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Integration University–Industry: Laboratory Model for Learning Lean Manufacturing Concepts in the Academic and Industrial Environments*

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In the current production scenario, with a globalized economic environment, companies increasingly need to become more competitive to face up to the global market. This means production systems are constantly changing in the direction of the replacement of the low productivity equipment, rearranging the plant layout, the redirection of the transport stream from the supplier to the end customer and adding new models to plan and control production. All these changes aim to improve product quality and to reduce production lead time by eliminating waste, reducing costs and increasing competitive advantage through the process flexibility. For these changes to happen effectively is necessary that the current employees and the future production engineers are inserted and fit in this new reality. Currently, the Lean Manufacturing concepts are applied in an industrial environment to optimize production flow eliminating the waste found in the process. However, there is a challenge to put these concepts effectively in the industrial environment and in the university environment. The traditional learning process based on teacher, classroom, non-integrated theoretical and practical concepts, case studies with static production characteristic (controlled variable) has been shown to be ineffective in the consolidation of these concepts in a dynamic production environment. In university, this same model applied in the production engineering course and fragmented into different disciplines makes production engineers not fully prepared for the challenges of the new industrial environment, requiring an adjustment period. This adaptation will result in low competitiveness of the company in front of global competitors. Thus, this article aims to present a laboratory model for integrated learning of the Lean Manufacturing concepts based in practices able to reproduce the dynamic production environment, thus speeding the process of training employees of the industrial environment and the learning of future production engineers.

Keywords: engineering education; production engineering; lean manufacturing; learning factory

1. Introduction

In the current industrial scenario where a globalized economic context predominates, a company needs to transform itself into more competitive to face up the market and new competitors that appear every day. Accordingly, the production systems muss constantly chance searching for a productivity rise, new layout arrays in factories and insertion of new planning and control production models. These changes intend to improve the production and information flows, reducing costs and raising the competitive advantage through an increase of the process efficiency [1, 2].

However, for implementing these changes successfully are necessary, among other matters, trained and motivated employees. One of the more critical problems that industry faces up, nowadays, is the lack of qualified work forces, especially the high qualified, in each hierarchic level. This situation is worse when engineers are the case, then due to scarceness they used to be hired immediately after obtaining the undergraduate degree and, therefore, need to be intensively trained, in order to have accomplishment results in a short time.

This industry needs change, which occurs in a dynamic way over the years and constantly modifies the engineer profile, becomes the principal challenge for engineer education in the 21st century universities [3–5].

In this context of historical engineer profile changes, it could be observed that until the Second World War, the engineering teaching was focused on practical skills development that could be immediately used in the industry. However, motivated by the Grinter report from 1956 [6] and the Sputnik launching in 1957, the engineering teaching was redirected to science with emphasis to understanding and analyzing phenomena, in other words, to academic research. Thus, the separation between what was teaching at the university and the needs of industry has begun [7].

Only in the 80's, with the fast transformation of industry in the developed countries such as USA, Germany and United Kingdom, it stars a process to reduce distance between the vision of engineer

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profile at the University and that of Industry. In the USA, through the National Science Foundation (NSF), the industry recommends new skills to the engineers such as entrepreneurship, creativity, administration, and their insertion on a social, political, and economic environment [3, 7, 8].

Fallowing the engineer profile restructuration process, Lamancusa and Simpson [9], distinguish honesty/integrity and communication skills, as the industry main needs for new engineer profile

In Europe, the Bologna Accords in 2005/2006, gave a new structure to the higher education system proposing two education cycles (undergraduate and graduate). The undergraduate study cycle lasts three years (Bachelor) and the graduate cycle are two years of specialization, in which the student obtains the graduate certificate (master). This new structure applied to engineering teaching initially causes, according to [10], a time reduction and, consequently deficiencies to the new engineer profile related to the industry needs.

Parallel to the profile engineer transformation in the developed countries, in 1958 is founded, in the Polytechnic School of the University of Sao Paulo (USP) in Brazil, an undergraduate course for Production Engineering as an option for the Mechanical Engineering undergraduate course, and attending the industry demand for an engineer with a management profile and an holistic vision of the production system.

However, the Production Engineer undergraduate course was barely validated by the Brazilian Education Department (known as MEC in Portuguese) with the resolutions 48/76 and 10/77, transforming the course in a secondary degree bounded to the six basic engineering areas (civil, electric, mechanical, material science, metallurgy and mining) [11].

In 2002, due to the increasing industry demand and aligned with the growth of the Production Engineering in Brazil (Fig. 1), the Brazilian Education Department defined the Production Engineering as a basic engineering area. This definition generated a new professional profile based on a generalist, humanistic, critic and reflexive undergraduate formation, capable of absorbing and developing new technologies for resolutions of to the society relevant problems.

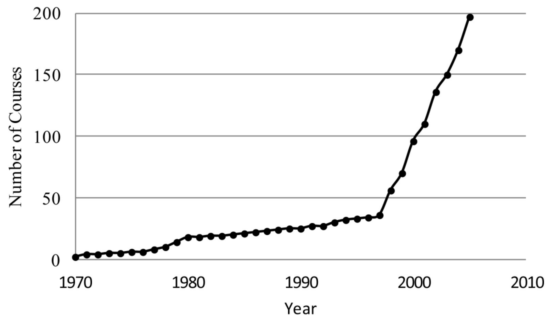

Fig. 1. Cumulative number of Production Engineering Courses in Brazil [12].

Table 1 shows the knowledge kerns and its respective curricular components, which compound the production engineering profile in Brazil, according to the Brazilian Association of Production Engineering (known as ABEPRO in Portuguese).

Despite the constant change of the engineering profile and consequently new proposals for the course reformulation in diverse schools around the world, in the last years, the search for an engineering education based on the balance between theory and practice and the development of interdisciplinary skills continues to be a challenge at the universities.

Searching for solutions of this challenge, diverse works about engineering teaching has been published, which are based on the Project Based Learning (PBL) concepts. Among them, Paton [13] analyses the engineering education performance in the German machine and equipment industry, and

Table 1. Knowledge Core for Production Engineering [11].

