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RETO DE LA INDUSTRIA 4.0 EN ENTORNOS EDUCATIVOS

CHALLENGE OF INDUSTRY 4.0 IN EDUCATIONAL ENVIRONMENTS

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Resumen: El artículo presenta un proyecto exitoso de Innovación Curricular basado en la Metodología General Ajustada (MGA) y aprobado por la OCAD del Sistema Nacional de Regalías del Gobierno de Colombia. La propuesta central es un Laboratorio de Fabricación Digital (FabLab) que busca fomentar el autoaprendizaje, el aprendizaje colaborativo y por descubrimiento, impulsando así la innovación y el emprendimiento a través de la cooperación entre la Universidad, el sector productivo y los emprendedores. Esto crea un flujo positivo de ciencia, ingeniería y transformación digital de la sociedad. Las principales lecciones aprendidas incluyen la importancia del liderazgo, el trabajo en equipo, la confianza institucional, el trabajo virtual, la promoción del acceso abierto al conocimiento y la colaboración entre entidades educativas y gubernamentales.

Palabras clave: Laboratorio de Fabricación, Innovación, Diseño Curricular, Emprendedor, Transformación Digital

Abstract: The article presents a successful Curricular Innovation project based on the Adjusted General Methodology (MGA) and approved by the OCAD of the National Royalties System of the Government of Colombia. The central proposal is a Digital Fabrication Laboratory (FabLab) that seeks to foster self-learning, collaborative and discovery learning, thus boosting innovation and entrepreneurship through cooperation between the University, the productive sector and entrepreneurs. This creates a positive flow of science, engineering and digital transformation of society. The main lessons learned include the importance of leadership, teamwork, institutional trust, virtual work, promotion of open access to knowledge and collaboration between educational and governmental entities.

Keywords: Fabrication Laboratory, Innovation, Curricula Design, Entrepreneur, Digital Transformation

1. INTRODUCTION

A permanent demand to the University is that its educational offerings be relevant in practice, while remaining rigorous. This demand is part of the old debate or commonplace of Rigor and Relevance, which proposes that academics should be more closely linked to the professional world and that projects should be developed that articulate the training processes with the practical reality of the productive sector (Benbasat & Zmud, 1999; Hevner et al., 2004; Straub & Ang, 2011; Irwin, 2019). This need is much more visible in academic programs related to Information and Communication Technologies (ICT), since Industry 4.0 is generating permanent changes, of great magnitude and very quickly (Oztemel & Gursev, 2020; CONPES 3975 National Policy on Digital Transformation and Artificial Intelligence, 2019), so it is urgent to make incursions into new curricular proposals.

Considering the above, the Systems Engineering program of the Universidad Francisco de Paula Santander Cúcuta (UFPS) conducted a rigorous search in international sources, inquiring about innovative and feasible curricular proposals of application in its context. From this exercise, the trend of Digital Fabrication Laboratories (FabLab), originated at the Massachusetts Institute of Technology (MIT), was identified.

This type of initiatives such as FabLab are very interesting both for the University, in terms of curriculum, as well as for the productive sector and government policies. However, it involves large investments, which is why the University decided to apply for a call from the Colombian Government's National Royalties System (SGR) Collegiate Body for Administration and Decision Making (OCAD), and was awarded a budget of almost three billion pesos ($2,921,000,000). With this budget, the physical space will be adapted, the FabLab will be equipped and its operation will begin offering educational and professional services, with the vision of articulating the University, companies and entrepreneurs.

The remainder of the document discloses the philosophy and practice of the FabLabs, the high-level curriculum proposal, the successful experience of formulating and awarding the investment project before the OCAD / SGR and the conclusions and work derived from this experience.

