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RESEARCH PAPER

Simulation of productive processes using Lego® blocks for application of the concepts of integrated production management

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ABSTRACT

Goal: This article describes a simulation exercise based on the premises of the experiential learning approach, using Lego® blocks to build a production plant model.

Design / Methodology / Approach: The simulation was applied to groups of 4 to 6 participants, enrolled in production management or similar classes.

Results: The use of this approach promoted a learning environment with greater interaction and stimulated the students to put their reasoning, decision-making and communication skills into practice.

Limitations of the investigation: Because the simulation is only a representation of reality, it can generate some generalization, and since it is a controlled experiment, all the variables are known in advance. Therefore, the practices using the simulation should be discussed and contrasted with real-world practices after application of the method.

Practical implications: This simulation enables examining themes such as inventories, supply chains, production planning and scheduling, layout, MRP, and mainly integration of organizational processes in practice, promoting hands-on experience.

Originality / Value: The reports of the participants indicated a positive impact of the proposed simulation, by stimulating the development of skills and capabilities for their training as future managers.

Keywords: Methodology; Experiential Learning; Industrial Simulation; Production Management; Integration of Processes.

INTRODUCTION

The educational system is one of the main sources of a country's development. The educational process is not only an obligation of the government; it is shared with society at large, including families, companies and schools. With respect to formal education by schools, there is an ongoing need to update knowledge regarding new technologies and interpretation of their effects.

The teaching-learning process has evolved greatly. At the start of the 1990s a new pedagogic model emerged associated with empowerment, where the teaching of knowledge is interactive and the teacher is a collaborator or facilitator.

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In this context, information and communication technologies along with recreational learning strategies are increasingly being employed, enabling more interactive learning processes. The utilization of these technologies and strategies leads to the creation of an alternative pathway that connects the student to knowledge, favoring the development of new methods and practices in the learning process. These technologies are changing teaching as well as research (Langlois, 1998).

This work presents an alternative to develop an environment for applying knowledge about integrated production management, utilizing Lego® blocks to build a small assembly factory that serves to materialize the problems and constraints of a real environment, helping the professor (facilitator) to develop the capabilities and skills of future management professionals.

For questions of space limitations, we chose to give more emphasis to the methodological aspects than to a comprehensive theoretical framework, since the underlying themes about learning methods have evolved greatly since the 1990s, especially regarding the use of information and communication technologies. Another factor is that this work proposes an application, so methodological aspects are more relevant in terms of presentation and use of the available space.

LITERATURE SURVEY

Experiential learning, or learning by doing, does not start deductively in the exposition of a theory, but rather, for example, involves resolution of non-structured problems, as proposed in simulation of processes. The learners are required to make a decision on what to produce and when to do so, not only in the sphere of theory, but in practice, at that moment, to meet the demands of customers. This materializes knowledge, after which the results of the decisions made will be analyzed and any deviations between planned and achieved targets will be observed. Through conceptual review, the results are examined in light of the theories. The plans are reviewed with respect to deviations, maintaining the policies already used when the results are as expected or desired, or revising them and trying other alternatives to improve the results when they are negative. These steps constitute the experiential learning cycle as presented by Kolb (1984).

