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# Learning Factory: The Path to Industry 4.0

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**Abstract**

Nowadays, there are plenty of studies that seek to determine which are the skills that should be met by an engineer. Communication and teamwork are some of the most recurrent ones associated with a knowledge of the engineering sciences. However, their application is not straight forward, due to the lack of educational approaches that contributes to develop experience-based knowledge. Learning Factories (LF) have shown to be effective for developing theoretical and practical knowledge in a real production environment. This article describes the transformation process of a training-addressed manufacturing workshop, in order to structure a Learning Factory for the production engineering program at EAFIT University. The proposed transformations were based on the definition of three pillars (didactic, integrative and engineering) for the development of an LF.
We argue that a proper transformation process may contribute to ease the path towards new manufacturing trends such as industry 4.0 into an academic context that strengths the engineering training process.


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*Keywords:* Learning Factories ; Engenering education ; Industry 4.0; Active Learning.

## 1. Introduction

The manufacturing sector currently accounts for 14.7% of global GDP [1], as one of the most important activities to generate wealth in any nation. Colombia is not an exception, this sector represents 12% of GDP and it is the fourth productive activity of its economy [2]. Scenarios such as fierce competition, short life cycles, frequent product introductions and demand variations generate new challenges in manufacturing field [3]. For this reason, Colombian companies are now struggling to increase their productivity and competitiveness.

There is a worldwide movement in some of the most advanced economies seeking to improve the productivity and efficiency in industrial manufacturing by incorporating the latest advances in information and communications technology (ICT) [4]. The German approach to this trend is named "Industrie 4.0". It aims to boost communication between people, machines and resources, in order to transform centralized production control processes to a decentralized and autonomous model [5]. The final report of the Industrie 4.0 Working Group [6], recommend training and continuing professional development as priority areas for actions within industry 4.0 implementation. Following

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this manufacturing trend and adapted to the situation of the Colombian industrial sector, The EAFIT University aims to develop a didactic scenario where the demanding skills required by the engineer can be formed. In this context, Learning Factories(LF) appear as highly complex learning environments that allow the development of high quality and autonomous competences [7], which are linked to training, education and research including the industry 4.0 [8].

This paper presents the development of a conceptual model that EAFIT University is applying to transform both the practices of production engineering curriculum and its physical infrastructure. The final aim is to construct a LF projected towards industry 4.0. The basis for this proposal are the observed experiences developing different learning factories and some conceptual models, architecture and key elements for the manufacturing strategies posed in the four model transformations.

## 2. State of the art

### *2.1. Engineering education*

Engineering Education (EE) has a strong connection with global economic and social development [9]. To continue this synergy, previous research have been performed to align EE with the socio-economic needs [10][11]. These studies indicate that an engineer requires strong skills in human relations associated with knowledge of the engineering sciences [12]. Additionally, highlight the significant challenge of EE is the access to practical experiences in real contexts [13]. The situation in Latin America, specifically in Colombia, does not differ and engineering schools are intended to transform pedagogical practices in higher education to achieve a balance between social skills, science knowledge and technical training [14]. Based on this context, EAFIT University decided to reform its production engineering curriculum, in order to implement a new teaching-learning structure; with these transformation objectives:

• Implement new learning strategies for the practices of the curriculum of production engineering in the direction of active and experiential learning.

• Consider a transformation framework that integrates the latest industry global trends with academic content, physical infrastructure and engineering practices.

### *2.2. Learning Factories*

Initiatives such as LF have sought to develop experiences through the inclusion of industrial projects under the active learning approach on the curriculum of some engineering programs [8]. Preliminary studies have shown a better performance in the development of skills and acquisition of knowledge than traditional approaches [15].

The LF concept was mentioned for the first time in an initiative of a group of universities from the United States in 1995, since then, there have been multiple proposals of LF; additionally, institutions such as the European government adopted as an official initiative for the education of engineers[8].

Currently, a LF is defined as an idealized replica of sections of the value chain industry where informal, non-formal and formal learning take place [7]. These LFs have been used for educational purposes, research and training in areas such as manufacturing (TU Darmstadt) [8], energy efficiency (Green Factory Bavaria) [16], service operations processes (McKinsey Capability Center Atlanta) [8] among others.

In Latin America, the concept of LF has been accepted and diffused [17]. However, initiatives are few; the Brazil Model Factory, which is a union between the SENAI (Serviço Nacional de Aprendizagem Industrial) and McKinsey & Company to build a functional factory with real products, operators, machines and a realistic performance management system [18].