2. PROPOSAL CURRICULAR

The curricular proposal is theoretically based on Ecological Systems Theory (Bronfenbrenner, 1977; I-Wah, 2011; Ettekal & Mahoney, 2017; Sukhbaatar & Tarkó, 2018) and methodologically based on Science Design (Hevner et al., 2004; Wieringa, 2014). And in practice it is grounded in the proposals of the FabLab network, which has its own theoretical background on education and FabLab (Paulo Blikstein, 2013). The following first details everything related to FabLabs, according to what was proposed in the OCAD/SGR call and then specifies the curricular proposal to implement FabLabs at the Francisco de Paula Santander Cúcuta University.

2.1 Laboratorio de Fabricación Digital (FabLab)

The Digital Fabrication Labs (FabLab) is an initiative of the Massachusetts Institute of Technology (MIT). They consist of a set of off-the-shelf industrial-grade electronics and manufacturing tools and a suite of open source software and programs. They offer users the ability to conceptualize, design, develop, manufacture and test almost anything locally. FabLabs provide capabilities for engineering application in the design and manufacture of Industry 4.0 solutions and open up numerous possibilities for innovative solutions to societal problems. They also enable local communities to foster innovation, mainly with sustainable solutions. In addition, the labs act as an incubator for local microenterprises or entrepreneurs (Paulo Blikstein, 2013; Souza et al., 2020). Globally, the FabLab Foundation has a network that groups all digital fabrication laboratories and where 1863 FabLabs are currently registered, as shown in Figure 1 (FabFoundation, 2020).

Fig. 1. FabLab Global Network

Some of the most prominent laboratories worldwide

are FabLaB (MIT), FabLab Barcelona and FabLab Valencia. Colombia has not been oblivious to this boom in new technologies and creative cultures and some universities have FabLabs, such as Universidad de los Andes, Universidad Nacional de Colombia, Sede Medellín, Universidad Autónoma de Occidente and the Makerspace of Universidad de Caldas. Figure 2 shows a map of the distribution of FabLabs in Colombia (FabFoundation, 2020).

Fig. 2. FabLab Colombia Network

In the Digital Fabrication Labs, creativity is valued as one of the most important values and its efforts are focused on developing, nurturing and giving real possibilities to creative people. The philosophy of FabLabs is to streamline the prototyping of ideas and learning by doing. Moreover, it is not a concept of a particular discipline but covers a wide range: architecture, basic sciences, Systems Engineering. Electronics, Mechanical, Electromechanical, Industrial, among many others.

A digital fabrication lab is a fully equipped workshop where people have the opportunity to make something, to transform an idea into a concrete object. They are spaces that function as technological workshops, which, due to their dimensions, allow large-scale work to be done, but, above all, they develop creativity, research, learning and collaborative work, and therefore, they are a source of economic and technological development. This type of laboratory is composed of tools for manufacturing, industrial electronics, Internet of Things (IOT) and Graphic Design; ready-to-use tools that use both open source and proprietary software. The lab allows research groups and faculty and students to have a place where ideas become reality, where researchers and entrepreneurs have the chance to experiment and see the products of their imagination come to fruition. The idea is that they can translate their great idea into a technology that can quickly be brought to industrial scale.

The FabLab proposal for the Francisco de Paula Santander University consists of an area of approximately 500 square meters, which will be composed of the areas of (i) 3D printing, (ii) cutting and marking with laser or milling, (iii) IOT (Internet of Things) area, (iv) modeling area, (v) virtual/augmented reality area, (vi) mobile development area, (vii) Artificial Intelligence area, (viii) drone application area, (viii) digital content area, and (ix) assembly or finishing area. Additionally, it will have two special areas for ideation and coworking.

The FabLab proposed for the UFPS will allow working with different materials by having machinery for cardboard, plastic, polyethylene, polyester, rubber, paper, acrylic, fabric, electronic leather, wood, textile, among others. Laser cutting, welding, 3D printing, arduinos, specialized software and 2D and 3D design programs.

In Industry 4.0 trend topics such as IOT and Artificial Intelligence, it allows the design and construction of electronic devices for process automation or data capture from objects interconnected by internet and cloud applications to use techniques such as machine learning and deep learning.

