are also involved in activities like reading, discussion, and writing. Finally, (v) greater emphasis is placed on the exploration of student's values and attitudes. Yet, Konopka et al., (2015) indicate that promoting AL is not an easy task to be achieved, and Mesquita et al. (2016) explain that it is not simple since it implies facing a multiplicity of challenges, ranging from structural (institutions and courses' academic and administrative organisation) to teachers/mediators and students-apprentices' pedagogical conceptions (beliefs, values and ways of doing). The authors add that for educational innovation to occur there must be new levels of knowledge organisation and production in connection with the challenges of practice and the struggles that emerge in different social fields.

In this sense, the objective of this study is the production of boxes in different configurations in a simulated environment, which translates as an efficient AL in knowledge apprehension, when reproducing the factory floor, arousing practical interest, questions and criticisms to each layout and work organisation model studied. This study contributes to change in the teaching-learning process in engineering, changing the "active teacher-agent X passive learner-agent" view to one where the training takes on a reflective, investigative and critical stance, seeking to give new meaning to knowledge among students.

2. Brief Theoretical Framework on Models of Work Organisation

The simulation is planned by analyzing the work organization techniques which are used by the entire auto industry. In reality, companies currently use the most varied nuances and techniques of all the models, with one or another model predominating, as chosen by the industry to adapt to each location's cultural and social production patterns. So, in practice, it would be impossible to state that the Ford factory exclusively uses the classic model or that Toyota has no labour division and works 100% in multifunctional production cells. Still, for didactic purposes, three Work Organisation models will be simulated: (a) Taylorist-Fordist Classic Model, which, for didactic purposes, will simply be called the Ford Model; (b) Swedish Semi-Autonomous Group Model, including the Positions' Enrichment, which will be named the Volvo Model; and (c) the cells' production and lean concept Toyota Model.

2.1 FORD Model (Classic American-English model of work organisation, Taylorist-Fordist)

Taylorism aimed to achieve maximum labour fragmentation in order to minimize superfluous movements and tasks, as well as learning time. The management task was to determine the best way for the employee to do his job, provide adequate tools and training and incentives to perform above the target in an individualized and remunerated way (Taylor, 1911). Fordism was a work organizing principle, an extension of Taylorism, where the moving belt was added, establishing a more dynamic labour rhythm. Ford understood that his workers were and could be his consumers. There was product standardization and large-scale production (Tomac et al., 2019).

Fig. 1 - Ford logo

The consequences of these Taylorist-Fordist principles were a sudden productivity and profit increase. However, the workers' frustration grew, as they were restricted to a single function. Aggregated principles: (a) separation of who plans and who executes; (b) a large labour division in single tasks; (c) monotonous work; (d) presence of a supervisor, a foreman type; (e) line layout; (f) no worker autonomy; (g) very low flexibility; (h) pushed production; (i) rigid vertical structure; (j) labour rhythm imposed by management, according to calculated standard time; (l) mass production according to scale economy; (m) generation of large inventories; (n) quality control performed at the end of the assembly line. Taylor improved production efficiency and Ford transformed the means of production by the mechanisation and simplification of work processes. That is, Taylor organised the labour, as a mechanical engineer, and Ford used that work as an entrepreneur (Paxton, 2012).

2.2 VOLVO Model (Swedish Work Organisation)

A semi-autonomous group recommends that for the same technology there are different ways of organising work, therefore it does not entail a specific technology and many techniques are accepted. At that moment, Positions' Enrichment was used, which clashes with the single-task Taylorist-Fordist model).

Fig. 2 - Volvo logo

Volvo's Kalmar plant in Sweden incorporated some of the main theoretical assumptions of socio-technical thinking. It sought to redefine its industrial organization in order to achieve the business objectives, in an environment more favourable to the insertion of man as responsible for the operation of a plant characterized by mass production of a reasonable number of different models (Apolinário, 2015). Thereby productive efficiency depends on the joint optimisation of the two systems – social and technical. In the social aspect, the most relevant point is the cooperation required between the constituent elements of the group, that is, the support for the interrelationship between people and work relationships. In the technical aspect, the fundamental point is self-regulation. In forming groups, posts are eliminated and there is increased flexibility (Gomes, 2011).

Concomitantly, the concept of lines' modularisation was introduced with the constitution of groups of workers responsible for a series of specific assembly tasks (and not of a product in its entirety). Each group had its workstation (a "mini-line" or part of it), with possibilities for position rotation and very broad tasks (Mucha, Bencke, 2016). This position rotation arose from a Taylorism-Fordism reaction named "position enrichment", idealized by motivational theory psychologists, as a way of escaping repetitive labour. Volvo was not its creator, but it was one of the first using it in the auto industry.

i. Position rotation consists of the simple trade of the worker between workstations so that he may acquire one more skill and break the monotony
ii. The horizontal extension consists of allowing the worker to perform two different tasks, but with similar concepts, such as, for example, cutting a shirt and pants (shirt and pants have different fabrics and cuts, but the act of cutting uses the same tool)
iii. Vertical extension consists of allowing the worker to perform two tasks with different concepts, for example, cutting and sewing a shirt using different tools

The principles added to the semi-autonomous groups Volvo system was full employment and developing a creative, flexible, multifunctional employee, thus focusing on (a) abandoning the layout rigidity in terms of assigning activities to groups of workers to be performed in fixed areas, (b) increasingly using the worker as a "smart" resource in detriment of the previous period, where the most important aspect was the use of physical strength, (c) using cooperative and flexible technological, physical and human resources exchange schemes, (d) introducing the concept of buffers, intermediate stocks, meaning the installation of "mini-lines", where the labour is enriched and developed in a semi-autonomous way, relatively to others, (e) developing new projects relying on the participation of local and national unions representatives, (f) considerably increasing the worker's autonomy and flexibility (Apolinário, 2015; Mucha, Bencke, 2016).