### *2.3. Industry 4.0*

The industry 4.0 concept was born from the initiative made by academics, industrials and the German Government, with the objective of strengthening the competitiveness of the manufacturing sector in the country through the convergence between industrial production and Information and Communication Technologies (ICT) [6]. This trend makes use of technologies as the Internet of Things (IoT) and services (IoS), Cyber Physical Systems (CPS), industrial automation, continuous connectivity and information, cybersecurity, intelligent robotics, PLM, semantic technologies, industrial big data and computational vision to improve the productivity of the manufacturing industrial systems [4].

Initiatives to link the ICT in the industrial systems are being carried out in countries as Germany (Industrie 4.0), France (the Nouvelle France Industrielle), United States (Advanced Manufacturing Partnership) and Spain (Industry Connected 4.0). In Latin America, Mexico is considering the route to implement this trend in its industry [19] and Brazil is not belittled; however, there is uncertainty regarding the cost and return on investment.[20].

To form the skills that the engineer requires in the face of this new vision of the industrial sector, strategies of learning-teaching are being rethought [8].

## 3. Research process

With the aim of implement a model that guides the actions to transform the practices of production engineering in direction of an LF, a research process has been developed. It is composed by two stages:
Identification of relevant aspects of LF as: thematic, objective group, educational purpose, teaching-learning strategies, technological infrastructure in different LF proposals. To recognize the main aspects of the LF were performed the following research steps: identification of literature, Quantitative text analysis and Qualitative text analysis. The second stage consisted in the structuring of the model, which is based on three pillars. These pillars are the characteristics that must be acquired in the proposed transformations. The model is divided into 4 phases with which are expected that the infrastructure and didactics of production engineering practices are intervened with the objective of forming a learning factory.

### *3.1. Identification of relevant aspects of LF*

To establish the most relevant aspects within the LFs, a literature research has been carried out using three databases: SCOPUS, ISI Web of Science and ScienceDirect. In addition, we searched the indexes of engineering and engineering education journals that include publications of related subjects, including the Journal of Engineering Education, Advances in Engineering Education, Journal of Science Education and Technology, European Journal of Engineering Education, International Journal of Engineering Education and Procedia CIRP. Key phrases used for this search were composed by the terms "learning factories" and "learning factory", obtaining a result of 123 papers that contained these words in their titles, abstracts and keywords. This group of publications was filtered, excluding those its contents were not referred to the learning factories as a didactic proposal in industrial and academic contexts. The next stage was a quantitative text analysis[21] to identify the key words of the 115 selected publications.
The analysis steps consisted in generating two lists of keywords (unigram, bigrams and trigrams) identified in the publications; The former list referred concepts to educational purposes and the latter to engineering. As a second step was a frequency analysis, gathering occurrence numbers within this literature selection (Table1).

Table 1. Frequency analysis - Ten most frequents words

| List 1: Educational purposes | Number of occurrences | List 2 : Engineering purposes | Number of occurrences |
|---|---|---|---|
| Education engineering | 78 | Manufacture | 79 |
| Project development | 46 | Production | 65 |
| Curricula | 44 | Design | 59 |
| University | 41 | Industry | 48 |
| Research | 41 | Products | 47 |
| Knowledge development | 37 | Technologies | 45 |
| Training | 33 | Management | 43 |
| Development of experience | 33 | Lean | 23 |
| Teaching | 30 | Efficiency | 19 |
| Based-practice | 29 | Assembly | 17 |

To identify the meaning context of the resulting words from the quantitative text analysis, a qualitative text analysis was carried out[22]. This consisted in observing the meaning of each word in the context of the papers, to later classify the words with common thematic by clusters. (Table2). These clusters link the central aspects of LFs that the model of transformation of EAFIT University must take into account.

Table 2. Seven Clusters

| | | |
|---|---|---|
| **Cluster1** | Target group | Universities |
| | | Graduates |
| | | Undergraduates |
| | | Engineering Education |
| **Cluster 2** | Educational goal | Project development |
| | | Research |
| | | Knowledge development |
| | | Development of experience |
| **Cluster3** | Learning strategies | Based- practice |
| | | Action oriented |
| | | Active learning |
| | | Experiential learning |
| **Cluster 4** | Value chain areas | Manufacture |
| | | Production |
| | | Design |
| | | Management |
| | | Logistics |
| **Cluster5** | Technologies | ICT |
| | | Software |
| | | Additive manufacturing |
| | | RFID |
| | | Cyberphysical |
| | | IoT |
| **Cluster 6** | Engineering goals | Efficiency |
| | | Technologies |
| | | Sustainable |
| **Cluster 7** | Strategies | Changeable systems |
| | | Management |
| | | Lean |
| | | Adaptable Manufacturing |
| | | Industry 4.0 |