Knowledge Core	Curricular Components
Product Engineering	Product Planning, Product Design.
Factory Project	Location Analysis; Industrial Facilities; Layout; Handling of Materials.
Production Processes	Discrete manufacturing; continuous production; Automation; Process Planning.
Production Management	Production Planning and Control; Maintenance Planning; Logistics and Supply Chain Management; Manufacturing Strategy, Environmental Management.
Quality	Quality Management; Statistical Quality Control; Standardization and Certification; Metrology, Inspection and Testing; Confiability.
Operations Research	Mathematical Programming; Stochastic Models; Simulation of Production Systems; Assessment and Support for Decision Making.
Engineering Labour	Work Organization; Ergonomics; Industrial Hygiene and Safety, Engineering Methods and Processes.
Strategy and Organizations	Strategic Planning; Industrial Organization; Industrial Economics; Technology Management; Information Systems.
Economic Management	Engineering Economics; Production Cost; Economic and Financial Feasibility.

identifies that only 16.5% of the knowledge associated with management tools application are acquired during engineering education.

Gomez Puente *et al.* [14] address that although the Design Based Learning (DBL) concept has been introduced at the Eindhoven University of Technology in 1997 and posteriorly adapted as a Project Based Learning (PBL) model, its application in engineering education needs yet to be developed.

In some cases, the teaching model based on PBL results merely in the introduction of projects along the course curriculum, while in other cases, it involves the application of new teaching methods. For some innovative courses, this teaching model is intended as an immersion of students and professors in an industrial environment.

Having as goal the learning curve reduction and acceleration of the insertion process of new engineers in the production system, Smith *et al.* [2] propose an engineering teaching based on real industrial environment practices, which stimulates the in group work skills and the multidisciplinary knowledge. In this case, the course curriculum should be flexible to absorb the industrial needs dynamic.

Ribeiro and Mizukami [15] applied a teaching method based on the PBL model to a post graduation student group of production engineering. This method was applied by means of resolution of 12 real problems during 15 meetings of 200 minutes each, in which the students developed the knowledge (management theory), the skills (oral and written communication, problem resolution, interpersonal characteristics) and attitudes (ethic, collaboration, opinions) through the resolution of the 12 real problems. This study concluded that teaching based on the PBL model helps to motivate the students, to develop the skill of learning to search knowledge, beside the opportunity of learning to solve problems.

A study developed by Salvador and Oliveira [10] approaches the PBL concept for increasing the practical skills of new engineers graduated by the new curriculum of the Bologna Accord. The Fig. 2 illustrates a model proposed by these authors.

As it can be observed in Fig. 2, engineering teaching is based on projects with real problems, through which goals to be reach are defined by the student group involved, using a problem resolution cycle and being supervised by professors across the learning process.

Wang *et al.* [16] have identified that also in China there is an offset between what the industry expects from an engineer and what the universities are doing in that sense, thus they propose as solution an engineer teaching based on strategic cooperation between university and industry. This cooperation should evolve from an isolated stage, in which the single interest is the graduation of engineers for the work market, having as base a curriculum developed internally by the university, to a converging stage, in which both assume strategic positions aiming to develop an engineer teaching that qualify the engineers with skills and competencies directed by this cooperation.

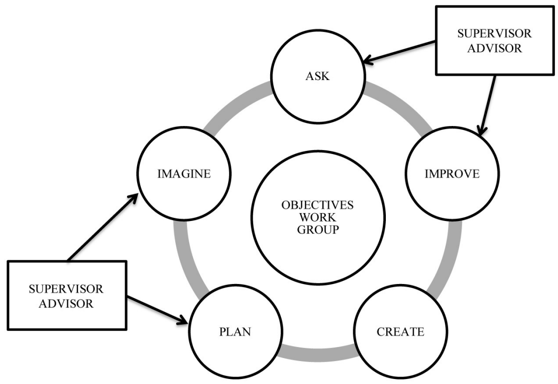

Fig. 2. Cyclic engineering problem solving with advising/tutoring [10].

Pasin and Giroux [17] analyzed the impact of simulation system (simulation games) insertion into the teaching of operations management, and present as result the student skill increase for making complex decisions in comparison with the traditional teaching.

Jorgensen *et al.* [18] have proposed a teaching based on the product development process, in which student groups examine, test and re-project the chosen product using benchmarking. These authors identified the efficiency of this practice to transmit quickly concepts and skills to the students.

Barton [19], observing a historical deficiency in students associated to concepts and use of statistical tools in industrial environment, propose a teaching laboratory for quality process based on industrial practices.

Lamancusa *et al.* [20] give the following reasons for changes in the engineering education:

- Engineering teaching should be based on real experiences for grounding theoretical concepts;
- Industry is the main client of universities and its needs are constantly changing relative to engineer skills and competencies;
- Only the university and professors/researchers experience is not able of qualifying students in concordance with the industry needs;
- Psychology and pedagogy experiences should be introduced into the engineering teaching environment.

Based on these reasons, the mentioned authors

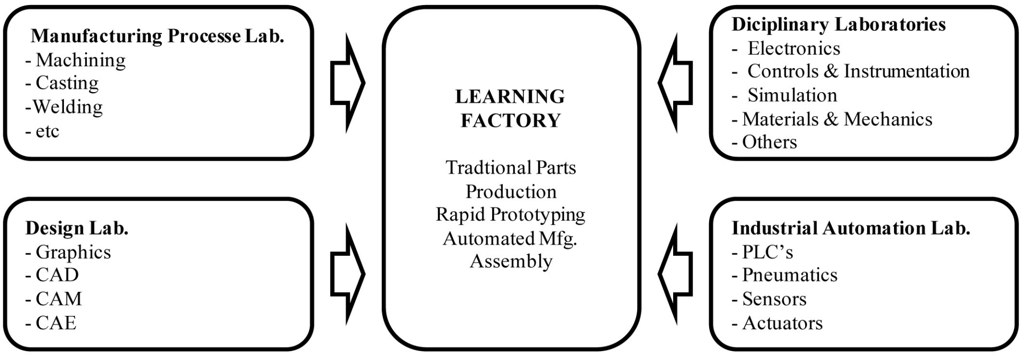

Fig. 3. Learning Factory implementation concept [21].

developed the learning Factory concept, which was awarded, in 2006, with the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. This concept is based on interdisciplinary environments, developed in partnership between university and industry, in which the engineering students are required to solve real industry problems.