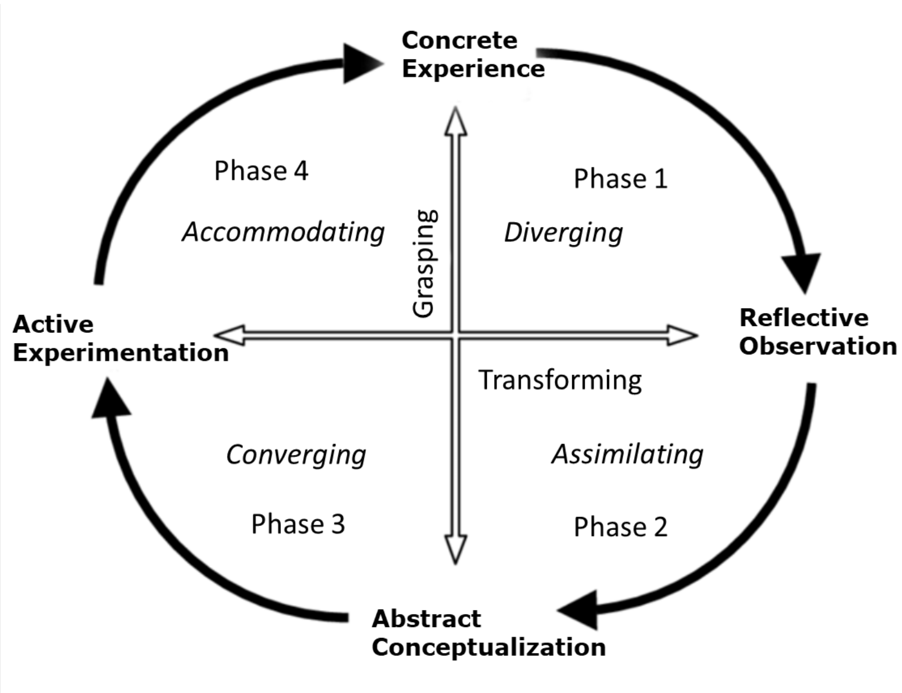

Figure 1: Experimental learning cycle.
Source: Adapted from Kolb (1984).

The cycle always starts a new step of the learning chain, and by building experiences undergone by each participant, creates dynamic and systemic knowledge in an ongoing process of experiential learning (Sauaia, 1997).

As seen in Figure 1, in the majority of cases, learning starts with an action that produces effects that participants can feel (concrete experience). Based on this, understanding occurs of these effects, whereby if the same action is taken in the same circumstances, it will be possible to anticipate what will occur (reflective observation). In this pattern, the next step is to understand the general principle under which that experience occurs, to form a generalization (abstract conceptualization). And when the general principle is understood, the last step occurs by means of action in a new circumstance (active experimentation). However, in this last step the opportunity for new learning appears, starting a new cycle (Alvarenga and Sauaia, 2011).

Other theories exist related to experiential learning methods, among them the "Experiential Learning Cycle" proposed by Gramigna (1993), which has five phases for learning: experiencing, reporting, processing, generalizing and applying, in a continuous cycle of experimentation, as depicted in Figure 2.

According to Gramigna (1993), the first phase, "experiencing", involves characterization of the simulated environment and activities like "doing, realizing, constructing". For example, constructing activity can involve making a new product for a simulated company or for building a prototype based on basic information. These activities have the basic characteristic of freedom of creation of the participants.

Figure 2: Experimental learning cycle
Source: Adapted from Gramigna (1993).

The second phase is the "reporting" of the experience by the participants. This is the moment where the group has the opportunity to share feelings, reactions and emotions.

The simulated environments provide moments for excitement and tension, eliciting strong involvement of learners in the attempt to resolve the problems or challenges faced. During the intense participation in the process, the learners cannot hide their difficulties and capabilities, which directly affect the emotional state of each one.

According to Gramigna (1993), the third phase is the most important of the experiential learning cycle, because it is in this phase that the learners can understand the results and relate them to their actions. This phase involves interaction of the participants to discuss the patterns of performance. For example, in this phase a very important tool is the discussion script. The team meets to consider the results and discuss the errors and successes, to enable improvement in the next decision period.

In the fourth phase, "generalizing", the participants already have the capability to leave the simulated world and enter the real world. The generalization phase is when analogies with real business routines are made.

The fifth phase, "applying", closes the experiential learning cycle, when it is necessary for the facilitator to encourage change, because at this moment the participants will already have identified their failures and aspects for improvement. The participants should be aware of their weak points, and be willing to change. In this phase, the role of the facilitator (teacher) intensifies, because it is essential to direct the participants toward self-development and growth of a group feeling.