### *3.2. Three pillars of transformation*

The model proposes that each pillar be a set of characteristics that must be developed to achieve an LF. Consequently, the actions planned in the four transformations of the model(Figure1) aim to build each of the pillars to a greater or lesser degree depending on the stage of the model. The three pillars that are presented below are the result of uniting the clusters that had a common thematic:

- Didactic pillar: conformed by these clusters: target group, educational goal and leaning strategies. Which links the entire didactic component of the LF. Additionally, focuses on the selection of users and their learning objectives.
- Integration pillar: Although, the manufacturing area has the highest frequency within value chain cluster, different learning factories also involve activities such as design, logistics, planning and control production. This pillar aims to promote actions that integrate the schools of engineering, administration, marketing and economy in the FA.
- Engineering pillar: this pillar covers the cluster technologies, engineering objectives and strategies. Becomes the driver of the technical and technological contents that take part in the LF.

### *3.3. Transformation Model: From manufacturing lab to Learning Factory*

With the development of 4 transformations is projected to create to this new scenario(LF) the realism of a productive system, which contains the processes and technologies of the current industry to perform the practices of production engineering in a didactic context.

The three pillar-based model has been proposed to acquire in a progressive and guided way the most important characteristics of a LF. (Figure 1). The model consists of 4 transformations:

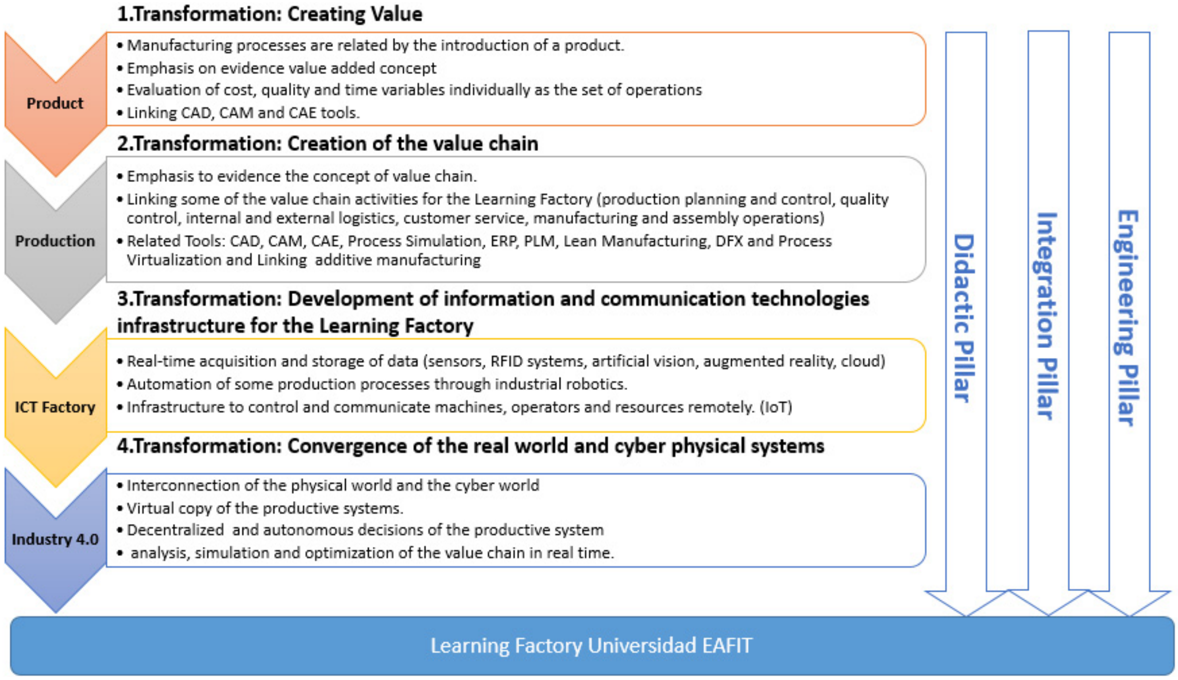


Fig 1 Conceptual model of the transformation LF Universidad EAFIT

- Value creation: Is focused on transforming manufacturing practices through the introduction of products. Although the result is a physical product, the main objective is didactic, and is to evidence the concept of value added. The didactic pillar is the principal character of this transformation and takes part of the learning methods and the educational goal to propose the changes in the practices in the direction of an LF.
- Creation of the value chain: In the second transformation, is intended to form the integration pillar by the introduction of modules of logistics, planning and control of the production and assembly operations to the already developed manufacturing activity of the first transformation. Through this integration is intended to create the concept of value chain in both didactic and physical infrastructure aspects.
- Development of Information and Communication Technologies infrastructure for the Learning Factory: In the last two transformations the pillar of engineering has taken part through participation in activities of the value chain, however in the third and fourth transformation this pillar is strengthened by introducing trends in both productive strategies as in the technologies applied to them.
- Convergence of the real world and cyber physical systems: By means of the construction of the three pillars in the past transformations (didactic, integrating and engineering), is expected to develop the bases to implement in a real and academic context the concepts that can lead to LF EAFIT University to a state close to the industry 4.0.

