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Experiential Learning for Industry 4.0 in Higher Education: A Challenged-Based Learning Case Study

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ABSTRACT

Organisations and institutions worldwide know the need for trained workers to handle future workplace challenges. This assertion focuses on the growth of digital literacy and abilities known as digital transformation competencies. Universities, employers, governments, and institutions recognise an existing gap in the students' education about developing, utilising, and implementing new technologies. The contribution of this work is to present an educational innovation case study in which students used and customised Industry 4.0 technologies. The undergraduates designed an assembly line with a collaborative robot and real-time data-accessing dashboards with an Overall Equipment Efficiency (OEE) indicator. Students start the experiential learning process by time and motion studies and designing workstations. Digital tools helped to track assembly line availability, efficiency, and quality in real time, demonstrating the positive impact of a collaborative robot on production. By introducing Industry 4.0 into the industrial engineering curriculum, students can improve their digital tools knowledge, problem-solving, teamwork, and communication. This study provides future directions for students' activities incorporating more technologies and digital enablers in Industry 4.0.

Keywords: Higher Education, Educational innovation, Human-robots collaboration, Digital transformation, Industry 4.0.

INTRODUCTION

Service and manufacturing companies seek to increase their efficiency and flexibility in the face of client demands and high competition. Digital transformation allows connectivity and efficiency in organisations by providing real-time data for decision-making (Simões *et al.*, 2022). Due to the accelerated changes in the last years, managers started to shift towards the digital transformation of their processes (Cimini *et al.*, 2020), not only questioning how to deliver new innovative products and services with a higher added value; but more about how to integrate human factors and capabilities (cognitive, physical, sensory, and team dynamics) into a production or service system (D'Addona *et al.*, 2018). In Industry 4.0, digital technologies have revolutionised manufacturing and production techniques by developing and adapting technologies for collaboration with people (Romero & Stahre, 2021). To have flexible production systems that can meet the increasing demands, manufacturing companies have directed their efforts to these changes (Cimini *et al.*, 2020). Technological developments have a high impact on people to achieve innovative experiences and solutions in production environments.

To be able to face these changes, it is essential to have people with digital skills for these new jobs. To develop new skills, some authors propose learning spaces for developing digital transfer in universities (Bygstad et al., 2022); (Mohamed Hashim et al., 2022). A student who develops these skills can participate in digital environments and understand the importance of their digital identity.

The main challenge for teaching Industry 4.0 is to define the specific digital transformation skills required to recruit new employees (Morgan, Sibson, and Jackson, 2022). Companies should understand the current level of digital competencies of their labour force, how to develop digital competencies in the workforce to increase the use of new technologies and human-robot collaboration, and the minimum requirements for people with the necessary skills to take on the challenge of digital transformation. In addition, training new professionals to integrate these technologies is essential to correctly implement Industry 4.0 in companies (Koyuncuoğlu, 2022).

Faced with these changes, the increased demand for people to obtain and develop digital skills is essential for current and future jobs (World Economic Forum, 2016, 2020). Digital transformation is looking to find solutions to the problems in its field with the intelligent and timely incorporation of cutting-edge digital technologies (Tecnológico de Monterrey, 2019) (Tecnológico de Monterrey, 2018). Current challenges, such as the integration of individuals in a globalised world, technological advancements, and the demand for new skills in the market are leading to the transformation of higher education institutions and the creation of new educational models (Tecnológico de Monterrey, 2021) (Olivares Olivares *et al.*, 2021).

METHODOLOGY

This research was developed in an experiential learning space using Challenge-based Learning and Competency-based Education. Figure 1 shows the steps in the design for a Digitally enabled Learning Experience.

The first step was to define the learning experience research, learning outcomes, and learning objectives. As a result, the student can apply the knowledge acquired during his career designing, analysing, and improving production processes through fieldwork experience. Next, a Digitally enabled Learning Experience was considered with a collaborative robotic arm and a digital Andon system. Furthermore, this step included the basis of the digital transformation context and learning space by transitioning from manual workstations and manual data-gathering registers to the implementation of digital equipment and ergonomic improvements. The final step