Initially, this concept was successfully implemented in the USA, in a program financially supported by the government with the collaboration of three engineering programs (Penn State, University of Puerto Rico—Mayagüez, University of Washington) and 100 industry partners. Fig. 3 illustrates the laboratory integration of traditional disciplines of an engineering course by the Learning Factory concept.

Among the principal results of the Learning Factory insertion into the engineering education, the knowledge curve and practical skill acceleration and, consequently, the reduction of the adaptation period in an industrial environment, are the higher points.

In this perspective of adaptation to the industrial environment can be pointed out an insertion of the Lean Manufacturing Philosophy in the production engineering profile. This philosophy, developed from the Toyota Production System, comprises a set of methods and tools to improve the performance of a production system by means of waste elimination and value flow improvement under a consumer perspective [22–25].

Among the main Lean Manufacturing tools are 5S, KANBAN, pull production, Value Stream Mapping (VSM), Takt time, balancing line, Single Minute Exchange of Die (SMED) and one-piece flow [25–27].

Relative to waste concept, the Lean Manufacturing defines the following eight waste types: overproduction, waiting time, transport, inventory, movement, processing excess, defects, and inefficient use of human resources [25].

Therefore, this paper presents a laboratory model for the integral learning of Lean Manufacturing concepts. The Lean Manufacturing Learning Laboratory comprises practical activities able to reproduce the dynamic production environment, and thus speeding the qualifying process of the industry employees and the education of future production engineers.

The Schaeffler Brasil Ltda, company that developed the teaching laboratory concept, is a multinational company, component supplier for the automobilist industry, and already uses the Lean Manufacturing concepts in its processes. The company has as main challenge the improvement of its production capacity in an environment of high productive oscillations due to demand variations and introduction of new products.

2. Teaching learning methodology

The Lean Manufacturing Teaching Laboratory Model was developed based on a literature review about Learning Factory, on the teaching experience of the Methodist University of Piracicaba (UNIMEP) and on the employee internal training experience (Academy MOVE—Mehr Onhe VErschwendung, in English: More Without Waste) of the German company Shaeffler Brasil Ltda, as illustrated in Fig. 4.

Within the scope of the Learning Factory concept, the laboratory consists of two integrated rooms (theoretical and practice), wherein the first room is used to introduce the theoretical concepts which will be apply during the practical activities performed in the production room (second room).

In the laboratory, definitions and concepts are applied in 80 hours distributed in 20 meetings along the semester, within the scope of the discipline "Application of Production Systems". Inside the laboratory, five practical scenarios for production optimization are developed, involving production execution, analyze of performance measures and

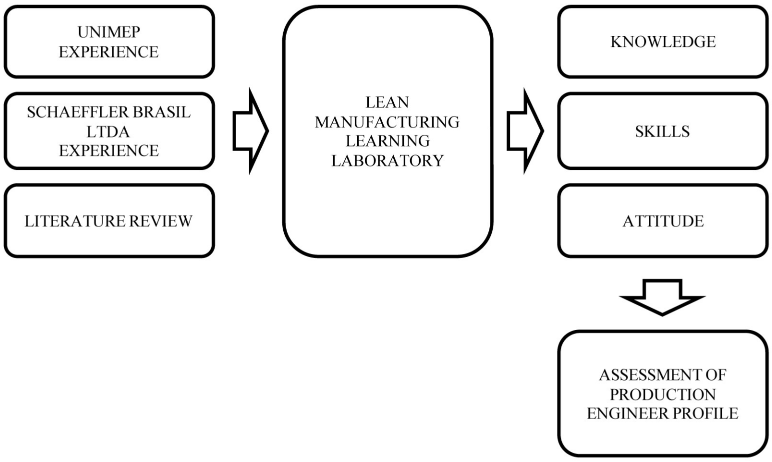

Fig. 4. Method used for development of the Lean Manufacturing Learning Laboratory.

optimization of these scenarios using concepts of Lean Manufacturing such as 5S, Supermarket, Kanban, Pull Production, Value Stream Mapping, Takt Time, Balancing line, Single Minute Exchange of Die and One-piece flow.

It is expected that, with these scenarios, knowledge, skills and attitudes of the students develop relative to the Lean Manufacturing definitions applied for the production optimization.

The production engineer profile evaluation was performed by means of a questionnaire comprising twenty questions, through which the perceptions about knowledge and skills, before and after the Lean Manufacturing Learning Laboratory, of twenty one students was evaluated, in a scale of 0 to 10.

The significant difference between the perception of knowledge before and after the Lean Manufacturing Learning Laboratory was verified by the nonparametric Wilcoxon signed-ranks test with a significance level of 0.05. In addition, an exploratory analysis was conducted by means of frequency graphs.

Beside the questionnaire, an interview was made with five managers of the Schaeffler Brasil Ltda, which have in their staff new recently undegraduated engineers with and without the integrated laboratory experience for teaching Lean Manufacturing. The interview was intended to evaluate the laboratory contribution to the acceleration of practical knowledge of production engineers and the consequent reduction of adaptation time to the industrial environment.

3. Main results

3.1 UNIMEP experience

The Methodist University of Piracicaba (UNIMEP) is a traditional university of the metropolitan region of Campinas city in Brazil, which offers the undergraduate course in Production Engineering since 1975, having as philosophy to educate an engineer with a solid scientific formation, able of identifying, formulating and solving complex problems associated to work project, operation and management activities and to production systems of goods and/or services.

The metropolitan region of Campinas, comprising nineteen municipalities, is one of the most dynamic in the Brazilian economic scenario and represents 2.7% of the Brazilian GNP.

The Production Engineering course of the UNIMEP was recognized by the MEC in 1980 with the denomination "Mechanical Production Engineering".

In 1998, the course got through a curricular reformulation process that resulted in the elimination of the minimum curriculum of Mechanical Engineering and strengthening of an education focused in Production Engineering with a total of 3600 hours (5 years). In 2005, after MEC evaluation, the recognition as a Production Engineering undergraduate course was published in ordinance No. 3.556.

In 2009, the course curriculum was newly reformulated aiming to actualize the engineer profile in concordance with the industry needs through the introduction of new disciplines having theory and practice integrated with computational systems such as: Project Management (MSproject), Product Planning and Project (CAD Systems), Product Management (PDM Systems), Operational Performance Analyze of Productive Systems (Plant Simulation), as well as applying the Project Based Learning concept through the disciplines Application of Production Engineering (EP) developed in the 3th, 5th and 7th semesters and the discipline Application of Production Systems in the 10th semester.