## 4. Learning Factory EAFIT University

### *4.1. First Transformation: Value creation*

This transformation aims at the student to identify and develop the added value concept within the learning process, through the manufacture of a final product, created by related processes.

Traditional teaching practices involved individual tasks performing, getting as a result the students disorientation. However, the implementation of a final product construction idea, provided the students a holistic point of view. For example, when performing a CNC blending tube practice, the result of the operation was imprecise piece not belonging to a product (Figure 2a). Whereas, in figure b, a complete process picture was provided before performing the task, obtaining, greater process understanding and better results.

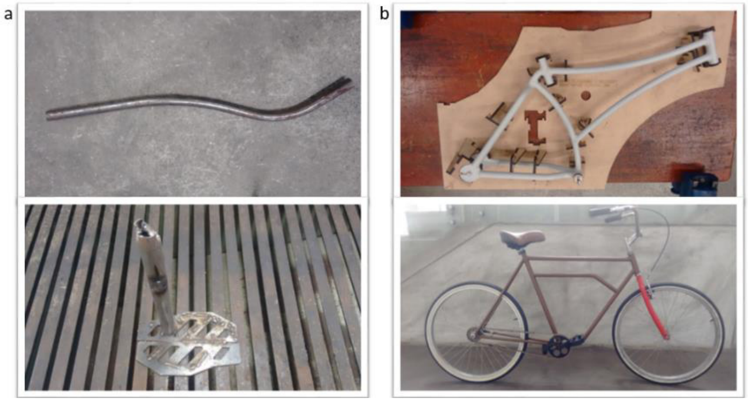


Fig 2. (a) Isolated practices; (b) Adding value between manufacturing process practices

### *4.2. Second Transformation: Creation of the value chain*

The manufacturing operations are not isolated activities, and they depend on others processes within the value chain (design, inbound and outbound logistics, production planning and control, quality control, maintenance, customer service). In order to link the other activities of the production system a second transformation was proposed. The objective of this stage is twofold; first, to create a value chain for the learning factory (Figure 3) and second, to introduce a PLM platform to manage product information.

In this transformation was implemented a modular chess set[23]. The original design is presented in figure 3. During the development of the course, the students assume the role of the production manager within the value chain. The feedback from students and teachers was positive. However, due to chess set characteristics, the assembly operation, inbound logistic and warehousing were elementary, limiting the integration of the value chain. To give projection to

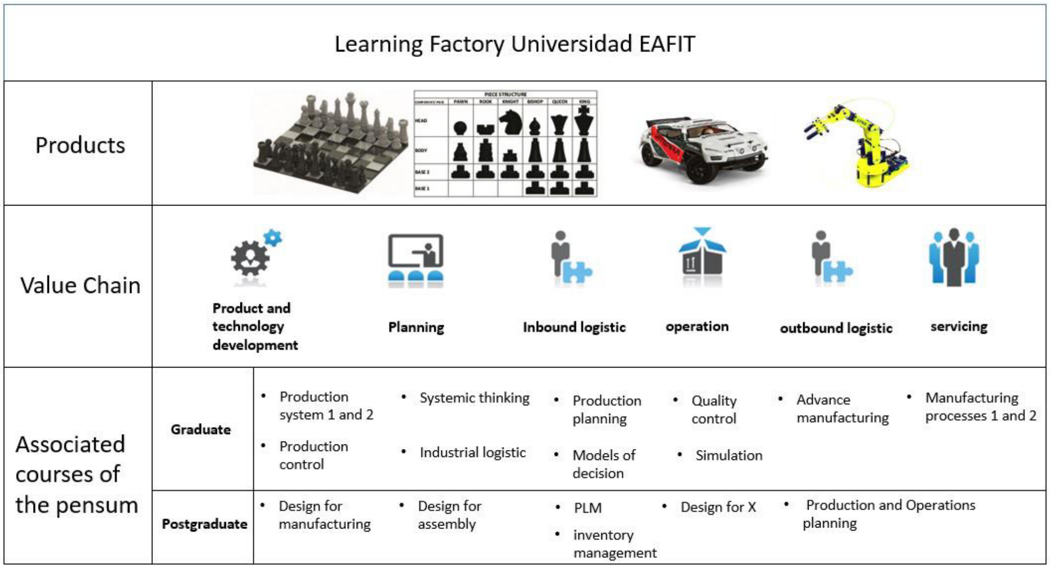


Fig 3. Products, value chain and associated courses

the value chain activities were linked new products, which changed the conditions of manufacturing operations, assembly, logistics and production planning. These products increase the number of assemblies and subassemblies. Under these conditions, were introduced to the learning factory new modules associated with concepts of lean manufacturing, production management, changeable manufacturing systems (modularity, scalability, flexibility) and design for X.

