ISBN: 978-628-96613-1-6. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2025.1.1.1910

Developing Research Projects on a Learning Factory – a Tool to Enhance Learning and Teaching

Armando Roman-Flores[1]; Enrique Cuan-Urquizo[2]; Carlos Vazquez-Hurtado[3]; Luis G. Castillo-Herrera[4]; Luis F. Macías-Duarte[5]; Daniel Robledo-Rios[6]; Saul Sandoval-Padilla[7]

[1,2,3,5,6,7] Tecnológico de Monterrey, School of Engineering and Sciences, Monterrey 64849, México, armando.roman@tec.mx, ecuanurqui@tec.mx, cvazquezh@tec.mx, a00227306@tec.mx, a01540363@tec.mx, daniel.robledo@tec.mx, saul.sandoval@tec.mx

[1,2] Tecnológico de Monterrey, Institute of Advanced Materials for Sustainable Manufacturing, Monterrey 64849, México, armando.roman@tec.mx, ecuanurqui@tec.mx

Abstract— A learning factory is a concept developed to mimic industrial settings for academic or consulting services. This environment offers the space where Industry 5.0 concepts can be understood through experiential learning. Interest in these settings has increased in recent years because of their potential to offer an enriched setting for engineering education, training, and research. This work aims to present a roadmap towards the development of a learning factory in academia, starting from the conceptualization of the idea, and recommendations for implementation based on previous developments by the authors. The proposed approach is described from planning, development to validation phases, and finishes with a discussion of lessons learned and useful best practices. This document also describes the experiences of developing projects for undergrad courses, capstone projects, research internships and graduate projects. Projects include work on additive manufacturing, collaborative robots, artificial intelligence, augmented and virtual reality, mechatronics, automation, to name a few. Some of the results obtained from these projects include obtaining grants, publications, conference presentations, collaboration with other institutions, and the development of entrepreneurships.

Keywords—Industry 4.0, Industry 5.0, educational innovation, active learning, Undergraduate Studies.

I. Introduction

In engineering education, a Learning Factory is an academic environment that replicates real industrial settings, enabling students to interact with advanced technologies in a teaching-oriented space [1]. This experiential approach effectively bridges the gap between theory and practice, allowing students to comprehend complex concepts while acquiring technical skills directly applicable in professional contexts. Moreover, the Learning Factory not only enhances technical proficiency but also fosters transversal skills, such as project management, teamwork, and self-management, as students engage in realistic, collaborative projects that demand strategic planning and effective communication [2].

With the integration of Industry 5.0, which emphasizes human-technology collaboration through advanced tools like collaborative robots, artificial intelligence (AI), and additive manufacturing, the Learning Factory has become an ideal platform for preparing students. This environment enables them not only to master emerging technologies but also to adapt to the increasing demand for customized, intelligent, and collaborative systems [3]. Such a pedagogical approach ensures that students experience the complete product lifecycle, from conceptualization to production and quality control, fostering a holistic understanding of industrial processes [4].

The evolution of the Learning Factory concept at the Tecnológico de Monterrey has progressed through three key stages. The first stage focused on establishing a basic production line, providing students with hands-on experience in automation, additive manufacturing, and collaborative robotics. The second stage expanded the scope to include research internships, where students developed innovative solutions such as soft robotic grippers and reconfigurable workstations. The newly introduced third stage emphasizes mechatronics project development, serving as the capstone experience for Mechatronics Engineering students. This stage encourages students to propose and execute self-directed projects within the Learning Factory environment, fostering not only technical proficiency but also critical soft skills like leadership, communication, and project management.

The global relevance of Learning Factories has also grown, leading to international interest in creating networks that facilitate collaboration across borders. This networked approach envisions institutions from different countries sharing projects, methodologies, and resources, ultimately working on joint ventures where components of a product are developed in different regions and integrated into a final solution collaboratively. This international perspective further enhances the educational value of Learning Factories, preparing students for the increasingly interconnected world of modern engineering.

This project aims to develop tools through experiential learning in a Learning Factory, specifically focusing on developing new ways to teach project-based techniques for Industry 5.0. The project includes developing a platform based on infrastructure that mimics a real work environment and a methodology that focuses on improving the manufacturing process. This paper provides a structured roadmap for implementing a Learning Factory, from planning to validation, and discusses key results and lessons learned.