Finally, the FabLab philosophy can be summarized in five pillars: collaborative work and mentoring, learning by doing, prototyping, entrepreneurship and open access. These five pillars correspond to FabLab's theoretical foundations, such as experiential learning, critical pedagogy and constructivism, following the ideas of Dewey, Montessori, Piaget, Freire, Papert and Resnick, the latter two prominent in the world of computing for their Logo and Scratch languages (Paulo Blikstein, 2013; P. Blikstein et al., 2017; Souza et al., 2020).

2.2 The UFPS Curricular Proposal

Various theories, methodologies, work frameworks, approaches, strategies and educational approaches can be found in the literature, in addition to Colombian regulations and experiences in the daily practice of the University. An interesting theory is the one proposed by Bronfenbrenner, the Ecological Systems Theory. According to this theory, the ecosystem has much influence on education and five (5) ecosystems are proposed (Figure 3): micro, meso, exo, macro and chrono (Bronfenbrenner, 1977; I-Wah, 2011; Sukhbaatar & Tarkó, 2018).

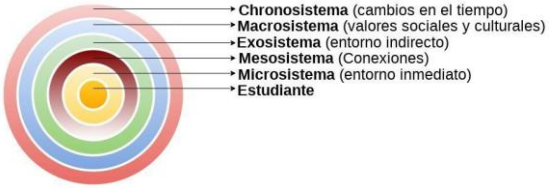

Fig. 3. Ecological Systems Theory Diagram

If it is a question of facing Industry 4.0 from education, it may be appropriate to accept this theory and in that case it is essential to create an educational ecosystem that favors the articulation of the learning process with the productive process. The real problems of business, government and society can serve as a learning tool for students and their ideas and proposed solutions can be rapidly prototyped and evaluated in real practice. That is precisely what a FabLab pursues, that is its philosophy.

However, the theory guides the vision but does not say how to achieve it. For this purpose, the proposals of Science Design are followed, especially the methodology proposed by (Hevner et al., 2004), which is illustrated in Figure 4.

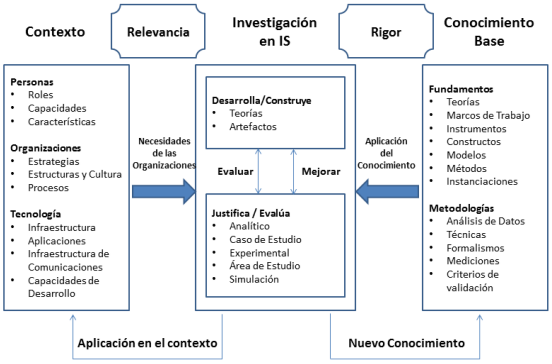

Fig. 4. Methodology Science Design

This methodological proposal allows a balance between rigor and practical relevance and focuses on solving real-world situations, articulating research and professional practice, something that FabLabs foster. In addition, a virtuous circle is achieved in which problems are solved in practice and at the same time scientific dissemination is generated, so that the learning process allows the development of skills for professional practice and for the academic world.

But theory, methodology and the FabLab are not enough; a support network is required, a network of collaborative work. Although the FabLab network contributes a lot, it is worth mentioning that in practical terms the UFPS already has an ecosystem of several years, due to its experience in entrepreneurship programs such as Apps.co, Punto Vive Digital Lab and the Transportation Hackathon, real experiences on articulation between the University and the productive sector, which gave rise to initiatives such as the one presented in this document..

Finally, it should be clarified that this is a high-level curricular proposal and its detailed specification is beyond the scope of this document. However, according to the above, it can be seen that the proposal of a FabLab is consistent with the Ecological Systems Theory in the sense of promoting the ecosystem to articulate the University with the reality of the productive sector and society. Likewise, the Science Design approach generates opportunities for curricular innovation in each specific discipline. Once the University has the FabLab and it starts operations, research on educational change, digital transformation, curriculum evolution and the impact on society and the synergy between the University, companies and entrepreneurs can begin to be evaluated

3. OCAD/SGR EXPERIENCE

In Colombia there are several opportunities for calls from the National Government to obtain resources to develop projects from the University. One of these opportunities is the National Royalties System (SGR), which is channeled through the OCAD (Collegiate Body for Administration and Decision Making). The only caveat is that it is closed to the use of the Adjusted General Framework (MGA) methodology, which applies to investment projects and not so much to science projects. Considering that in this work the curricular proposal was previously presented, in a balanced way the following is presented regarding the MGA and the experience of UFPS in the call for proposals.