2.3 TOYOTA Model

TOYOTA Model was a Japanese work organisation model that includes lean philosophy with all the aggregated techniques, such as production cells, Poka-Yoke tools, DMAIC and others). Toyotism is a form of work organisation developed by the Japanese Taiichi Ohno, in the Japanese Toyota automaker. Two principles define this philosophy: (i) Just in time (JIT) principle: which consists of minimising stocks by producing according to the demand and (ii) Five zeros principle: zero delay, zero defects, zero inventories, zero breakdowns and zero papers. The aims were to reduce production and set up time, integrate suppliers, eliminate waste, synergise the entire administrative process (Spear, Bowen, 1999).

Fig. 3 - TOYOTA logo

In Toyotism, teamwork is an important factor, with organised groups that control their work in order to obtain continuous improvement. Thus, a horizontal work organisation emerged, intending to obtain products of excellent quality. In implementing Toyotism, it is necessary an integral rethinking of the basic principles of the classic Taylorist-Fordist system, thus becoming difficult its implementation since it depends on a culture shift. Therefore, many companies have tried to apply it and they have failed (Coetzee et al., 2016; Mathew, Jones, 2013; Jayamaha et al., 2018).

The principles associated with the Toyota system are (a) diversified production; (b) elimination of waste; (c) autonomy; (d) workers with multiple tasks, working in production cells; (e) quality control throughout the manufacturing process; (f) labour rhythm determined by the workers; (g) small-batch structure; (h) production planning based on customer demand; (i) stock in existence; (j) reduction of hierarchy structure (Spear, Bowen, 1999; Mathew, Jones, 2013; Jayamaha et al., 2018). Some of the tools affiliated with this work organisation model are: 5S, JIT, Kanbam, DMAIC, Bottleneck Analysis, Jidoka, Kaizen, Poka–Yoke, KPI, SMED, Gemba, Heijunka, VSM, Hoshin Kenry, Andon and others.

3. Materials and Methods – Factory of Boxes' Active Learning

The basic education process consists of the production/manufacture of boxes and lids ornamented with a small adornment, involving the students-apprentices in the most diverse role and job assignments, which are continuously modified throughout the process to convey the possible changes that occur in a factory, simulating different work organisation models.

Data were collected through an experiment, in a classroom, in two Universities (Universidade Federal da Paraiba - UFPB – Brazil and Universidade da Beira Interior UBI – Portugal) in TVET, in both cases with master students in Industrial Engineering. The data were analysed in the aspects of productivity and cycle-time.

Fig. 4 - Classroom experiment

Regarding the validity of the data, it is not possible to generalize whether the Ford, Volvo or Toyota model is best. In the experiment carried out, the results were not simulated exhaustively. In fact, each model was tested only three times, as the aim was not to test the efficiency of each model in relation to the other but to present students with the characteristics and implications of adopting one model or another. In this way, the experiment was in keeping with the intended objective. The activities' flowchart as Figure 5 below:

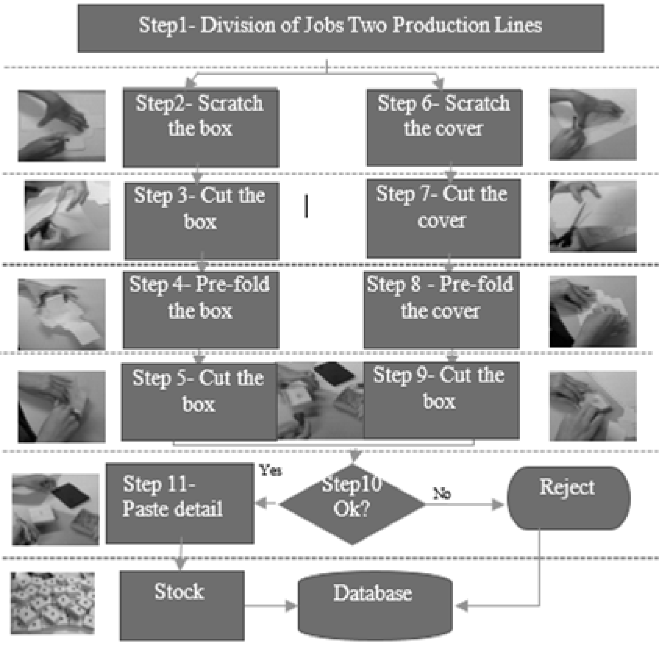


Fig. 5 - Work flowchart

The flowchart covers seven stages:

i. Step1 is the stage of distributing the raw material (paper)
ii. Steps 2 and 6 scratch the boxes and lids
iii. Steps 3 and 7 cut the boxes and lids
iv. Steps 4 and 8 pre-fold the boxes and lids
v. Steps 5 and 9 fold the boxes and lids
vi. Step 10 inspects the quality and size of the lids fitted on the boxes
vii. Step 11 sticks on a decoration and stores the finished product

Hence, the entire manufacturing process is divided into three stages or production lines without automated stations, according to different layouts, fulfilling a 50-minute working day, divided into two 20-minute shifts with an interval of 10 minutes for debates, criticisms survey of each model and layout, small discussion of the reasons for errors and adaptations and necessary adjustments. The simulation is organised by analysing the three models of Work Organisation and the planning of a simulation with automated stations' classic model. Each simulation round is required: Raw material, 15 cardboards, 1 tube of white glue, 20 pearl beads and Tools, 4 scissors, 4 pencils, 1 stamp, 1 clipboard, 1 chronometer.