In these disciplines, students apply knowledge and interpersonal skills acquired during former semesters in situations such as:

- Application of Production Engineering I: each group formed by five students chooses a product or service to be produced/supplied by a company. They must define the pretended public (clients), business, mission and vision of the company. After that, the demand is analyzed and an SWOT is done. The functional organization chart is developed, the process classified and the production strategic defined. Then a company layout is proposed and the workstations are dimensioned.
- Application of Production Engineering II: each group develops an "in sight" management project for the company together with a continuous improvement suggestion. Then, the warehouse project is developed including work routine descriptions for reception/delivery of products/materials, a stock politic is defined based on ABC classification, and the warehouse layout and dimensioning are projected. Finally, a Quality Manual is elaborated.
- Application of Production Engineering III: each group should apply management and economic knowledge to the company administration using concepts of business games.
- Application of Production Systems: each group should develop the production Planning, Programming and Control System for the company. An optimization for the production process should be proposed having as start point the construction of several scenarios of the production process in virtual simulations environment and the application of Lean Manufacturing concepts.

Aiming the flexibility of the production engineer profile and considering the industrial need dynamic, a discipline about advanced topics in production engineer was introduced in the last semester, the knowledge content of which is defined in a meeting of the course board before beginning each semester, in concordance with the industrial specific needs.

The Fig. 5 illustrates the evolution of the production engineering undergraduate course of the UNIMEP, in which beside the discipline contents actualization, the practical teach hour proportion has gone from 7.5% to 17.5% of the total time.

3.2 Schaeffler Brazil Ltda experience

With more than 50 years in Brazil, the Schaeffler company has its headquarter in Germany and is one of the world leader for automotive, industrial and aerospace components. Present in more than 180 locations around the world, the company has 76 000 collaborators and an invoicing of 10.7 billion Euros in 2011.

In the company strategic planning, training is a strategic component to increase the company efficiency in the following indicators:

- Performance of delivery to the client in time in an order of 70%;
- Reduction of stock levels;
- Elimination of production cost deviation;
- Reduction of consumer complains;
- Reduction of over head costs;

Because of this, the MOVE academy was created in 2010 having as goal the dissemination of the Lean Manufacturing philosophy inside the company and

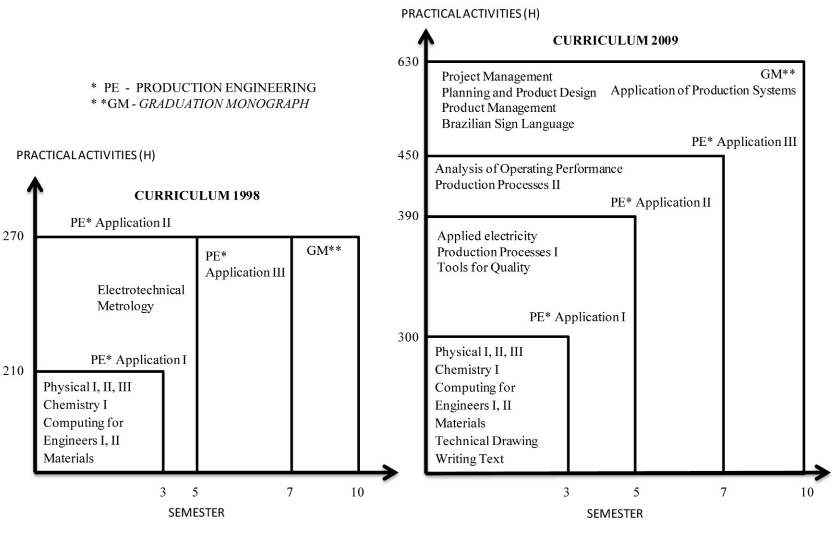

Fig. 5. Evolution of the production engineering graduate course of the UNIMEP.

Class Room	Production Roon
Objective: Development of theoretical concepts that will be applied in practical activities.	**Objective:** Project-Based Learning - Application of theoretical concepts in a real environment Production.
Infrastructure: • High resolution projector • 30 White dry-erase board • Tablet Arm Chair • 6 Computers for Production Planning and Simulation • Production Simulation Software	**Infrastructure:** • 11 Workstation; • Visual Management: Floor Marking; Heijunka System Box; Information Boards; Information Labels; Kanban System Box • Tools and Equipment in General

Physical Space= 100 m^2

Fig. 6. Environments of the Lean Manufacturing Learning Laboratory.

since then it has qualified more than 1100 collaborators, including all the technical and command board of the company.

The obtained results in the three years of MOVE practice allowed the sustainable growth of the company, minimizing the necessity of structure investments such as new constructions, equipments and machines, and mainly providing a reduction of labor force due to the index of value added.

Inside the MOVE academy, groups of up to 20 peoples are trained in a 16 hours period (2 days) using presentations with theoretical blocks up to 20 minutes, immediately followed by practical activities.

During training the Lean Manufacturing concepts and the different tools used for improving the production efficiency and controlling the information and materials flow are presented.

Practical activities aim to provide an experience in the use of Lean Manufacturing tools as well as to develop team work skills and an analyze experience based on numbers, data and facts.

3.3 Lean manufacturing learning laboratory

The Lean Manufacturing Learning Laboratory concept is based on a production system with two integrated environments (class room and production room), as can be observed in Fig. 6, and was developed at the university in the discipline Application of Production Systems (80 hours) in the last semester of the course.

In the class room, the theoretical concepts and definitions used in the practices developed inside the production room are introduced and it has available visual and audio resources as well as computational means to facilitate the concepts introduction of production system simulation. In the production room real practical activities are developed based on the Schaeffler experiences which involve the assembly process of a bearing type and the manufacturing of its internal and external rings as can be observed in Fig. 7.

A final assembly cell that receives the external ring from a grinding operation and the internal ring from a pre-assembly operation builds a production environment (room) configuration. Before the pre-assembly stage, the internal ring goes through drilling, removing of rough edges and inspection operations in its manufacturing process. The materials purchased are supplied by the Logistic in batches of 5 pieces, according to the manufacturing operations needs. The expedition stage receives the bearings from the final assembly and forwards it to the clients considering the orientations from the sales and production planning, programming and control (PPC) sectors.