II. METHODOLOGY

The concept of Learning Factory was applied as a pilot project to create a realistic, safe industrial environment where students could apply theoretical knowledge. Industry 5.0 technologies like automation, collaborative robotics, and additive manufacturing were incorporated, fostering experiential learning [5]. Based on early positive outcomes, the initiative was implemented by the authors in other universities, retaining a multidisciplinary approach with educational goals [2]. The factory operates as a based project model to ensure continuity and evolution of technology.

Since its inception, student groups have been integrated into term projects within this space, enabling continuous evolution in activities and the technologies employed. This model reflects principles established in prior research on Learning Factories as flexible and adaptable platforms [5], [6].

The use of agile project management methods allowed students to work in iterative cycles, receiving constant feedback from the partners. This approach ensured that students not only applied theoretical knowledge but also adapted to real-world challenges, such as optimizing production processes and managing resources effectively. The Learning Factory became a space where students could experiment with cutting-edge technologies while developing essential soft skills, including teamwork, leadership, and problem-solving.

The following describes the projects developed during the first two stages of implementation.

A. *Development of Academic Projects*

First Stage: Basic Production Line Setup

During the first term of implementation, a team composed of mechatronics students worked on integrating a basic production line that incorporated various advanced manufacturing technologies. This production line, as shown in Figure 1, features key components such as collaborative robots, conveyors, and additive manufacturing systems, which were programmed and configured to simulate automated production lines. The objective was to design a functional line that demonstrated the principles of an automated production chain. In this phase, students integrated:

- Automation: Handling components and controlling processes by integrating robots, conveyors, sensors, and actuators programmed with PLCs, following industrial automation standards [1], [6].
- Additive Manufacturing: Utilizing 3D printing to create customized components, such as grippers and anchoring systems, aligned with sustainability principles and design for manufacturing [3].
- Collaborative Robotics: Implementing collaborative robots for assembly and material handling, including their interaction with operators simulated by students [7].

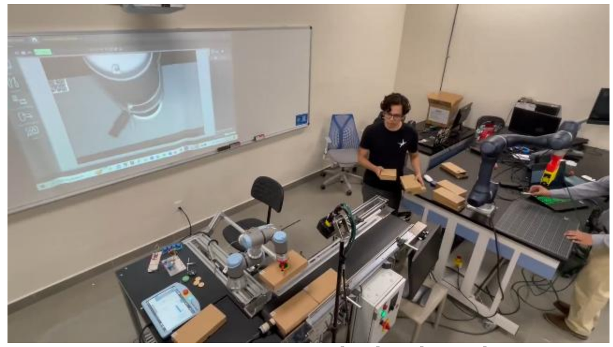

Figure 1. First stages: a simulated production line.

This phase introduced students to a realistic production environment, allowing them to experiment with industrial workflows and understand the interdependence of key technologies [8].

Second Stage: Research internships

In the second term of implementation, a more diversified approach was adopted, dividing efforts into four main projects, each with a specific goal and a central technology focus:

- Project 1: Collaborative Robot Gripper.
  Students designed and manufactured a "soft gripper" for a UR collaborative robot, as shown in Figure 2. This gripper, based on additive manufacturing and metamaterials, adapts to objects of different sizes and textures, improving the handling of complex and delicate parts [9].

Figure 2. Integration a "soft gripper" with a UR collaborative robot.

- Project 2: Adjustable Table with Tilt and Palm Axes.
  A team designed an adjustable table capable of tilt and palm axis adjustments to enhance user ergonomics across various work positions. This innovation allows the table to adapt to variable heights and angles, ensuring comfort and safety [10].
- Project 3: Reconfigurable Workbench with Interactive Mapping Guidance.
  A workbench equipped with interactive mapping technology was developed to guide users during assemblies via digital visualizations, as shown in

Figure 3. Automatic reconfiguration improves ergonomics and work efficiency [11].