Gramigna (1993) mentioned an important consideration regarding the power of educational games to promote learning, because the climate of good humor and spontaneity promotes confidence and permissiveness to make decisions. In experiential learning, the main role shifts to the learner, who becomes the center of the process, unlike in traditional teaching. This facilitates greater involvement in the competitive and cooperative pursuit of knowledge. Work in groups prevails over individual expositive presentation by the instructor (Alvarenga and Sauaia, 2011).

The two experiential approaches described above form the basic guidelines of the method proposed here, as presented in the following sections.

METHOD

The simulator recreates the organizational setting of a small assembly plant, both in its internal and external aspects, allowing evaluation and analysis of the possible consequences of decisions made by the group. The simulated environment has clear and well-defined rules and encourages a competitive spirit, with identification of winners and losers, where all the participants variously experience fun, fascination and tension. It can simulate specific business areas, such as marketing, production and finance (Gramigna, 1993). It can simulate organizations that form an oligopoly (compete in the same market) or organizations that produce distinct products without apparent competition, or even an entire supply chain. The configuration of the simulation will depend on the production management concept targeted for application.

The use of simulators in the learning process is a method in which the learner (participant) is inserted in a determined environment that should be as close to reality as possible. The main characteristic of this method is to explore the competitive side of the human personality, by which people are stimulated to compete with others, utilizing all possible tools to win the simulation, as the case may be (Kopittke, 1992). According to Fries (1995), the active participation of learners is of fundamental importance, especially in the case of programs intended to develop skills of a practical nature.

FIRST PHASE – PREPARATION

The first phase involves the structuring of the simulation. The rules, constraints and procedures of the simulation are presented. Each group receives a sheet of A3 paper, to serve for designing the layout of the plant (Figure 3) and the Lego® blocks available to make the final products assembled by each plant (Figure 4). It is important to provide sufficient parts so that each group can assemble products in sufficient final volumes during the simulation.

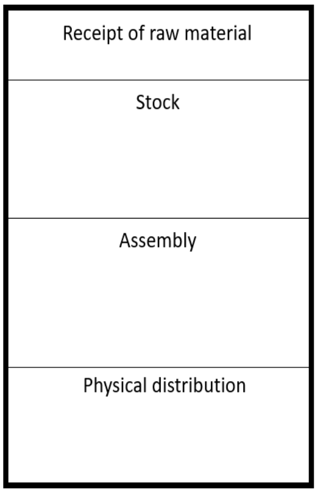

Figure 3: Layout made by a group

Source: The authors

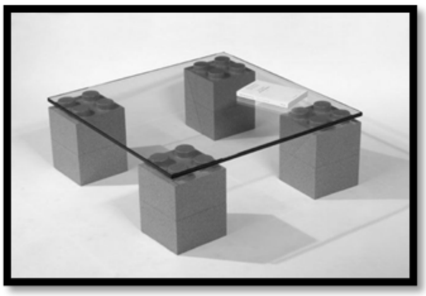

Figure 4: Product made by a group

Source: The authors

This is the phase of experiencing defined by Gramigna (1993) and the phase of concrete experience according to Sauaia (2013). Figure 3 depicts the process of creation and structuring the layout of the factory. It is the responsibility of the group, without interference of the facilitator. Any errors in dimensions or improper choices of sectors should be perceived during the simulation and discussed afterwards, in a more suitable phase (prototyping).

The size of each sector designed on paper limits the number of blocks that can be stored. The larger the area designed is, the more blocks it will take for construction. This decision almost always impacts the capacity to meet variations in demand. At this moment, each learner will be assigned to or choose an area of responsibility.

Depending on the size of the group, the number of participants in each functional area can vary, but it is important to have at least one participant in the areas of sales, operations (inventory and assembly), procurement and finance.

With respect to Figure 4, blocks of different sizes and shapes are supplied so that the groups can have freedom to create their products, at first only two types of products per plant, necessarily formed by a common part. This serves to create an extra difficulty in the process of acquiring parts, because it obliges the group to consider the number of orders for the two products when buying the input materials.

The groups must present their final products, the corresponding list of materials necessary for production and the structure for assembly of each product. Figure 5 illustrates the parameters prepared by a group of learners.