Ford Model - Classic Taylorist-Fordist: The purpose of this simulation is to show the apprentice the existing labour's great division. The teacher-mediator should first talk to the "supervisor" to exercise the role of a very emotionally and physically demanding leadership, and with a great distancing from the other apprentices-workers. It is recommended that the supervisor speaks loudly and in an authoritative manner. The timekeeper gives the beginning of the production simulation round at the Step1 station who will receive written orders from the Planning and Production Control – PPC (the teacher-mediator), configuring the pushed production. The supervisor cannot allow parallel conversations to happen, that is, he must not allow any kind of verbal communication between the working stations, remembering that Ford said "my factory is not a place for people to talk… a simple look to the side may decrease production", for this reason, the supervisor must suppress all the workers' initiatives.

It is crucial to remember that in this Work Organisation model, the worker was trained for a single task and was not allowed to give his opinion inside the factory. Normally, in that situation, with the insistent voice of the supervisor's command to increase production, the employee in the lid or box "cutting" station tries to "innovate", trying to cut two pieces at the same time to increase production, an action that the supervisor must immediately hinder. It must be understood that, in this production model, the worker was not at liberty to change the prescribed way of work.

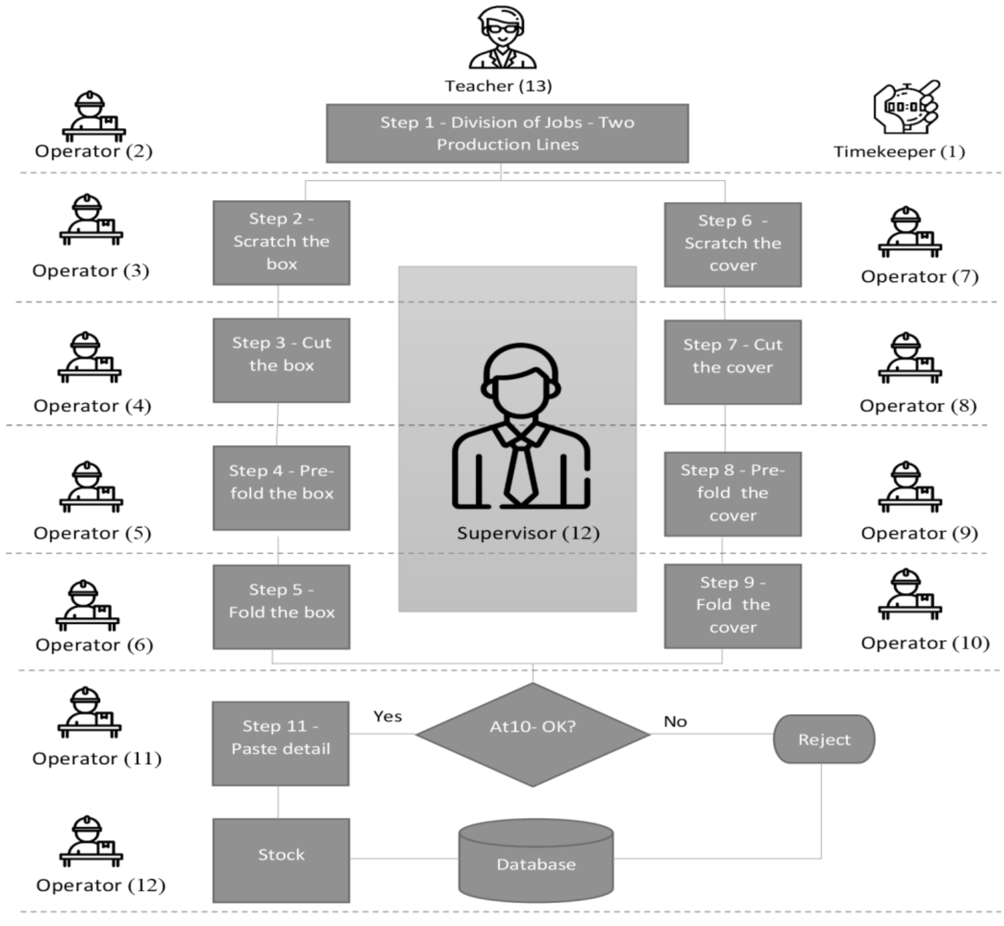


Fig. 6 - Ford Model Simulation (Classic Taylorist-Fordist)

In this Fordist model, entrepreneurship development is not found because the task is divided into repetitive movements, separating intellectual from physical work. This production model was coined to support an economy that needed non-customized and large-scale products, that is, the market absorbed everything that was produced (Stamm, Neitzert, Singh 2009). This setting caused few entrepreneurs to emerge, as was the case with Ford, who was famously quoted as saying "if you want it done right, do it yourself" (Tomac, Radonja & Bonato, 2019). In this case, equipment and people are needed: 13 student-apprentices, 12 ergonomic chairs, and 13 tables.

After completing the two work sequences, the line is suspended, bringing the students-apprentices to complete the measurement table, checking the evident bottlenecks, the mistakes and adjustments of the inflexible labour, and labour division. Then the hypotheses of balancing the line are raised, proposing to mitigate the Taylorist-Fordist rigidity with horizontal position extension, thus subtly starting the Positions' Enrichment.