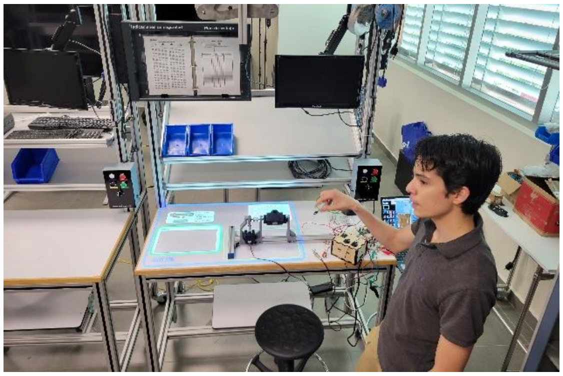

Figure 3. Interactive mapping system integrated with the reconfigurable workbench.

- Project 4: Mechanical Base for an Automated Guided Vehicle (AGV). Development of the mechanical base for an AGV included integrating the necessary elements for autonomous navigation and material transport. This project lays the groundwork for an automated logistics system within the Learning Factory [12].

Each of these projects addresses a unique set of technical skills while also fostering transversal competencies such as project management, teamwork, and self-management. Interdisciplinary collaboration promotes a holistic approach, emulating professional work environments where cooperation and effective communication are essential [13].

This project-driven model provides a flexible structure for incorporating new initiatives each cycle, continuously enriching the learning environment. Moreover, it ensures that students engage in relevant projects aligned with current industry demands.

B. *Project Planning and Monitoring*

Project planning and monitoring in the Learning Factory are managed through weekly sessions involving all team members, including students from various disciplines and academic levels, as well as project advisors and faculty members. These meetings play a fundamental role in organizing and advancing projects, as they ensure clear communication, establish shared goals, and collaboratively solve problems [2], [4].

Each weekly session is structured around the following key elements:

- Presentation of Work Progress: Students present the progress achieved during the week, enabling all team members to stay informed about the overall status of each project, as shown in Figure 4. This practice fosters transparency and facilitates the identification of significant milestones, ensuring that each phase of the project aligns with the general objectives of the Learning Factory [5]. Additionally, active feedback from advisors is encouraged, offering critical perspectives to adjust strategies in real time.

Figure 4. Weekly presentation in the Learning Factory classroom.

- Weekly Activity Planning**:** At the end of each session, specific activities for the following week are defined. This provides a clear work framework and enables students to set realistic and attainable goals, optimizing time management and ensuring an equitable distribution of responsibilities [1], [6]. This structured approach is based on agile methodologies, which promote iteration and continuous improvement, key characteristics for projects related to Industry 5.0 [3].

- Collaborative Problem-Solving: A central aspect of these meetings is the discussion of challenges or issues encountered during project development. By sharing these challenges with the group, participants can contribute ideas and innovative approaches to resolve them, as shown in Figure 5. The diversity of academic backgrounds and knowledge within the team is particularly valuable, allowing problems to be addressed from multidisciplinary perspectives [7], [8]. For instance, collaboration between students in digital design and mechatronics has resulted in more comprehensive and creative solutions for optimizing additive manufacturing processes.

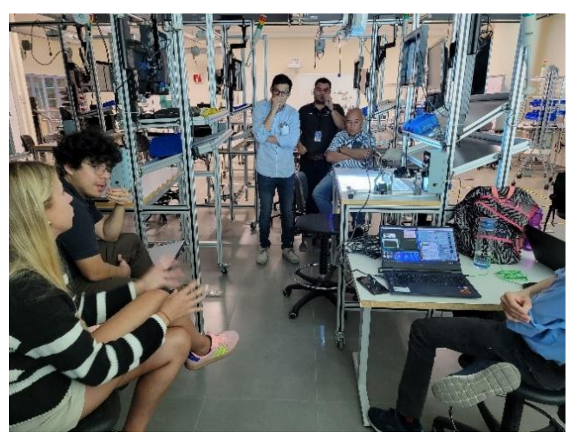

Figure 5. Professors and students from diverse disciplines collaborating to solve project challenges.

- Exploration of Emerging Technologies: In addition to reviewing weekly progress, these sessions include a dedicated space for the presentation and discussion of emerging technologies that could be implemented in the Learning Factory. Technologies such as virtual reality (VR) and augmented reality (AR) have been recurring topics, as they offer significant potential to enhance practical learning and the visualization of complex concepts [9], as shown in Figure 6. This innovation space allows students and faculty to explore tools that expand the capabilities of the Learning Factory and align its objectives with current Industry 5.0 trends, such as sustainability and human-centric approaches [10], [11].