Figure 8 illustrates the information flow in production room of the bearing assembly process, which is transmitted to the production planning, programming and control sector. The production orders are emitted as response to information from sales sector and production strategy.

In the initial configuration, the PPC sector emits production orders based on a traditional production system (make to order) and oriented to maximal production capacity of each workstation.

The activities to be developed in the Lean Manufacturing Learning Laboratory are divided in seven stages, as can be observed in Table 2, the theoretical blocks are utilized to introduce the students into the Lean Manufacturing concepts and the production system functioning. The production cycles involve theoretical practical activities for skills development.

In the first theoretical block, Lean Manufacturing concepts relative to value definition under a client perspective; value flow identification; creation of continuous flow; pull production and perfection

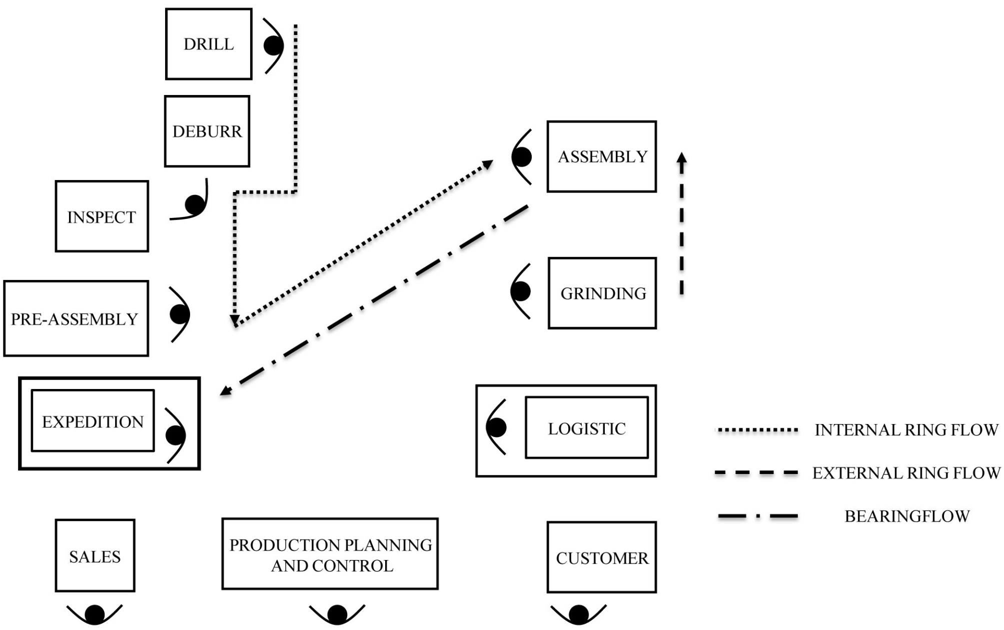

Fig. 7. Production Room Configuration—Assembly Process of a Bearing.

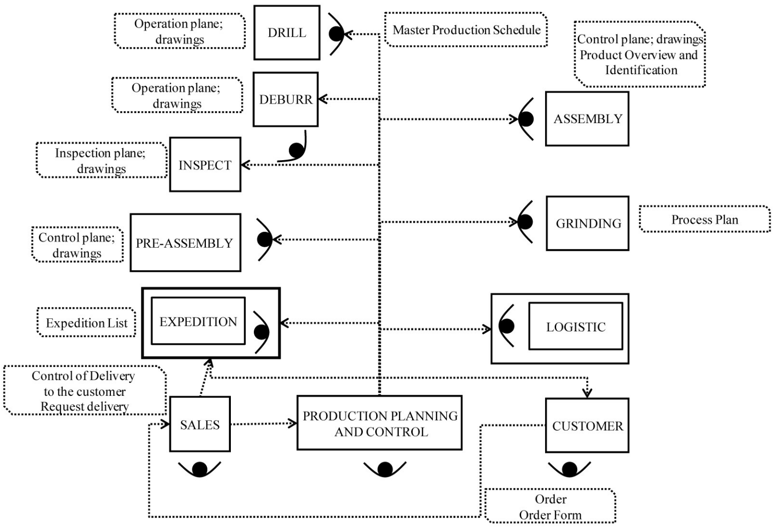

Fig. 8. Information Flow in the Production Room.

search are introduced. Additionally the elimination of the eight waste types is addressed. The focus is to show that the implementation of a lean production system will allow the company to grow and increase competitiveness without the necessity of significant new resources (like increasing staff and investments), i.e. making a better use of the existent resources.

The second theoretical block focuses on waste identification and separation between activities that add value and those that doesn't add value. In this moment a question is addressed about the fact that some not-adding value activities can't be simply eliminated.

Even at this stage, the students begin activities in the production room having as star point the description of product and its variations; manufacturing operations sequence; productive indicators, administrative and monitoring workstations. In this stage, students are distributed and trained in the workstations.

The first production cycle aims to simulate a pushed production system (make to order) and to use 5S. Thus, before beginning to produce, the

Table 2. Activities developed in the Lean Manufacturing Learning Laboratory

Stage	Theoretical Concept	Practical Experience
1 Theoretical block	Lean Manufacturing Concepts.	
2 Theoretical block	Waste identification; Activities that Add Value and those that doesn't Add Value; Production Cycle Presentation.	Production Cycle Training
1 Production Cycle	Make to Order	Production Oriented by the Maximal Capacity; Identification and Monitoring of Productive indicators.
2 Production Cycle	Supermarket system and a KANBAN system work; Pull Production Concept; 5S; Flow Management (FIFO: First In—First Out)	Introducing the Concept of Pull Production; Application of the 5S and FIFO tools.
3 Production Cycle	Production in Continuous Flow (One Piece Flow), the concepts of "takt time", balancing production line and chronological analyze; Value Stream Mapping (VSM); Information Flow Mapping (Swimlane); SMED.	Production in Continuous Flow Determination of cycle times and Takt time; Balancing Production Line; Application of the VSM; Swinlane and e SMED tools.
4 Production Cycle	Total Productive Maintenance (TPM) and Zero Defect; Overall equipment effectiveness (OEE).	Production with confiability
5 Production Cycle	Milk Run Concept	Lean Manufacturing

needed concepts are worked out with the students in the teaching room. In the production room the "operators" are asked to produce oriented by the maximal capacity. Each one in his workstation tries to produce so many products as possible in a given period of time.