Volvo Model – Semi-autonomous groups: This simulation aims to reduce the labour division, mitigating the rigidity of the classic model by implementing Positions' Enrichment. The positions' enrichment, as a rule, may be implemented through horizontal extension and vertical extension. Horizontal extension which allows positions' coupling in which tasks of the same nature are performed, namely (a) the tasks of scratching a box or lid are different, as they have different moulds, but their essence is the same; (b) the same for the tasks of cutting a box or a lid; (c) the same for the box and lid demarcation and (d) the same for the box or lid assemblies. Meanwhile, vertical extension which allows positions' coupling in which tasks of a different nature are performed, namely: (a) the tasks of scratching and cutting the box or lid; and (b) pre-folding and assembling the box or lid; and (c) Product Inspection (stamp and adornment glue). This simulation will use this case. In both cases, there is still the figure of a supervisor. However, he must be chosen internally, within the semi-autonomous group. In this case, the supervisor is much more of a facilitator, who can also perform a manual function. The beginning is given by the timekeeper at station Step 1, configuring the pushed production.

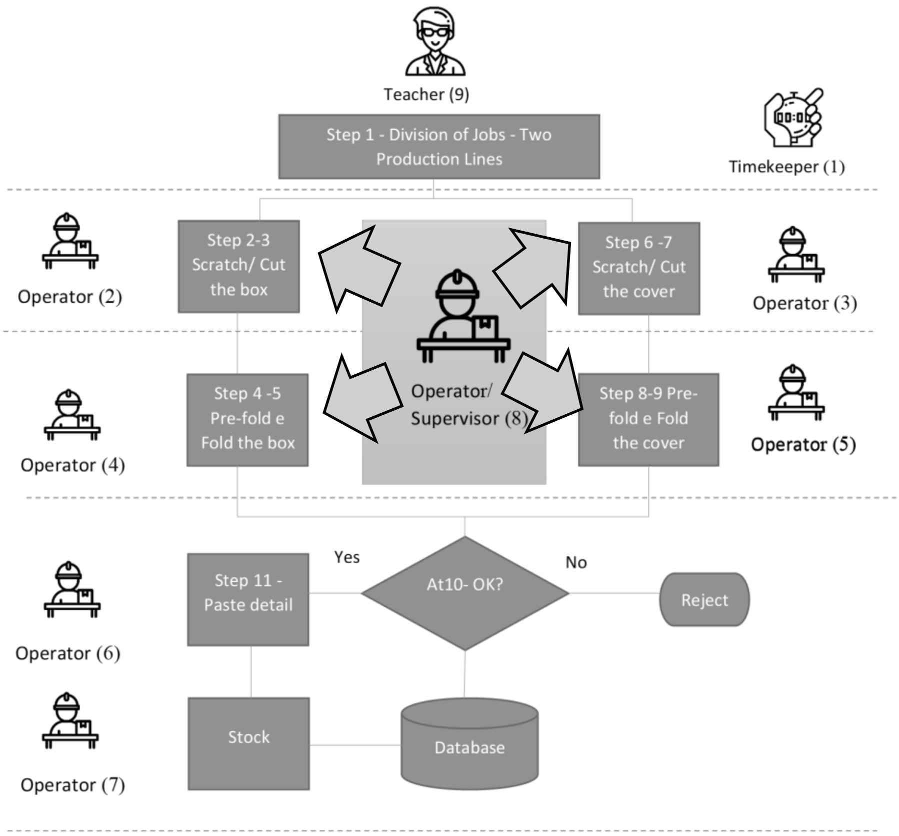


Fig. 7 - Volvo Model Simulation (semi-autonomous groups/vertical extension)

Two student-apprentices are "dismissed" in the vertical extension, so it will be needed: Equipment and people: 9 student-apprentices, 8 ergonomic chairs and 9 tables. Despite reducing two people and two tables, production should not drop, thus implying a slight increase in productivity. In the Volvo model, we find entrepreneurship. Because the tasks have a greater activities' range and the operator has greater control autonomy and responsibility for the quality, the worker's creativity is considered a competitive strategy (Vargas, Cleto and Seleme, 2015). This model developed an innovative socio-technical process, at the time, as it was developed from the involvement of unions and workers in the production organisation (Bondarik and Pilatti, 2008).

Toyota Model – Lean line, with production cells and pulled production: Its objective is to introduce production's basic concepts in a Lean line working with production cells. The concept of production cells incorporates the notion of enriched positions and multipurpose employees with self-supervision. Hence, the labour division is quite reduced and employees are free to work in various positions. In addition, usually, some techniques are incorporated in real factories, such as the Kanban method and Just-In-Time (JIT), with which production begins in the last workstation, designating the "pulled production".