3.1 Adjusted General Framework (MGA)

The General Methodology for the Formulation and Evaluation of Public Investment Projects (MGA) is a methodology and a computerized tool developed by the Investment and Public Finance Directorate of the National Planning Department (DNP). The tool records information for the formulation and evaluation of an investment project with allocation

of resources from the different public budgets. Its conceptual underpinning the Logical Framework methodology (or Adjusted General Framework), derived mainly from the procedures and instruments of the Objective-Oriented Planning (in German ZielOrientierte Project Planung - ZOOP), and from the principles of preparation and economic evaluation of projects of the Colombian government (DNP, 2016).

The MGA is made up of modules and chapters, organized in a sequential manner so that the information obtained and worked on during the formulation process is progressively recorded. It starts with the identification of a negative situation experienced by a certain group of people and one or more alternative solutions, and continues with the evaluation of the technical, social, environmental and economic feasibility of each of these alternatives, which allows the most convenient one to be chosen and the fulfillment of the proposed general objective to be programmed in terms of indicators and goals.

3.2 Experience MGA FabLab Project

The Universidad Francisco de Paula Santander, according to its mission and vision, has been characterized by leading regional transformations through teaching, research and extension. This leadership is reflected in its academic programs, several of which are accredited for High Quality, in the process of obtaining Institutional Accreditation and the recognition of Colciencias for research groups and research seedlings. However, although UFPS has several laboratories, it does not have spaces to develop Digital Fabrication activities, so it is necessary to adapt physical spaces and equip them according to the standards proposed by the Digital Fabrication movement (FabLab) worldwide.

Additionally, a regional challenge for UFPS is to turn the socioeconomic crisis resulting from the Venezuelan migration phenomenon and the post-conflict situation into opportunities, an evolution of educational approaches towards open and collaborative models that foster creativity, innovation and entrepreneurship, as well as greater agility in the transfer of knowledge and technology to the productive sector.

In this sense, following the guidelines of the MGA, UFPS formulated the problem tree in Figure 5.

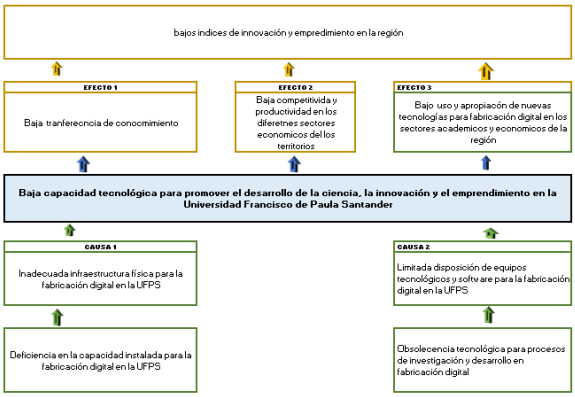

Fig. 5. Problem Tree

The central problem of this tree is that the UFPS has a low technological capacity (infrastructure and human talent) for the promotion of Science, Innovation and Entrepreneurship, which generates a vicious circle that perpetuates the low competitiveness indicators.

It is therefore essential to invest in initiatives such as a Digital Manufacturing Laboratory (FabLab). Not only because there are no such laboratories, but also because these spaces allow the University to improve its integration with the productive sector, encourage research, prototyping, innovation and entrepreneurship, which contributes substantially in transformations for the region.

According to MGA, this desirable situation that is expected to be achieved with the implementation of the FabLab project is built from the technique applied in this case the objective tree (Figure 6), where it is proposed to redefine all the negative conditions of the problem tree to transform them into positive conditions that can be achieved in practice, taking into account the following considerations:

1. The main problem of the problem tree will become the general objective.
2. The direct and indirect causes will become the specific means or objectives.
3. The direct and indirect effects will become the ends.