Figure 6. Students testing a virtual simulation of a physical control plant using VR technology.

These weekly planning and monitoring sessions have proven essential for accelerating projects within the Learning Factory. They not only maintain workflow and ensure project continuity but also foster a collaborative and multidisciplinary learning environment that enhances both technical and transversal skills among students [12], [13]. Combined with the continuous exploration of emerging technologies, this approach ensures that the Learning Factory evolves in parallel with the needs of modern industry and technological advancements.

III. Results

The implementation of the Learning Factory has demonstrated multiple benefits, including: 1) the development of a structured roadmap for creating a Learning Factory that emulates an Industry 5.0 setting, 2) the establishment of guidelines for an academic approach that facilitates the introduction of abstract concepts through simulation and experimentation, and 3) the creation of an enriched platform that allows students to develop applied research projects with direct applications in industry. Although an important emphasis of these projects is on product fabrication, the primary focus of this work is to design a flexible infrastructure that can evolve over time and adapt to changes in production processes. This framework not only supports the understanding of Learning Factory principles but also helps identify potential gaps in current research.

The Learning Factory has matured into a space where students can apply technical knowledge in a collaborative environment, connecting various groups within the Tecnológico de Monterrey and other institutions. Over the first two terms, this space has become an interdisciplinary ecosystem for technological development, involving students from undergraduate and graduate programs, digital design, technical disciplines, and additional campuses [4], [14]. Notable achievements include:

- Internal Collaborations as an Innovation Ecosystem: One of the most significant outcomes has been the creation of a collaborative network within the Tecnológico de Monterrey. Weekly meetings now include the participation of postgraduate students and disciplines such as digital design, fostering the generation of innovative ideas and multidisciplinary solutions [2]. This model has allowed the Learning Factory to consolidate as an ecosystem that integrates technical and creative contributions to address industrial challenges with comprehensive approaches [5].
- Implementation of Multidisciplinary Projects: Projects span areas such as collaborative robotics, gripper design, and reconfigurable workstations, enabling the application of knowledge in additive manufacturing, automation, and simulation [6]. Collaboration across disciplines has enriched each project, leading to more robust and innovative solutions [1].

The Learning Factory has proven to be an effective environment for both learning and technological creation. Key benefits include:

- Establishment of a Roadmap as an Innovation Ecosystem: The Learning Factory's approach transcends its physical infrastructure, becoming a dynamic space that promotes technological development through collaboration between students, faculty, and external stakeholders [3]. This framework has enabled the definition of a clear roadmap for the evolution of the ecosystem into a reference model for applied projects [7].
- Facilitation of Abstract Concepts and Development of Self-Management Skills: This environment fosters self-management and time administration skills, facilitated by collaborative support among students, researchers, and faculty [8]. Students engage with advanced technologies while acquiring competencies such as effective communication and leadership, which are essential for modern industry [9].

Several key lessons and best practices have been identified during the implementation of the Learning Factory:

- Multidisciplinary Collaboration: The diversity of academic backgrounds and levels has enriched projects by addressing problems from varied perspectives, fostering more effective and innovative solutions [10], [11].
- Agile Methodologies for Project Development: These methodologies have enabled teams to quickly adapt to changes and maintain a structured focus on continuous improvement. They have proven essential for managing complex projects, especially in the context of Industry 5.0 [12].
- Exploration of Emerging Technologies**:** The integration of tools such as virtual reality (VR) and augmented reality (AR) has been fundamental for keeping the Learning Factory updated. These technologies have enhanced practical learning and the visualization of complex concepts, ensuring the space evolves alongside industry trends [13].
- Flexibility and Adaptability: The infrastructure at the Tecnológico de Monterrey has allowed students to test various configurations, fostering creativity and ensuring a safe environment for experimentation. This approach ensures the ecosystem can adapt to changes in educational and industrial demands [6], [14].