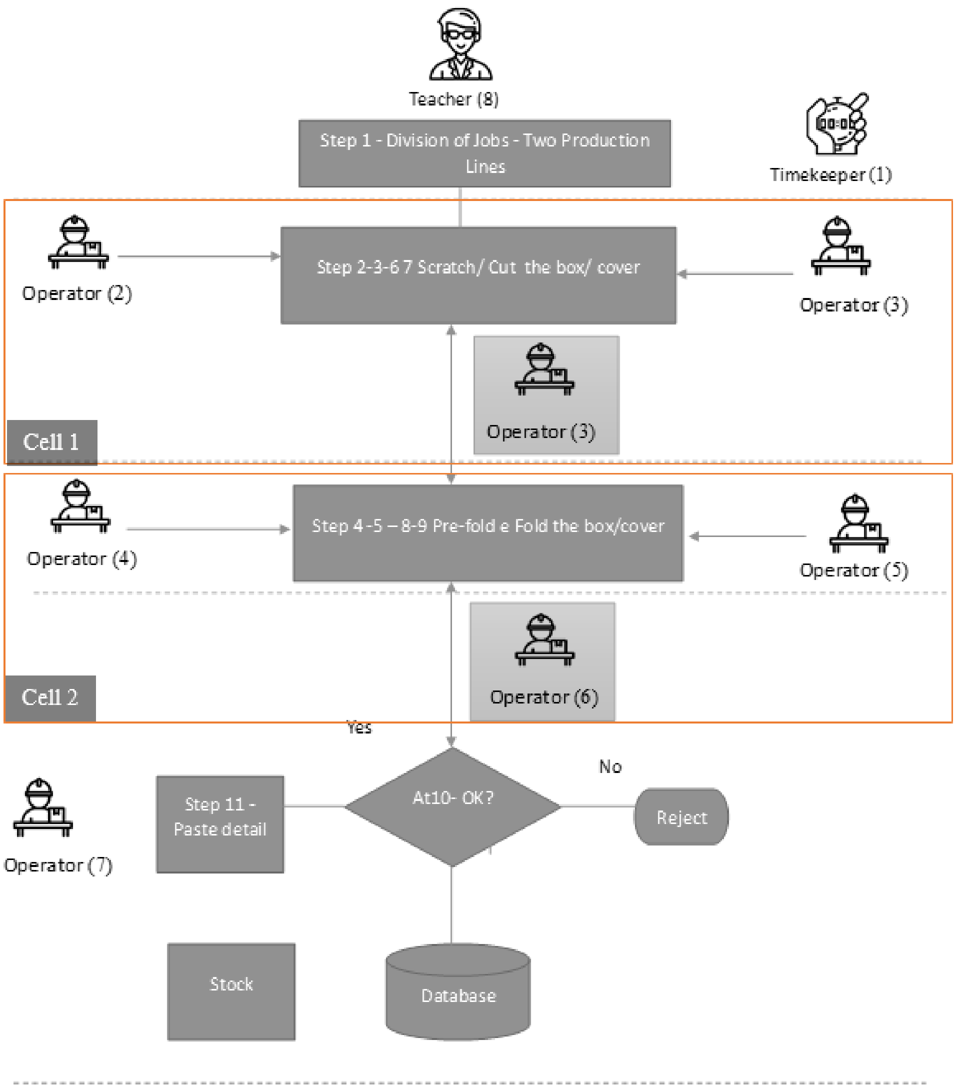


Fig. 8 - Toyota Model Simulation (production cells)

In this case, there is no supervising figure, as each employee is aware of his work, the production pace, where only a quality product is forwarded to the next position, that is, the product has its quality tested throughout the production process, thus the penultimate position's role is only to glue the adornment, therefore invalidating the existence of activity 10 (final inspection of the product). The introduction of multi-tasking and self-managed cells concepts greatly decreases the number of workers, only requiring Equipment and people: 8 student-apprentices, 8 ergonomic chairs and 9 tables. Immediately after changing the layout, there was a fall in production and productivity, showing the learner-students that implementation of new ideas in the work organisation requires training and not all changes are reflected in immediate increases.

The Toyota model is suitable for entrepreneurship development, as this model operated in a superior manufacturing paradigm, based on the pulling philosophy instead of pushing production (Stamm et al., 2009), requiring a new way of thinking about the work organization. Such a change in the way of thinking qualifies the workforce. One of the reasons for this valorization of knowledge, which leads to entrepreneurship, was producing a greater variety of products in smaller batches (Liker, 2003), which required the worker to adapt. It is observed that the historical needs, inherent to the society drove the "paradigm shift" from Fordism to Toyotism (Stamm et al., 2009).

4. Results of the Simulation of the Work Organisation Models

The teaching-learning process followed 3 steps, simulating every configuration with no automation. The three models were simulated at the Federal University of Paraíba - UFPB (Brazil) and at the Beira Interior University - UBI (Portugal), using an identical methodology and conditions. The results can be seen in Table 1 and Graphs 1 and 2.

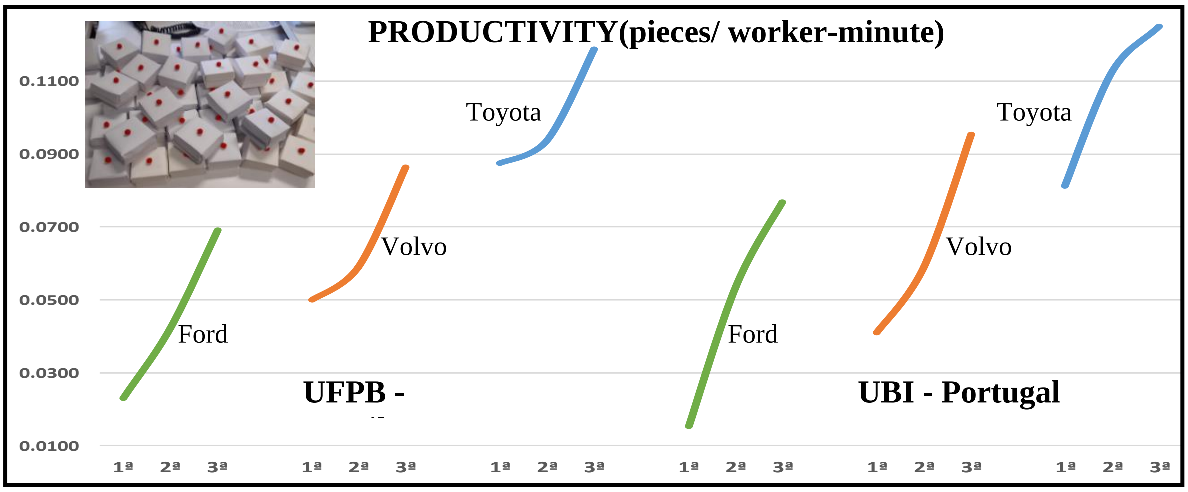
Table 1 - Lab simulation result UFPB (Brazil) and UBI (Portugal)