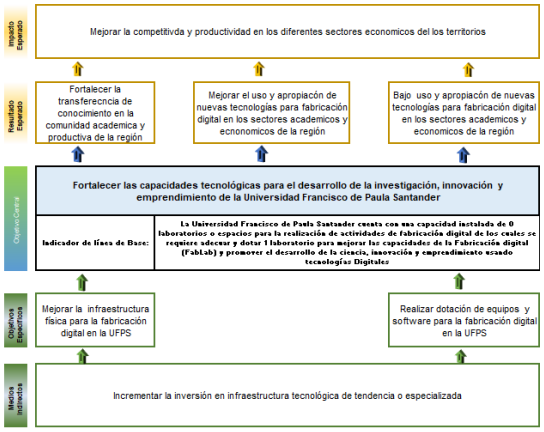

Fig. 6. Objective Tree

The following objectives are proposed for the execution of the project:

3.3 General Objective.

Strengthen the technological capabilities for the development of research, innovation and entrepreneurship at the Universidad Francisco de Paula Santander.

The proposed indicator to measure the general objective was proposed as follows: Increase the number of Digital Fabrication Laboratories at the Universidad Francisco de Paula Santander. Goal: 1

3.4 Specific Objectives

Improve the physical infrastructure for digital fabrication at the Francisco de Paula Santander University.
Provide equipment and software for digital fabrication at the Francisco de Paula Santander University.

The materialization of the specific objectives and the fulfillment of the expected result of the project is only possible through the products with their requirements and characteristics of the goods and services proposed in the three solution alternatives for this project:

Alternative 1: Create a Technology Development Center for digital manufacturing in the department of Norte de Santander.

Alternative 2: Create a digital manufacturing laboratory at the Universidad Francisco de Paula Santander to promote the development of science, innovation and entrepreneurship.

Alternative 3: Strengthening of existing laboratories in the different academic departments of the Universidad Francisco de Paula Santander; involved in digital fabrication.

To determine the alternative to be selected, different factors such as institutional capacity, installed capacity, probability of achieving the objectives, profitability and coverage were analyzed..

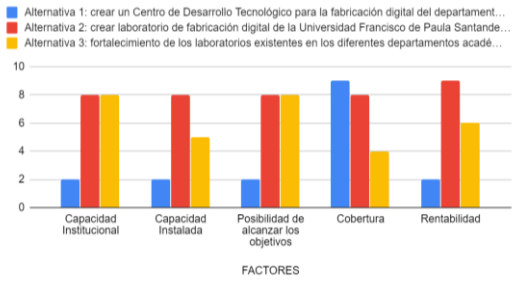

Fig. 7. Evaluación de Alternativas

It can be concluded (Figure 7) that, according to the weighting of factors, the most viable alternative to satisfy the CTeI needs is the Adequacy, Endowment and Implementation of a Digital Manufacturing Laboratory to Promote the Development of Science, Innovation and Entrepreneurship at the Universidad Francisco de Paula Santander, since this alternative has the best score of the factors analyzed.

The Adequacy, Endowment and Implementation of the Digital Fabrication Laboratory of the UFPS is only achieved through different transformation processes where activities are involved that use a set of inputs whose unit values allow estimating the costs of the Laboratory.

This FabLab linkage (Table 1) of inputs, activities, products, for each specific objective and the results that generate value for society, is called value chain in public investment projects.

Tab. 1: Value Chain FabLab Laboratory

Specific Objective 1. Improve the physical infrastructure for digital manufacturing at UFPS.	
Output 1. Adequate research infrastructure **Quantity: 1**	**Activity 1.** Carry out the civil works
	Activity 2. Carry out metal carpentry
	Activity 3. Install Electrical System and Structured Wiring

	Activity 4. Carry out Project Management Supervision and Controlling.