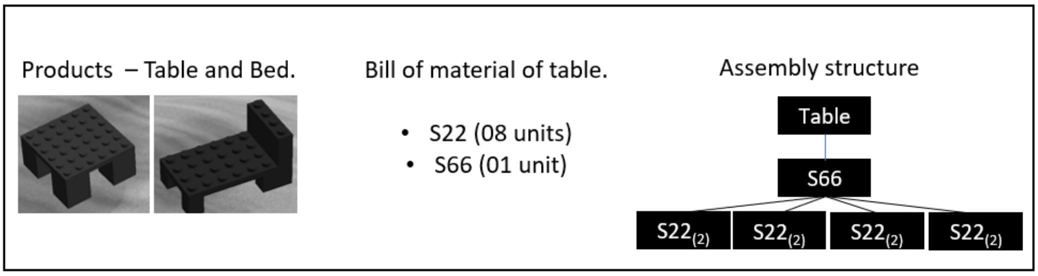

Figure 5: Products, bill of materials and assembly structure

Source: The authors

As a restriction, the products must have at least two levels of assembly. And to facilitate communication, a part coding system was created. For example, a Lego® block with 2 rows and 2 columns (thus square shaped) has the code Q (square) 22. Hence, the product shown above is formed by a table top (Q66 block) and legs (each with 2 Q22 blocks). Figure 6 better illustrates this convention.

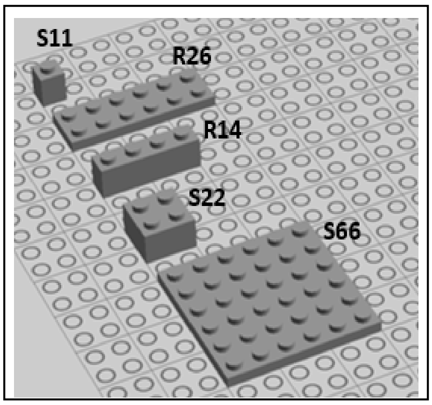

Figure 6: Lego® part coding

Also, in this phase the dynamics of the simulation are presented. The total simulation period is composed of three cycles, each lasting different time (the first for 30 minutes, the second for 20 minutes and the third for 10 minutes).

These times were calculated for a class with four groups of four participants, and can vary according to the number of groups.

Decreasing time periods were used in each cycle as a strategy to inhibit the formation of plants merely to meet dependent demand. With a cycle with a shorter time frame, some type of inventory will be necessary to meet possible new demands. If this were not the case, all products ordered would be delivered just in time and the revenues would always be maximized, which is divorced from the real world, at least for the majority of organizations.

Finally, perhaps the most important rule is that no part moves in the plant without a formal requisition in writing. Data such as date, sector of origin, sector of destination, what and how much is needed are necessary to start the flow of material moving, from the supplier to the end consumer. This procedure also avoids direct communication by voice, because the participants are physically close, but in the real world this communication is through an informatics system and requires some degree of formality.

And so, the plants will not start with their inventories empty, about 20% of the raw materials (distinct parts) is supplied to accumulate the initial stock of each plant.

SECOND PHASE – PROTOTYPING

With the plant built and the final products assembled, as well as the initial procedures understood, the next phase can begin, that of prototype testing.

The simulation is structured as a simple supply chain, with a first-tier supplier and the plant acting as the first-tier customer, selling to the end customer (Figure 7).

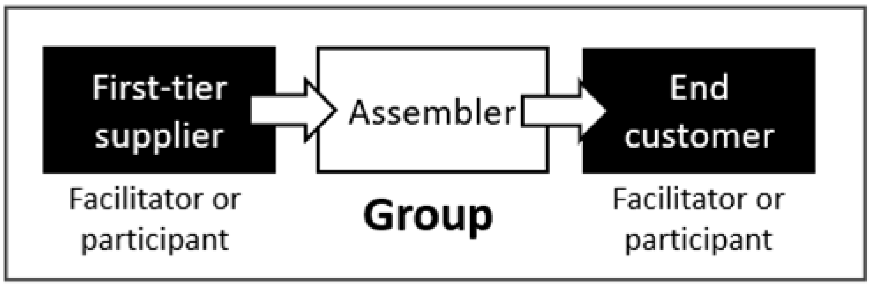

Figure 7: Supply chain simulation
Source: The authors

As can be seen in Figure 7, the facilitator assumes the roles of the supplier of input materials and end consumer. These agents have the power to manage situations that will require making decisions on subsequent actions of the group, thus handling uncertainties and concerns that will require the participants to put into practice their management skills and also find ways to handle conflicts.