UFPB - Brazil (a) Model Ford (Classic Fordist Taylorist)									
Step	Number of workers	Number of pieces	Correct pieces	Non-conforming pieces	Processing	Productivity (pieces/ worker-minute)	Productivity (pieces/ minute)	% Correct pieces	Cycle Time to the first box of each step
1ª	13	6	6	0	2	0.023	0.30	100.0%	10.32
2ª	13	13	11	2	4	0.042	0.55	84.6%	6.91
3ª	13	18	18	0	6	0.069	0.90	100.0%	4.50
UBI - Portugal (a) Model Ford (Classic Taylorist Fordist)									
Step	Number of workers	Number of pieces	Correct pieces	Non-conforming pieces	Processing	Productivity (pieces/ worker-minute)	Productivity (pieces/ minute)	% Correct pieces	Cycle Time to the first box of each step
1ª	13	6	4	2	16	0.015	0.20	66.67%	10.05
2ª	13	16	14	2	4	0.054	0.70	87.50%	5.40
3ª	13	22	20	2	5	0.077	1.00	90.91%	4.60
UFPB - Brazil (b) Volvo model (semi-autonomous groups/vertical magnification)									
Step	Number of workers	Number of pieces	Correct pieces	Non-conforming pieces	Processing	Productivity (pieces/ worker-minute)	Productivity (pieces/ minute)	% Correct pieces	Cycle Time to the first box of each step
		14	11	3	4	0.050	0.55	78.6%	9.50
2ª	11	17	13	4	4	0.059	0.65	76.5%	5.83
3ª	11	20	19	1	7	0.086	0.95	95.0%	4.50
UBI - Portugal (b) Volvo model (semi-autonomous groups/vertical magnification)									
Step	Number of workers	Number of pieces	Correct pieces	Non-conforming pieces	Processing	Productivity (pieces/ worker-minute)	Productivity (pieces/ minute)	% Correct pieces	Cycle Time to the first box of each step
1ª	11	10	9	1	9	0.041	0.45	90.00%	6.40
2ª	11	15	13	2	4	0.059	0.65	86.67%	5.08
3ª	11	22	21	1	8	0.095	1.05	95.45%	4.40
UFPB - Brazil (c) Toyota model (production cells)									
Step	Number of workers	Number of pieces	Correct pieces	Non-conforming pieces	Processing	Productivity (pieces/ worker-minute)	Productivity (pieces/ minute)	% Correct pieces	Cycle Time to the first box of each step
1ª	8	15	14	1	5	0.088	0.70	93.3%	7.38
2ª	8	16	15	1	6	0.094	0.75	93.8%	5.57
3ª	8	21	19	2	6	0.119	0.95	90.5%	4.57
UBI – Portugal (c) Toyota model (production cells)									
Step	Number of workers	Number of pieces	Correct pieces	Non-conforming pieces	Processing	Productivity (pieces/ worker-minute)	Productivity (pieces/ minute)	% Correct pieces	Cycle Time to the first box of each step
1ª	8	14	13	1	7	0.081	0.65	92.86%	5.25
2ª	8	18	18	0	6	0.113	0.9	100.00%	4.43
3ª	8	21	20	1	8	0.125	1.00	95.24%	4.04

Source: Simulation Data

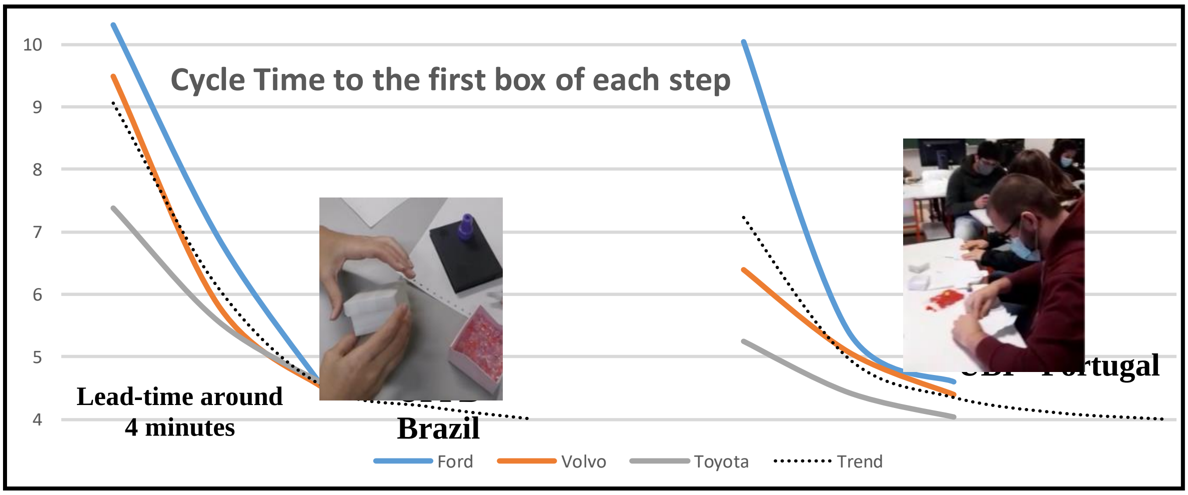
Table 1 presents horizontally: (a) “Number of workers”, representing the number of students involved in the experiment; (b) “Number of pieces”, showing the total number of pieces produced in that round; (c) “Correct pieces” representing the number of pieces correctly produced; (d) “Non-conforming pieces” which is the number of pieces produced with defects; (e) “Processing” refers to the number of pieces being processed, unfinished on the line; (f) “Productivity (pieces/worker-minute)”, showing operator/minute productivity; (g) “Productivity (pieces/minute)” meaning productivity in time; (h) “% Correct pieces”, is the percentage of correctly produced pieces, and; (i) “Cycle Time to the first box of each step”, is the time necessary to finish the first product.