The Learning Factory has proven to be a valuable environment for both technical skill development and the strengthening of transversal skills. This ecosystem not only allows students to apply knowledge in realistic contexts but also fosters a culture of continuous innovation and experimentation. The lessons identified provide a solid foundation for its expansion and represent a replicable model for other institutions aiming to implement practical and collaborative engineering programs.

A. Quantitative Achievements

Scientific Publications: Three conference papers were published, showcasing the results of student projects developed in the Learning Factory.

- Student Involvement: More than 15 students from various engineering disciplines have participated, including international students from partner universities, enriching the learning experience through cross-cultural collaboration.
- Career Advancement: Several students have applied the skills developed in the Learning Factory directly in their professional environments. Examples include:
    - A student who joined an international company due to their experience working on an interactive mapping project, similar to the one they developed in the Learning Factory.
    - A student with a strong interest in research, inspired by their experience in the Learning Factory, who decided to pursue a graduate research position.

B. Qualitative Impact and Student Feedback

The Learning Factory has not only provided technical skills but also fostered an environment of freedom and creativity, where students can explore their interests in a collaborative setting. Key qualitative outcomes include:

- Collaborative Learning Environment: Students emphasized the value of having a dedicated space where they can work on projects, experiment with new technologies, and receive mentorship.
- Self-Directed Learning: Many students highlighted that the Learning Factory allowed them to guide their own learning process, exploring topics aligned with their interests.
- Positive Impact on Motivation: The experiential learning approach motivated students to take ownership of their projects, resulting in higher engagement and satisfaction.
- Research Pathways: One student was motivated to pursue a research career, demonstrating the Learning Factory's potential to nurture future researchers.

C. Qualitative Impact and Student Feedback

Compared to conventional educational environments, the Learning Factory offers distinct advantages, as shown in Table I.

TABLE I
TRADITIONAL LABS VS. LEARNING FACTORY

Aspect	**Traditional Lab**	**Learning Factory**
Learning Approach	Theoretical	Hands-on, Experiential
Project Scope	Pre-defined	Student-driven
Skill Development	Technical only	Technical + Soft Skills
Industry Relevance	Limited	High (Industry 5.0 focus)
Collaboration	Limited	Multidisciplinary (including international students)
Publication Opportunities	Rare	3 conference papers published

The Learning Factory also aligns with multiple United Nations Sustainable Development Goals (SDGs), providing a direct contribution to educational quality and sustainable development:

- SDG 4: Quality Education: The Learning Factory offers a practical, hands-on approach to education, enhancing students' understanding of advanced technologies such as collaborative robotics, AI, and additive manufacturing.
- SDG 9: Industry, Innovation, and Infrastructure: By integrating emerging technologies and promoting applied research, the Learning Factory fosters

innovation and supports the development of sustainable industrial practices.

- SDG 17: Partnerships for the Goals: International collaboration with exchange students and cross-disciplinary teamwork promote global partnerships, enriching the learning experience and fostering cultural exchange.

IV. Conclusions and Future Work

The Learning Factory offers a dynamic platform that bridges academic learning with real-world industrial applications. This setting not only facilitates technical skill transfer but also enhances essential professional skills like self-management and problem-solving [1].

The implementation of the Learning Factory in an academic setting has proven to be a dynamic and effective platform that enables students to apply their knowledge in a realistic context aligned with industry demands. This approach not only facilitates the transfer of technical knowledge but also promotes the development of essential practical skills, such as self-management, teamwork, and solving complex problems [4][14].

The Learning Factory functions as a collaborative ecosystem where students from diverse disciplines and levels interact with faculty, researchers, and other experts in a horizontal environment. This structure fosters innovation and creativity, motivating students to take an active role in their learning and propose technological solutions to address the challenges of Industry 5.0 [2], [5].

To maximize the impact and sustainability of a Learning Factory, it is essential that its physical and technological infrastructure be flexible and adaptable. This flexibility allows the space and its tools to meet the evolving demands of the industry and emerging academic needs [6]. Incorporating advanced technologies such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) is critical to maintaining the ecosystem's relevance while opening new areas for research and experimentation [1].