Since the work of the facilitator is extensive, other participants can be recruited (who are not part of the groups) for assistance.

The simulation starts with the generation of demand by the end customer (role played by the facilitator) for each of the products of each group. We recommend using an electronic spreadsheet to store the data and use the randomization function to generate the quantity of the purchase order for each product. The use of this function is an attempt to make the simulation impartial and insert an independent variable.

The chronometer starts ticking and the simulation begins in earnest with the groups having 30 minutes to deliver the products to the end customer, according to the quantities ordered. The facilitator discloses the demand by delivering a simple form to the person in charge of sales of the simulated company, containing the date and time of the purchase order, the product and quantity desired. It is important that the other participants of the group only learn about the demand after receiving formal communication through an internal form.

The sales sector, with knowledge of the quantities of products to be delivered, sends a written requisition (on paper) to the inventory area or production area (depending on how each group designed its factory layout or processes). If the requisition form with the purchase orders is sent to the inventory area, it is responsible for evaluating each order and issuing a request to purchase new input materials, or an internal production/assembly order if the stock is sufficient to meet the demand.

If the production area is responsible for this process, it will requisition the quantity of stock necessary to assemble the final products, and if there is insufficient stock, it will prepare a request to the procurement area to purchase more input materials. Again, we stress that all this internal communication must be carried out formally in writing to prevent verbal communication, because in the real-world managers of different sectors are typically not physically near each other, so they need a means of formal communication. The requirement for communication via these forms is an attempt to simulate remote communication.

Another important point is that the way the processes are structured directly impacts the time of the assembly process, so it is up to each group to choose the most efficient way to structure their processes, to make them agile in terms of operationalizing the assembly.

Next, in possession of the list of parts (input materials), the procurement sector places an order with the supplier (role played by the facilitator) in accordance with the gross or net needs to make products. This supplier then delivers the parts in the quantity ordered to the person in charge of the procurement sector. Also in an attempt to create a limitation regarding the quantity of parts acquired, which in reality is a limited resource, a container of any size is used to limit the quantity of parts sent each time, as if this were due to restricted delivery truck space. A box, jar or even a toy dump truck can serve for this constraint.

It should be noted that the response to the procurement sectors of the plants is in order of arrival of their respective purchase orders (first come, first served), generating a substantial gain from on-time delivery to the end customer.

The "milk run" delivery model can be adopted, where the supplier carries the parts requested to each plant, but this requires more work by the facilitator, who without help and limited time available might not manage to meet all the needs of the plants satisfactorily. In this case, it is preferable for each group to organize themselves to pick up their own input materials.

Upon arrival of the input materials in the receiving area of the plant, it is necessary to check the items delivered, which can deliberately have small defects. If these are not detected and reach the end customer, the product will be returned, generating a negative impact on the entire process, including the financial aspects when monetization is applied to the simulation.

At this point, according to the organization of the processes of each group, the parts move to the inventory area or directly to the assembly line. When reaching the assembly sector, the parts are grouped according to the assembly structure and transformed into final products in the exact quantities requested by final customers. After assembly, they are delivered to the end customer, using the same space limitation as for purchasing input materials (box, jar or toy truck).

Finally, the end customer checks the products, and if everything is correct, attests this on a fictitious invoice, as a formal act acknowledging receipt of the products. The chronometer of that group is then stopped, and the total time between the order and delivery is recorded. After all the groups have delivered their products to the end customers, the prototyping phase is over.