Productivity increased in all the models between the first and third steps, as shown in Figure 9.



Source: Simulation Data

Fig. 9 - Productivity of Worker Labour for Model



Source: Simulation Data

Fig. 10 - Cycle-Time and Lead-time

The productivity growth behaviour at the two universities followed the same behaviour pattern. The classic Ford model presented lower productivity, although the highest growth peak was more than 300%. The low productivity may be explained by the type of "workforce" used in the simulation. It included master's students only, that is intellectual workers and not manual workers, as the model for the classic work organisation required. The theory of organisational learning may explain the peak of growth. In the first step, they had no practice and were progressively acquiring it, as the simulation process evolved.

Transitioning to the Volvo model, productivity begins immediately in the first step, more than in the Ford model, because (i) student-workers were given limited autonomy, simulating semi-autonomous groups. Therefore they opined for self-organization; and (ii) there was already cumulative learning. In fact, this model allows people greater flexibility and autonomy, facilitating the production line labour, with a certain freedom of operations and multifunctionality, and the "transformation" of the inflexible supervisor into a coordinator has humanised the work environment and changed the layout. In this regard, Vercellotti (2018) showed that, since the classroom context differed, the impact of physical space on learning gains must be considered a positive factor. The physical space may positively impact learning by creating a greater rapport among students, improving peer-tutoring, group learning community, and, when the furniture facilitates (rather than hinders), groupings and interaction.

The autonomous production cell Toyota model with self-supervision proved to be the most productive, since the first step, presenting a much higher productivity value compared to the other models. Although it cannot be said that in general, this model is better, in a simulated setting it was much more productive than all the previous ones. The increased productivity in the simulation was due to the student-workers self-management, and in addition, they were challenged to do the best possible, by an "orator-motivator".

As for the cycle time (presented in Figure 10), the Ford model begins around 10 minutes and then in the third round, its time is close to the lead-time of 4,2 minutes, caused by the training in service. The Volvo model had a slightly shorter initial cycle-time than the Ford model at around 9 minutes (UFPB-Brazil) and 6 minutes (UBI-Portugal) and the Toyota model has the shortest of all initial cycle-time at 7 minutes (UFPB-Brazil) and 5 minutes (UBI-Portugal), though on all models, in the third step, the cycle-time is already approaching the lead-time, around 4 minutes.

Hence, the students-apprentices experienced direct contact with three work organisation models, in several different layouts. They were able to ascertain industrial engineering techniques, namely individual labour in the Ford model, positions' enrichment and the semi-autonomous group promoted by Volvo and the cells production of the Toyota model, differentiation between pulled and pushed production, line bottleneck, psychologisation of the manufacturing environment, work with and without a supervisor, and so they acquired an overview of what can be accomplished inside a real factory. In addition, the simulation shows students-apprentices the potential for entrepreneurship when they had autonomy and flexibility.

5. Possibility of Simulation with Automation of Stations – Future Simulations

After simulating the Ford, Volvo and Toyota models without automation, there is the possibility of simulation with automation of some jobs, including concepts of mechanization, robotization and work with computer control of machines. Although all the models have the possibility of workstation automation, as an example, we will only present the Ford Model's automation.

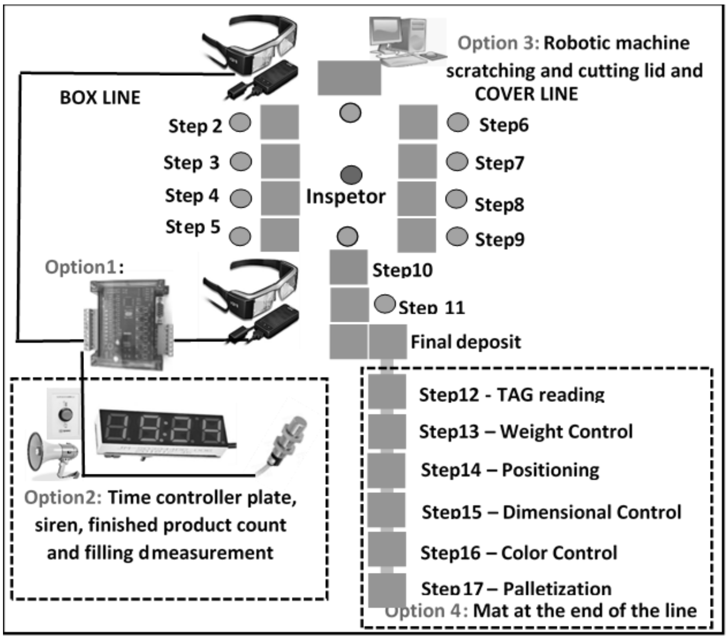


Fig. 11 - Ford Model with Workstation Automation

In this context, four automation options are presented:

i. Option 1: Automatize posts 1 and 11 using increased reality glasses: (i) at station At1, the information is received. This can come directly from the customer to change, for example, the product colour, allowing personalization; and (ii) at station At11, the boxes and the quality of the lid are inspected, according to size.