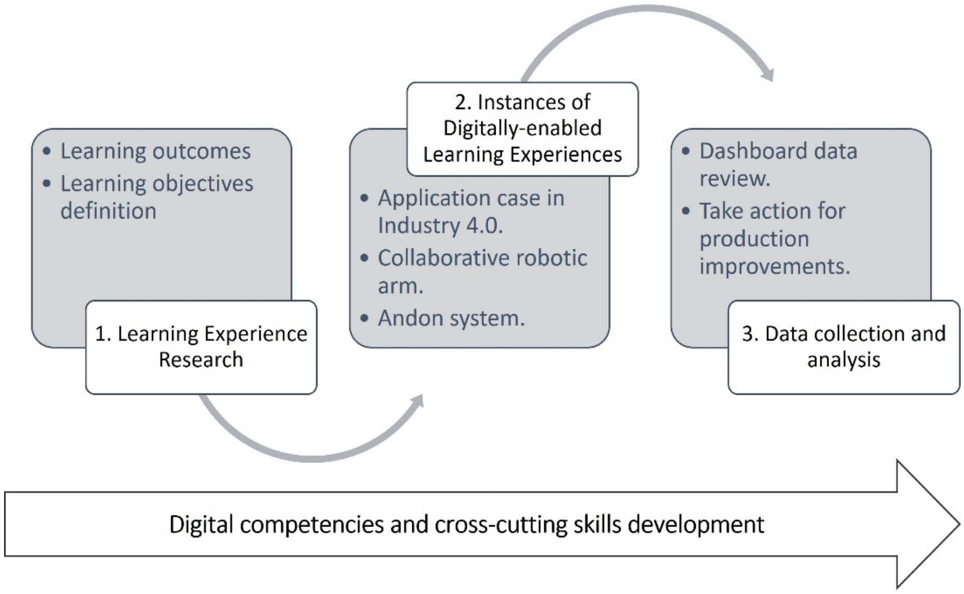


Figure 1: Methodology design for a Digitally enabled Learning Experience. (Adapted from Salinas-Navarro et al., 2023).

considered the digital transformation of processes and operations within the learning space, working in multidisciplinary teams using digital technologies to impact operational results in quality, efficiency, and availability. The students used different technologies, enablers, and tools to act for production improvements.

LEARNING EXPERIENCE: A HUMAN-ROBOT COLLABORATION CASE OF STUDY IN DIGITALLY ENABLED LEARNING SPACES

The methodology described in Figure 1 was developed in a senior-year Industrial Engineering course named IN3038 Operational Design and Optimization Laboratory (SAMP | Tecnologico de Monterrey, 2022). Sixteen undergraduate students designed and participated in a challenge to create a production process in two phases, the first one through manual assembly and the second customising, adjusting and implementing a digitally transformed assembly line design.

Phase one includes the production process design and assembly, structured in three stages: *i)* preparation, *ii)* standardisation and *iii)* transformation into a pull production system. These three phases are based on an experiential learning space named *Lean Thinking Learning Space* (Garay-Rondero, Rodríguez Calvo, and Salinas-Navarro, 2019). Furthermore, this work proposes applying a case study in **Phase Two** by implementing a *collaborative robotic arm* and a *digital Andon system*. These technology enablers allowed the development of the student's learning experience through the implementation and use of real-time dashboard information and human-robot collaboration, transforming the production line and process into a ***Digitally***

Figure 2: Assembly products used in the case of study: three different car side lamps.

enabled Lean Thinking Learning Space (Salinas-Navarro, Garay-Rondero, and Arana-Solares, 2023).

The production process consisted of three different family products of car side lamps. Each type with different shapes, sizes, and components or stock-keeping units (see Figure 2).

During Phase 1, students organised the workstations for the manual assembly process using scissors, screwdrivers, and an ink stamp. The process started with marking and cutting identification cards for packaging car side lamps and assembling the product. Afterwards, the assembly process for the packaging box took place. Then, the product was placed in the box along with the identification card; finally, the box was ink stamped.

Students applied their knowledge about time study and movement measures to obtain each activity's standard time. The results were as follows: marking and cutting 45.11 sec; lamp assembly 46.01 sec; box assembly and packaging 42.75 sec; and box stamping 12.03 sec.

The production run, batch, and shift took place every 30 minutes. Students performed a team back and rapped-up at the end of each round to study and present a manual report about the production results regarding safety and Key Performance Indicators (KPI) on the production line. Furthermore, they investigated each workstation observing the most relevant ergonomics factors such as seating postures and tools used in the workplace within reach of their hands. During this first phase, no defective parts were reported. The final cycle time, considering the manual operation was 55 seconds.