After the first production cycle the students are asked to identify the characteristics of a pushed production system. In this moment the quantitative production indicators, that will be used as reference in the comparison with the other production cycles, are defined and registered.

The monitoring indicators are: reliability of delivery relative to quantities, punctuality, crossing time, stocked piece quantity (raw material, material in process and finished), and area occupied by the operation, quantity of non-conformed pieces, quantity of produced pieces, together with the number of people in operation.

The second theoretical cycle describes how a supermarket system and a KANBAN system work, introducing the concept of pull production. In this stage the concept is: "all that is consumed muss be replaced". 5S and flow management (FIFO: First In—First Out) tools are presented focusing the creation, maintenance and constant improvement of production flow.

In the second production cycle the participants are asked to implement a pull production using a KANBAN system. Applying the 5S tool unnecessary materials are removed from production flow; the workstation identification as well as quality and maintenance aspects are improved and the FIFO flow management is granted.

At this moment, the production indicators are compared with those of the first cycle so that the students can identify the evolution of the production system through application of theoretical concepts. The expected result is a positive evolution of the production indicators, specially the stability of stocks in process, FIFO maintenance and consequently, the reliability increase of the process lead time.

The third theoretical cycle addresses the production in continuous flow (one piece flow), the concepts of "takt time", balancing production line and chronological analyze.

The practical part of this stage begins distributing the students in groups in order to measure time in all workstations, develop the balancing diagram with identification of adding value activities and not-adding value activities. Using this data the student calculate the "Takt time" based on client demand and define the ideal number of operators for the production system, considering only adding value activities.

Hereafter, a theoretical block about the tool kwon as Value Stream Mapping (VSM) and the information flow mapping (Swimlane) is presented. In the production room, once again groups are formed to ensure that all students really participate of discussions. The practical activity consists in doing the VSM of the second cycle situation and proposing a model for the next cycle.

At this moment one of the groups applies the SMED concepts to optimize the setup time of the drill workstation and another group develops a new layout solution.

The layout changes will be allowed only in the third cycle. This occurs to demonstrate that is possible to improve the process performance using only the pull production, aided by control elements (for instance, KANBAN). This improvement type presents a quick and low cost implementation if compared with the layout improvement.

In the third production cycle is used the continuous flow concept (one piece flow), for which the KANBAN cards are not more necessary. It is expected a real contribution of the Lead Time reduction to the improvement of the service level to client. The stock in process will continue stable and less than in cycle 2.

At this moment, students return to the teaching room for a review of all concepts presented and practiced during the production cycles. This review is made forming student groups, which should identify the used concepts and present it to the others groups.

The fourth theoretical cycle describes the tools known as Total Productive Maintenance (TPM) and Zero Defect. The concept Overall Equipment Effectiveness (OEE) is demonstrated including the calculation routine. The central focus is to discuss the importance of equipment's reliability and product quality. Concept: "accept no defect, produce no defect, and pass no defect to the next operation".

In each workstation, groups work on specific improvements aiming to improve reliability and quality of product and processes. To increase the difficulty level, an additional process (internal ring grinding) is inserted in the production system, which was before defined as a process made by an external supplier. In this way the added value index is internally increased, making use of the resources generated by the performed simulations in the prior stages.

In this stage a new layout change is allowed in order to accommodate the optimized processes and the new workstation. The production system keeps working with one-piece continuous flow.

In the fourth production cycle, all the client demands should be attended without overloading "operators" and even with reduction of the quantity of people working in the line even with an additional productive process.

The last theoretical cycle addresses central supermarket and supply routes (Milk Run). Advantages of those systems and the necessary steps to its implementation are presented in this moment.

The practical activity that follows is performed with all students distributed in two groups. The first group does plan routes, i.e. trajectory, duration and frequency, and the second group addresses the physical structure, supermarket, strollers, packaging, route signalization and workstations.

At this moment it is expected that 100% of client demands are serviced and that production doesn't overload "operators". The productive processes, layout and materials flows are optimized. Production occupies an area significantly less if compared with the first production cycle. The qualitative and quantitative measures were closed and the indicators improvements are discussed with the students.

The students distributed in groups should then elaborate a presentation correlating the production indicators evolution with the production system evolution during the production cycles.

3.4 Production engineer profile evaluation

According to paired non-parametrical Wilcoxon, as show in the Table 3, noticed that in all questions there was a significance difference (p value < 0.05) in the level of knowledge perception by students of lean Manufacturing before and after the proposed teaching model.

Figures 9 and 10 illustrates the frequency graphs of knowledge perception by students of lean Manufacturing before and after the proposed learning model.

Analyzing the students knowledge perception it is possible to observe that:

- The knowledge perception relative to the concepts of takt time, Chaku Chaku, VSM, Swimlane, SMED and Logistic respectively related to questions 1, 9, 11–13, 15 got from weak to strong;

Table 3. Comparison of questionnaires with the Wilcoxon Test.

Question	Median Before	Median After	Wilcoxon Test (p)	Question	Median Before	Median After	Wilcoxon Test (p)
1—Takt time	4	9	0.00100	11—VSM	2	9	0.00050
2—Make to Order	4	10	0.00500	12—Swimlane	3	9	0.00009
3—Continuous Flow	5	9	0.00400	13—SMED	2	8	0.00030
4—Zero Defect	8	10	0.00340	14—TPM	6	10	0.00020
5—Waste	7	10	0.00150	15—Logistic	3	10	0.00030
6—Kanban	7	10	0.00300	16—Milk Run	5	9	0.00020
7—5S	8	10	0.00830	17—Layout	7	10	0.00009
8—One Piece Flow	5	9	0.00050	18—Process optimization	7	10	0.00020
9—Chaku-Chaku	2	9	0.00020	19—Performance Indicators	8	10	0.00150
10—Creative Importance	7	10	0.00030	20—Inventory	7	10	0.00030