### *4.3. Third Transformation: Development of information and communication technologies infrastructure for the Learning Factory*

The ITC component within industry 4.0 is critical to acquire, transfer and manage real-time information among customers, suppliers, processes, machines and operators, with the aim of evaluating the elements of the production system when decisions are required [5][6]. Actions to develop the ICT infrastructure have been made in the last two transformations; for example, the linking of a PLM platform, fixed and wireless internet networks, wireless calipers, remote operation of the 3d printing process, telepresence system and display information equipment in the assembly line; however, it is proposed that in this transformation the ITC infrastructure should be complemented in order to achieve the basis for the interconnection of the entire value chain that was created in the second stage. The conceptual model of the third and fourth transformation is based on the 5-level architecture proposed by Lee et al. [24], which provides a guideline for developing and deploying CPS for manufacturing applications. The third transformation comprises the first two levels of 5C architecture, which divides them into two phases (Figure 4):

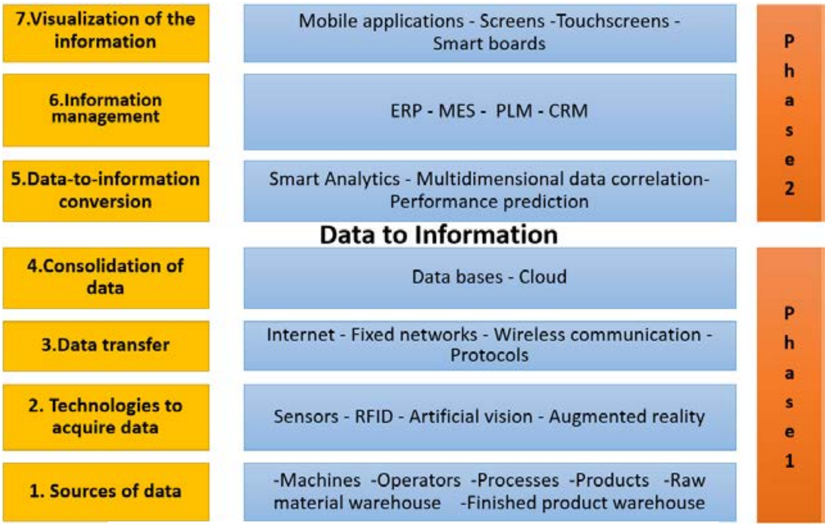


Fig. 4. Third transformation phases

### *4.4. Fourth Transformation: Convergence of the real world and cyber physical systems*

CPS systems are the transforming technologies for managing systems interconnected between their physical assets and computational capabilities[24]. This systems would allow to display the full potential in terms of optimization for decision making, efficiency and productivity of resources, decentralization and autonomy of the productive system [6].

In the LF EAFIT University the physical and technological infrastructure in last transformations has evolved. Additionally, simulation and virtualization of manufacturing processes has been developed. However, to deploy the CPS in the resulting LF value chain, in the fourth transformation is projected to implement actions guided by the last three architecture levels proposed by Lee et al. [24]; whit this intervention will allow the creation of scenarios to develop a state close to industry 4.0 in a didactical environment.

## 5. Discussion and conclusions

Learning factories are a promising approach to competence development. The linking of learning strategies and latest trends in manufacturing empower training, research and education in different areas of engineering.

This paper presents the transformation model to change the physical infrastructure and didactic structure of the practices of production engineering towards LF concept. The proposed transformations were based on the definition of three pillars (didactic, integration and engineering), which are a set of characteristics that must be developed to achieve a LF. Four transformations were proposed to develop each of the three pillars. In the first two transformations, the construction of the didactic pillar was the most critical, due to the challenges in the development of teaching-learning strategies linked to the educational objective, the target group and physical resources.

This model could provide a replicable guideline to gradually implement a Learning Factory. We argue that a proper transformation process may contribute to ease the path towards new manufacturing trends such as industry 4.0, into an academic context that strengthens the engineering education process.

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