It should be recalled that this is a learning phase and the first contact of the groups with the simulation. Thus, what is most important is for each participant to understand the dynamics of the entire process and his or her individual responsibility in the system as a whole. It is a phase of testing, learning the rules and clarifying doubts before staring the simulation per se. The time spent in each cycle can be made flexible, or the prototyping phase can even be eliminated.

This testing phase can be repeated as many times necessary until everyone understands the procedures.

THIRD PHASE – SIMULATION

Now that all the participants understand the simulation and know what and when to purchase inputs and to assemble, sell and deliver products, the simulation begins in earnest.

The simulation involves application of the procedures experienced in the prototyping phase, but with the three times cycles monitored with precision. Time is treated as a scarce resource and serves as a constraint variable, so a simulation round is composed of three cycles. As already presented, the first lasts 30 minutes, the second 20 minutes and the third 10 minutes. These distinct time intervals serve to stimulate different decisions and test the skill and capacity to deal with inventory in different ways.

Since in each cycle the demands are different, high volumes and briefer cycles lead to maintaining stock, while smaller volumes with longer cycles lead to just in time production in response to orders. In the simulation, the assumption is that the final stock of one cycle is the beginning stock of the next cycle. This gives a notion of the need for inventory planning, which in the monetized simulation has crucial importance to the plant's revenue stream.

Depending on the available time for the simulation, one or two rounds can be conducted initially, and later with practice in the simulation, up to three or four rounds, in an approximate period of two hours.

So far, the simulation has focused only on processes and information. The next step, a bit more complex, is to insert the monetary variable in the system.

FOURTH PHASE – MONETIZED SIMULATION

To insert the monetary variable in the simulation it is necessary to create a currency. This is called the Bit (B$). Each pin of a Lego® block has a value of B$ 1.00. Therefore, block Q22 (2 rows by 2 columns, total 4 pins) costs B$ 4.00.

Based on the introduction of money in the simulated market, some other factors must be respected. Each group is endowed with initial capital of B$ 200.00 (only in the first cycle). The total revenue is calculated by the sale of the final products (R = price x quantity sold), and the price is determined by the group, considering the cost of acquiring the input materials, tax of 10% on sales, and salaries of the plant managers of between B$ 5.00 and B$ 10.00 per cycle.

The determination of the profit margin is a decision of the group, which in an oligopolistic market can be a much more complex decision than just choosing a percentage of gain.

In this scenario, it is also important to inspect the quality of the parts, because if a defective part winds up being used in a final product, the customer will reject and not pay for it, reducing the sales revenue envisioned for the plant.

At the end of each cycle, another cost must be considered, that of storage and maintenance of stocks. For this purpose, the sum of the total pins of the blocks remaining in stock is calculated and a rate of 20% is applied as overhead. For example, if at the end of a cycle, 10 Q22 blocks remain in inventory, the calculation will be 40 pins, valued at B$ 40.00, at a rate of 20%, generating an expense of B$ 8.00 to be deducted from the gross revenue.

In practice, the money can be represented by chips of different values or colors, or even play money that can be purchased in stores.

It is clear that the group that has largest positive cash on hand at the end of the rounds established previously by the facilitator will be the winner, and those with negative cash status will be considered bankrupt. It is the job of the facilitator to assume the role of another market agent, a financial institution, which can lend money to plants in financial distress and charge the interest rate and set the loan maturity period as considered reasonable.

FIFTH PHASE - CLOSING

According to the experiential learning cycle of Gramigna (1993), the simulation presented has concluded the steps of experiencing, reporting and processing, and has now reached the moment of generalizing.

After the end of the simulation, the participants gather to hear the reports of their actions so that everyone can discuss the positive and negative points of each action in response to a situation provoked by the simulation. It is virtually inevitable that contrasts with the real world will appear.

Discussions can involve themes of integrated production management, such as: inventory management; types of demand; material resource planning (MRP); planning and scheduling of production; plant layout; and forms and methods to make processes more efficient, agile and flexible. It is also very common to detect the need for information and communication technology to integrate processes.