In summary, the Learning Factory has achieved significant milestones, including the successful development of interdisciplinary projects, the publication of scientific articles, and the creation of an innovation ecosystem that connects students, faculty, and industry partners. These achievements have had a direct impact on student employability, with several participants successfully transitioning to professional positions where they applied the skills acquired in the Learning Factory. To further enhance this initiative, future iterations should focus on increasing the number of international collaborations, expanding the diversity of technologies available, and implementing a structured evaluation framework to continuously assess and improve the educational impact.

To continue optimizing and expanding the scope of the Learning Factory, several areas of research and development have been identified that can strengthen this ecosystem as a learning and applied technology environment:

- Exploring Models of External Collaboration with Academia, Industry, and Government: As the Learning Factory matures as a collaborative ecosystem, the next step is to expand the network of external partners to include universities, companies, and government entities. These partnerships will enable addressing real-world challenges in the production sector while developing technological solutions that impact both industry and society [8], [9]. Additionally, such collaborations can facilitate larger-scale projects with a focus on sustainability and social innovation [11].

- Evaluating the Impact on Transversal Competency Development: Investigating how the Learning Factory contributes to developing skills such as leadership, effective communication, and problem-solving is proposed. Longitudinal studies could analyze the impact of these competencies on graduates' employability and professional performance [10], [12]. These analyses would provide valuable insights to refine pedagogical approaches and optimize teaching methods.

- Developing an Evaluation Framework for Continuous Innovation: Establishing an evaluation framework would enable the continuous monitoring, analysis, and adjustment of methodologies and technologies applied in the Learning Factory. This system could include feedback from students and faculty, as well as key performance indicators tailored to each project. Implementing this framework would ensure the ecosystem's relevance in an ever-evolving industrial and educational environment [13].

- Implementing Augmented and Virtual Reality in Educational Experiences: Given the interest in immersive technologies, it is suggested to explore how virtual and augmented reality can enhance the learning of complex engineering concepts. Simulations and interactive scenarios could improve knowledge retention and facilitate understanding of advanced principles, offering students innovative tools to address Industry 5.0 challenges [1], [11].

- International Collaboration: The work developed within the Learning Factory has attracted the interest of researchers at the Tecnológico de Monterrey, as well as from other academic institutions with which the university maintains international collaborations [1], [2]. This interest has led to the pursuit of opportunities abroad for students to participate in research stays and international collaborative projects [5]. Currently, agreements are being explored with universities in other countries to provide students with global experiences that complement their technical and project management training in advanced industrial settings [3].

Moreover, the Learning Factory methodology implemented in this project is gaining recognition within the global educational landscape, establishing itself as an innovative model for engineering education through experiential learning [14], [7]. As a future objective, the creation of an international network of Learning Factories is envisioned, enabling the sharing of projects, methodologies, and best practices among institutions from different countries [6]. This collaborative ecosystem would not only facilitate knowledge exchange but also foster joint product development, where each learning center would contribute to a specific part of the design or manufacturing process, with final integration carried out at another center [8]. This initiative aims to leverage the strengths of each institution, promote innovation, and provide students with the opportunity to engage in high-impact international projects, reflecting the dynamics of today's global industry [11].

These initiatives will strengthen the Learning Factory as an adaptable and relevant environment, fostering engineering education deeply connected to the needs and transformations of academic, industrial, and governmental contexts [10]. With these efforts, the Learning Factory will consolidate itself as a leading space for practical education and the development of applied technology [12].

- Third Stage, Mechatronics Project Development: The third stage of the Learning Factory project focuses on the development of mechatronics projects by students, serving as the capstone phase of the Mechatronics Engineering program at the Tecnológico de Monterrey. This stage aims to enhance and test students' project development skills, providing a framework for applying their acquired knowledge through self-proposed projects [1], [2]. The Learning Factory ecosystem in this stage encourages students interested in developing their capstone project within the space to propose their ideas under the Learning Factory framework and carry them out with the support of peers from other semesters who are also working in the space [3], [5]. This collaborative environment not only enables students to demonstrate their technical skills in mechatronics but also helps them acquire and test essential soft skills such as leadership, communication, resilience, resource management, and project planning [6], [7]. By fostering a multidisciplinary and collaborative setting, the Learning Factory becomes an ideal platform for students to develop comprehensive engineering solutions while preparing them for the demands of modern industry [8].

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