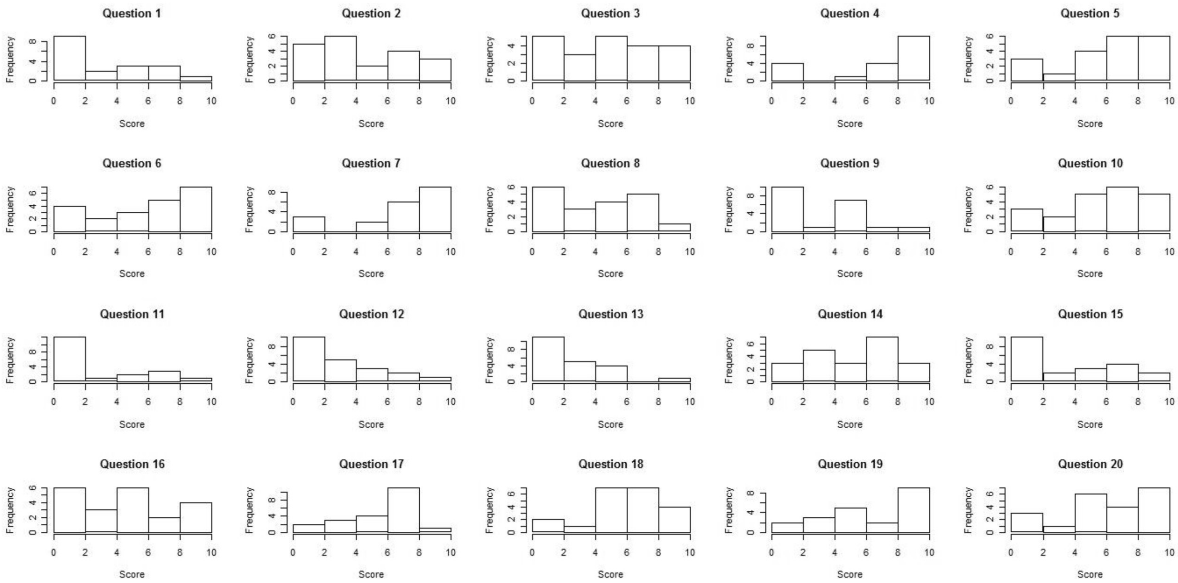

Fig. 9. Knowledge Perception by students before the Lean Manufacturing Learning Laboratory.

- The knowledge perception relative to the concepts of pull production, continuous flow, eight waste types of Lean Manufacturing, Kanban, one-piece flow production systems, creative importance, TPM, Milk Run, Process optimization and Inventory, respectively related to questions 2, 3, 5, 6, 8, 10, 14, 16, 18 and 20, got from without tendency to strong; one-piece flow production systems
- The knowledge perception relative to the concepts of Zero defect, 5S, Layout, and performance indicators, respectively related to questions 4, 7, 17, 19, remained the same. Students already had a high knowledge perception before the Lean Manufacturing Laboratory experience.

The interviews with managers of Schaeffler Brasil Ltda allowed to identify the following advantages of the teaching based on the Lean Manufacturing Laboratory:

- Students are more aware about the add value concept and becomes more critical and better observers relative to the production system;

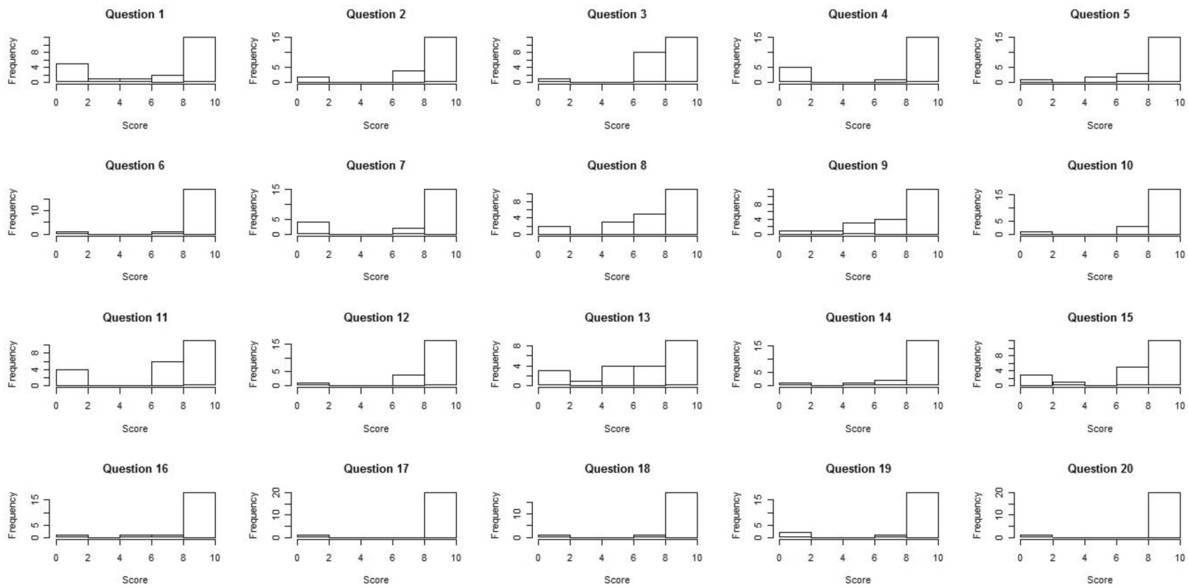

Fig. 10. Knowledge Perception by students after the Lean Manufacturing Learning Laboratory.

- There is an increase in response speed to problems of the production system;
- An acceleration in the response and learning curve was noted;
- Performance improvement in KAIZEN project coordination, since they have now a better defined work line. They demonstrate to know the steps to follow for concluding the project.

4. Future issues

An engineering education based on the balance between theory and practice and the development of interdisciplinary skills will be a challenge in the future and despite the PBL and Learning Factory concepts are a trend, its implementation in the university environment involves the following challenges:

- Develop a quantitative method for evaluating the acceleration of the knowledge curve;
- Synchronize the practical activities with real problems in the industry;
- Apply the PBL and Learning Factory concepts in all practical disciplines of the engineering course;
- Introduce the concept of Digital Factory in the Lean Manufacturing Learning Laboratory.

5. Conclusions

From the curriculum reformulation experience of the UNIMEP Production Engineering undergraduate course, aiming to accelerate the theoretical-practical learning curve through the Project Based Learning concept, it could be noted that such acceleration is only possible with industry involvement and with support of a multidisciplinary laboratory in order to develop real practices.