ii. Option 2: Replacement of the timekeeper by PLC-type equipment, which controls time, the start and finish of the journey through a siren, it counts how many products are finished using proximity sensors, and it fills the production/productivity table. In this case, only the timekeeper will be replaced by a PLC-type controller with sensors installed on the At1 and on the final deposit (in orange). The controller will sound a siren, indicating the start and finish of the shift, in addition to measuring the number of finished boxes in the final deposit and filling in the measurement tables.

iii. Option 3: Replacement of workstations 1, 2, 3, 6 and 7 by a computer-controlled workstation that scratches and cuts boxes and lids. Five work positions are thus suppressed in favour of a computerised table. It should be clear to the students-apprentices that this replacement requires the employee to be retrained/learn a different task other than a manual labour.

iv. Option 4: Moving belt at the end of the line: After finishing the box assembly process, the product quality check would proceed, ending with palletising. The passage to this line would occur through a moving belt after the boxes reach the final deposit.The first workstation (At14) would be composed of a TAG reading pistol and the operator/student, where the TAG reading would be done. In the Weight control (Step13), the box would pass through a weight sensor where its weight would be checked. The box would only be transferred to the Step14 workstation if it had the weight that TAG transmitted to the database; if it did not have this characteristic value, it would be pushed (pneumatic arm) to a deposit of rejected products.

At the Step14 workstation, using the augmented reality glasses again, the operator/student would position the box so that at the next workstation there would be no errors in the measurement of its dimensions by a laser (Step15). At the Step16 workstation, the colour that was predefined at the beginning of the process by the “customer” would be controlled, that is, if it was the correct colour. Finally, and after the quality verification and the “customer’s” requirements were finalised, palletising (Step17) would be performed, using a robot arm, and sent to the customer. In every checkpoint, all the boxes would not possess the characteristics read by the label at the beginning of the line, would be placed in a deposit of rejected products

6. Final Considerations

AL is a pedagogical approach that considers that teaching and learning must adapt to modern forms of knowledge transmission, especially in preparing ready-made students for work placement. In it, the student-apprentice builds his own knowledge, whose learning occurs from the action, from the (inter) action between the subject and the external environment (the object) (Alvarenga, 2018). The choice of the pedagogical activities and teaching resources is centred on the interaction between the student-apprentice, content and the subjects involved in the teaching and learning process (learner and mediator). Collaborative learning is valued here, as is the case of the “factory of boxes”.

It is an activity that is the opposite of instructionism that states that knowledge is transmitted or transferred to the subject, where the content is usually presented in an expository way. In instruction, the student-apprentice verifies if the information was understood, individually, through multiple-choice exercises, for example, which indicate the results of the “hit” or “wrong” type, and this “does not inspire”, in contrast with simulation. “This technology is also believed to provide the added benefit of better knowledge acquisition, improved critical thinking and greater engagement with the material” (Nicol et al., 2018).

In addition to the evident contextualisation with engineering, the AL methodology presented here may strengthen the participants’ entrepreneurial attitude, creating mental structures which enable these individuals to “think outside the box” (Baron, 2004). Thus, cognitive perceptions are built that enable participants to face the job market, with multiple options for actions, learning to live in constant renegotiation environments (Garud, Jain, & Kumaraswany, 2002). These results suggest that “students do form knowledge networks during courses that later assist them in connecting more abstract concepts to this network” (Cherney, 2008). In fact, entrepreneurship education consists of teaching students the process, knowledge and skills required for starting a new business. In this sense, work organisation study through the AL "Factory of Boxes" allows for a strong emphasis on developing communication and management skills that graduates need to succeed in starting a business enterprise (Silva et al., 2015).

This face of simulation enables the development of entrepreneurship, as it allows participants to perceive the limits of the present and transform the unknown and uncertain organisational future (Battilana, 2011). The current setting is composed of increasingly short product lifecycles. The ability to motivate individuals to use their intellectual capacities is crucial (Garbellano & Da Veiga, 2019; Nambisan, Wright & Feldman, 2019), including developing entrepreneurial skills and befitting TVET. The “Factory of Boxes” is an AL with a simulation technique that considers, through experimental activity, that the apprentice may make implications on various topics.

In the simulation performed here, three different Work Organisation models were tested in the laboratory: Layouts, Production Lines, Semi-autonomous Group, Production Cells, Study of the Workstation, Ergonomics, among others with no automation, and a power of learning synthesis was verified at the time that students-apprentices interact with the elements present in a factory line and, thus, absorb technical and systemic knowledge as the simulation involves different characteristics. In this case, “experimental teaching modifies the mental models that students have on a given subject and, through an investigative constructivist environment, the student materialises learning” (Silva, 2019). This method may improve students’ active learning ability and their self-efficacy. In short, the teaching staff coach students to find solutions to learning problems by stimulating their cognitive flexibility (Nicol et al., 2018).

The simulation also showed the most efficient Toyota model, however, this fact occurred in this specific case, even using psychologising techniques of the simulated factory environment, although it is only a teaching-learning tool and it cannot be said that this model is better than another, because in a real case, the choice of the adopted work organisation model depends on several factors, such as territorial, cultural, physical, product characteristics, external customer involvement. In this work, the results cannot be generalised, and this was not even the aim of the present study, but it can be said that the “factory of boxes” is an efficient AL technique.

It can finally be stated that the use of AL, simulating a box factory, requires more active behaviour by learners, allowing knowledge to be constructed, from relations in the environment, machines and social-human system, going beyond simply the teacher’s act of speaking. With this study, we intend to present a possibility for shifting from traditional teaching, where the student-apprentice has a passive posture, focused on the teacher’s speech act, where he captures and memorises information in order to process knowledge, to the training of teachers and students who assume a knowledge-creating posture with reflexive, investigative and critical actions, who seek to reframe already constructed knowledge.

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