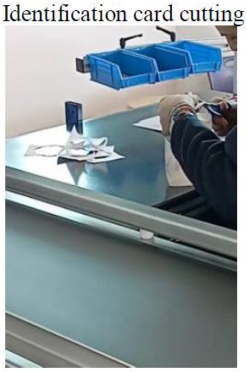
The experiential learning objective during this phase was for students to apply their knowledge, abilities, and values to make decisions to generate incremental improvements within the production process and observe their learning process and performance when a problem is being solved. The application of lean manufacturing tools aided this learning process. Figure 3 shows the comparison between the beginning of Phase 1 and how students changed the production process through the stages of improvement to Phase 2 and digital integration.

During the box assembly and packing time, the collaborative robot arm helped the third workstation, leaving only three activities (see Figure 3). The standard time was reduced due to the application of the pull system and lean manufacturing strategies, in addition to the implementation of technologies and digital enablers that helped to transform activities and their performance in the car lamp assembly line.

The initial stage in Phase 1: One workstation performs the entire activity.

Phase 2: Pull system assembly line and digital transformation implementation.

Station 1. Identification card cutting



Station 2. Product assembly

Station 3. Box assembly and packing.

Station 4. Batch stamping in box packaging-collaborative robot arm station and Andon system.

Figure 3: Evolution from Phase 1 - initial stage to Phase 2 - assembly line and digital transformation.

The following section describes the findings and discussion of the KPI and students' perceptions.

FINDINGS: COLLABORATIVE ROBOTIC ARM AND A DIGITAL ANDON SYSTEM IMPLEMENTATION

By implementing a collaborative robot and a digital Andon system, the conventional production line was transformed into a digitalised one, and

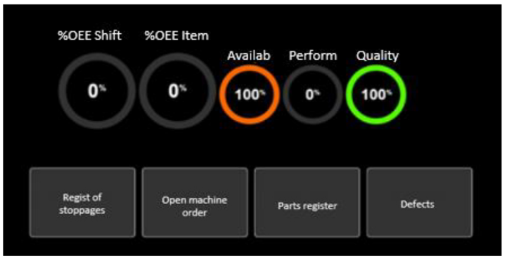


Figure 4: Digital Andon system-OEE dashboard results.

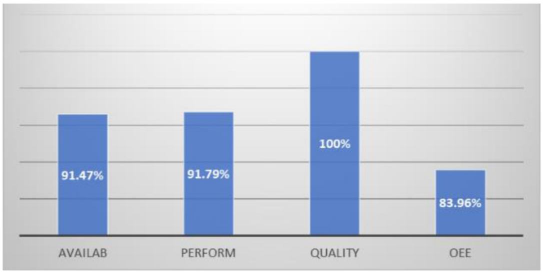


Figure 5: Overall Equipment Efficiency results: last production run.

the student's learning experience into a Digitally-enabled Lean Thinking Learning Space (Salinas-Navarro, Garay-Rondero, and Arana-Solares, 2023). During the digital Andon system implementation in Phase 2, each station had a tablet (hardware) and system interphase with the cloud (software) to gather relevant data and information during the production runs. The main objective was to determine the Overall Equipment Efficiency (OEE) KPI (see Figure 4). Each operator was responsible for registering stoppages and types, orders, Stock Keeping Units, parts, defects, and other additional information. The system recorded the data in the cloud to deliver OEE and other real-time information to tablets and dashboards visible in the production line.

Students paused at the end of each production run or 30-minute work shift to review OEE reports showing availability, efficiency, and quality. Then, before the next production run or the following shift, they decided which adjustments and changes were needed to improve the OEE indicators. This process is based on Digital Lean Manufacturing or Lean 4.0. Digital technologies support lean practices more than other technologies, and it is essential to understand these different implications over time (Cifone *et al.*, 2021). The reports generated by the OEE system are shown in figure 5.

CONCLUSION

This study proposes experiential learning research carried out in a Mexico university within the case study for the digitalization of the Lean Thinking Learning Space laboratory. The main findings present the results of implementing a human-robot collaboration within an Industrial Engineering Higher Education course in the context of a cutting-edge Learning Model with Challenge-based Learning and Competency-Based Education as pillars. Additionally, active and experiential learning proposes an innovative way to generate experience to develop digital transformation competencies and transversal skills for future generations. Future research aims to develop and provide more case studies implementing digital enablers around Industry 4.0, incorporating the concepts of Society 5.0, thereby gathering, measuring, and analyzing students ‘competencies.

The main contribution of this research work is to provide practitioners, academics, and learners, with new ways to teach and obtain knowledge in the era of Education 4.0 towards enhancing the students towards a more equitable and inclusive world technology at the service of humanity straight to the construction of a Society 5.0 (Holroyd, 2020).

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