Despite the success of MOVE academy in Schaeffler Brasil Ltda developing Lean Manufacturing concepts for its employees, the maintenance of a competitive global level is related to the engineer profile. Therefore, the acceleration of theoretical practical knowledge during the period spent at university will be a competitiveness factor in the future.

The practical teaching environment proposed by the Lean Manufacturing Laboratory Teaching Model allowed the student immersion in a multidisciplinary study, based on real industrial practical activities. Moreover, due to a flexible layout, beside the Application of Production Systems discipline, this laboratory can be configured for other industrial practices aiding teaching of other disciplines.

The practical activities set developed together with industry support allowed a dynamic teaching environment of the main Lean Manufacturing concepts and tools.

Taking into account the student perception about teaching based on Lead Manufacturing Laboratory, it was concluded that, except for the 5S, Zero defect and performance indicators concepts which seemed to be already dominated by students, the others concepts and tools applied during activities suffered an evolution. In this first moment the layout optimization didn't change in student perception.

The interview with managers of the Schaeffler company permitted to observed that the teaching based on Lead Manufacturing Laboratory accelerated the student learning process of theoretical and practical knowledge in so a way that the time to initiate activities as coordinators of improvement projects in industrial environment was reduced.

References

1. W. Elmaraghy, H. Elmaraghy, T. Yomiyama and L. Monostori, Complexity in engineering design and manufacturing, *CIRP Annals—Manufacturing Technology*, 2012, pp. 793–814.
2. R. P. Smith, R. R. Barton, C. A. Nowack and J. Z. Castro, *Concurrent Engineering: A Partnership Approch*, Proceesings of the ASEE Annual Meeting, June, 1996.
3. P. Gwynne, Engineering a Revolution in Engineering Education, Research Technology Management, July-August 2012, pp. 8–9.
4. M. M., Nose and D. A. Rebelatto, O Perfil do Engenheiro segundo as Empresas, XXIX Congresso Brasileiro de Ensino de Engenharia, 2001, pp.25–30.
5. G. Tryggvason and D. Apelian, Re-Engineering Engineering Education for the Challenges of the 21st Century, *JOM*, October, 2006, pp. 14–17.
6. L. E. Grinter, Report on the Evaluation of Engineering Education, *Engineering Education*, **46**, 1956, pp. 25–63.
7. J. S. Lamancusa, *The Reincarnation of the Engineering Shop*, Proceedings of the IDETC/CIE 2006 ASME International Design Engineering Technical Conference. Philadelphia, September, 2006.
8. J. Rojter, The Allocation to the study of humanities and social sciences at australian engineerning education, Joint International IGIP-SEF, Trnava, Slovakia, September, 2010.
9. J. S. Lamancusa and T. W. Simpson, *The Learning Factory—10 years of Impact at Penn State*, International Conference on Engineering Education, Gainesville, Florida, October, 2004.
10. J. Salvador and J. Oliveira, An Approach to Foster Engineering Skills at Graduation Level: Meeting the Industry Needs, *iJAC*, 2012.
11. M. Borchardt, G. L. Vaccaro, D. Azevedo and J. Ponte Jr., O Perfil do Engenheiro de produção: Visão de Empresas da região Metropolitana de Porto Alegre, Produção, maio/Ago, 2009, pp. 230–248.
12. V. Oliveira, C. Barbosa and E. Chrispim, Cursos de Engenharia de Produção: crescimento e projeções. XXV ENEGEP, Porto Alegre, Brasil, 2005.
13. R. A. Paton, R. Wagner and R. MacIntosh, Engineering education and performance: The German machinery and equipament sector, *International Journal of Operation & Production Management*, **32**(7), 2012, pp. 796–828.
14. S. M. Gómez Puente, M. van Eijck and W. Jochems, Towards characterising design-based learning in engineering education: a review of the literature, *European Journal of Engineering Education*, **36**(2), May, 2011, pp. 137–149.
15. L. R. C. Ribeiro and M. G. N. Mizukami, Problem-based learning: a student evaluation of an implementation in

postgraduate engineering education, *European Journal of Engineering Education*, **30**(1), March, 2005 pp. 137–149.
16. Y. Wang, Z. Qi, Z. Li and L. Zhang, Institute-Industry interoperation Model: an industry-oriented engineering education estrategy in China, *Asia Pacific Educ. Rev.*, **12**, 2011, pp. 665–674.
17. F. Pasin and H. Giroux, The impact of a simulation game on operations management education, *Computer & Education*, **57**, 2011, pp. 1240–1254.
18. J. E. Jorgensen and J. S. Lamancusa, *Product dissection—A tool for Beanchmarking in the process of teaching Design*, Proceedings of the 1996 Frontiers in Education Conference, Salt Lake City UT, November, 1996.
19. R. R. Barton, *A Laboratory Based Course in Process Quality Engineering*, 1994 ASEE Conference Proceedings, 1994
20. J. S. Lamancusa, J. L. Zayas, A. L. Soyster, L. Morell and J. Jorgensen, The Learning Factory: Industry-Partnered Active Learning, *Journal of Engineering Education*, **97**, 2008, pp. 5–12.
21. J. E. Jorgensen, J. S. Lamancusa, J. L. Zayas-Castro and J. Ratner, *The Learning Factory—Curriculum Integration of Design and Manufactuirng*, Proceedings of the World Conference on Engineering Education. Minneapolis, October, 1995.
22. J. Antony, Six Sigma vs Lean Manufacturing: Some perspectives from leading academics and practitioners, *International Journal of Productivity and Performance Management*, **60**(2), 2011, pp. 185–190.
23. M. Holweg, The genealogy of lean manufacturing, *Journal of Operations Management*, **25**, 2007, pp. 420–437.
24. J. P. Womack and D. T. Jones, The Manchine that changed the World, Rawson Associates, New York, 1990.
25. T. Ohno, The Toyota Production System: Beyond Large-Scale Production, Productivity Press, Portland, 1998.
26. R. Gapp, R. Fisher and K. Kobayashi, Implementing 5S within a Japanense context: an integrated management system, *Management Decision*, **31**(8), 2011, pp. 565–579.
27. L. Yang, X. Zhang, and M. Jiang, An optimal kanban System in multi-stage. Mixed model assembly line, *Journal of Systems Science and Systems Engineering*, **19**(1), 2010, pp. 36–49.

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