Specific Objective 2. Provide equipment and software for digital manufacturing at UFPS.	
Output 1. Research infrastructure endowed **Quantity: 1**	**Activity 1.** Provide furniture and supplies for the digital fabrication laboratory.
	Activity 2. Acquire and install equipment and software in the areas of the digital fabrication laboratory.
	Activity 3: Train officials, teachers and researchers on the handling, use and appropriation of the equipment of the digital fabrication laboratory**.**
	Activity 4: Conduct outreach and training sessions on the benefits of the digital fabrication laboratory to the academic, scientific and business community.
	Activity 5: Carry out Project Supervision

The concept of value chain is an integral part of a proper formulation and complements the logical framework methodology by specifying the project components in terms of the specific products that will be delivered through it, so that later in the follow-up stage they can be monitored in a more appropriate way, which in turn allows a better understanding of the project execution structure (DNP, 2016).

The Digital Manufacturing Laboratory entails a substantial investment and the implementation of the laboratory with UFPS own resources is difficult due to its status as a public university, which is why it decided to apply under the Biennial Plan of Public, Open and Competitive Calls of the Science, Technology and Innovation Fund - FCTeI - of the General System of Royalties - SGR - for the biennium 2019 - 2020.

UFPS submitted a list of eligible project proposals to the Call for Proposals for the strengthening of institutional and research capacities of public Higher Education Institutions - HEIs - in all areas of knowledge, through projects for the adaptation of infrastructure and equipment for the development of science, technology and innovation or research + creation activities. The need of each HEI is aligned with a current institutional strategic document (Colciencias, 2019).

The funding of the call for proposals was divided into the six regions of Colombia: Eje Cafetero, Centro Oriente, Pacífico, Centro Sur, Caribe and Los Llanos. A total of 44 project proposals were registered with a total amount of $91,559,737,331 in all regions. The criteria for the evaluation of the proposal were: Quality of the investment project proposal, Results, impacts and products expected from the project, Sustainability of the infrastructure and equipment, Conformation and experience of the work team, The minimum score for the proposal to be declared eligible is 65 points. The UFPS FabLab Laboratory project obtained a score of 86.67 in the Central East Region, which granted it the condition of eligible within the call to comply with the necessary requirements to present the investment project for the consideration of the Collegiate Body of Administration and Decision (OCAD) of the Science, Technology and Innovation Fund (FCTeI) for its prioritization, feasibility and approval.

The OCAD of the Science, Technology and Innovation Fund, accepted and approved the Universidad Francisco de Paula Santander as executing entity and as designated instance to advance the contracting of the auditing of the project: *"Adequacy, Equipment and Implementation of a Digital Manufacturing Laboratory to promote the development of Science, Innovation and Entrepreneurship in the UFPS"*.

UFPS complies with the prerequisites that support funding sources other than the General System of Royalties for the start of the implementation of the investment project of the Digital Manufacturing Laboratory at UFPS,

4. CONCLUSIONS AND FUTURE WORK

It is interesting that the curricular proposal is very academic, from the ideal world, from theories and scientific publications. On the other hand, the experience of formulating and awarding the investment project is more practical, more from the real world. And the FabLab manages to be that articulator to achieve the synergy to face Industry 4.0 from education.

FabLabs are much more than the traditional classroom laboratory, they are a learning environment that (following Bronfenbrenner's Ecological Systems Theory) allows the immediate (online) articulation of the University, the

productive sector and society. Students learn by doing real things that solve real problems and their learning is rigorous in theory and methodology, but also relevant and applicable in practice.

Due to the cost of a FabLab, it is difficult for a public university to implement it with its own resources. That is why it was necessary to bet on the OCAD/SGR call. And a successful experience was achieved by formulating the project and obtaining the required budget for the FabLab. For this it was necessary to appropriate the MGA methodology and move in the government ecosystem; without this, it is difficult to access state resources for CTeI.

In the future, it is expected to measure and evaluate the impact of the innovative curricular proposal in the teaching-learning processes and in the development results of the enterprises that bet on Industry 4.0.

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