The correct application, save the due proportions, should attain the objectives of the proposed simulation. Among these are changes stimulated in the visions, behaviors and motivations experienced by the learners that in one way or another can impact their abilities to manage problems and conflicts, make more accurate decisions and analyze overall situations. Furthermore, they will have put into practice their ability to communicate, persuade and lead, minimum requirements of organizations in the real world.

For purposes of illustration, below are some comments of the students who have taken part in this simulation:

- "The approach is excellent; it really complemented everything we have covered in the production management class." – Female business administration student (5^{th} semester);
- "This practical part of analysis of processes made a huge difference and completed the knowledge learned previously (Production I). This analysis makes it clear what an integrated system really is, how complex it is, and how to obtain solutions. It was fundamental for me." – Male business administration student (6th semester);
- "It allows perceiving that having correct information makes the difference; it is necessary to select the adequate data so that processing them will provide precise/desired information and feed the process at the correct moment. It was very valid, sincerely." - Male business administration student (6th semester).

CONCLUSION

Even with all the technological evolution, computers, software, systems and networks available for educational purposes, the reality of many Brazilian universities, especially public ones, is that the majority of classes are expository with a datashow procedure, because the resources are scarce, or absent.

It is hence the task of the teacher to search for new forms and new resources to approximate theory with practice, to stimulate the development of the skills and capabilities of future professionals who will face a highly competitive job market.

In this context, this article presented a proposed business game simulation with Lego® blocks to apply basic concepts of integrated production management, inserting the students in a setting where they have to make decisions involving an assembly plant, in the areas of procurement, assembly, delivery, sales and finance, in their proper proportions.

Simulation is an experiential learning method, allowing students to be the conductors of their own learning. It also permits, in playful form, the concepts of the intended area of knowledge (in this case integrated production management) to be put to the test, by trying to overcome the challenges imposed by the simulated environment.

The simulator proposed here can be applied to teach subjects such as inventory management; types of demand; factory layout; MRP; planning and scheduling of production; costs, revenues and expenses; marketing; management of processes; and integrated management systems. Or it can simply be used to present the functioning of an organization, as an extra activity. This can be enlightening to participants who have never entered a factory, which is very common among students these days.

The simulator can go beyond a learning tool and be used as a laboratory to experiment, analyze and test theories. This will be the next step of this research project.

As a final contribution, below we present a suggested plan for applying the simulation, which can be included in the class planning (Chart 1).

Chart 1: Plan suggested for application of the simulation

Meeting no.	Content to be covered (in approximately 2 hours)	Remarks
1	Presentation of concepts of experiential learning and simulation as a method.	
2	1st Phase – Preparation: decide on products, layout of the factory, list of materials and structure for assembly.	Document all the activities.

Chart 1: Continued...

Meeting no.	Content to be covered (in approximately 2 hours)	Remarks
3	1st Phase – Preparation: present the documents produced in the previous meeting, decide on the division of the work and explain the rules and procedures of the simulation.	Specify the entire simulation process.
4	2nd Phase – Prototyping: start the cycle without a time limit for the groups to familiarize themselves with the simulator.	At the end of this phase, everyone should know what to do and how to do it. If the number of groups is less than four, we suggest one more round in another meeting.
5	3rd Phase – Start of the simulation (one or two rounds according to the available time).	Remember that each round contains 3 cycles: the first of 30 minutes, the second of 20 minutes and the third of 10 minutes.
6	3rd Phase – Repeat the simulation with one or two more rounds (optional).	If the facilitator deems it necessary.
7	4th Phase – Monetized simulation. Introduction of new procedure and new rules.	One round of tests can be used to familiarize the groups, as in the prototyping.
8	4th Phase – Monetized simulation – one or two rounds.	
9	4th Phase – Repeat the monetized simulation with one or two more rounds (optional).	If the facilitator deems it necessary.
10	5th Phase – Closing. Obtain reports of the simulated practice about the themes directly and indirectly proposed by the facilitator, as well as about the dynamics, with suggestions for improvement and critiques.	

Source: The authors

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