Teaching Industrial Engineering Through Simulators Based on Gamification and XR Reality

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Abstract: The effective integration of gamification in industrial engineering education is increasingly gaining attention for its potential to enhance student engagement and learning outcomes. At Tecnologico de Monterrey, we seek new and innovative activities to improve the learning process. This research shows the results in three years of teaching with the MxREP ERP, Quality, Statistics, Project Management, and Data Science, implementing gamified classroom activities within the Industrial Engineering Department, focusing on using Enterprise Resource Planning (ERP) system simulators. These simulators are complemented by data visualization tools, project evaluation software, and lessons incorporating augmented and virtual reality (AR/VR) technologies. The primary objective is to assess how these tools influence students' learning experience and academic performance. The simulators utilized in the program replicate real-world ERP systems, providing a hands-on approach to understanding complex business processes and decision-making scenarios. Through interactive simulations, students can apply theoretical knowledge in controlled, risk-free environments, thereby reinforcing their comprehension of ERP systems' functionalities and interdependencies. Data visualization tools further supplement this learning by enabling students to analyze and interpret large datasets, fostering critical thinking and analytical skills essential for industrial engineers. Project evaluation tools embedded within the curriculum offer students the opportunity to manage and assess the progress of simulated projects. These tools are designed to mimic the project management challenges faced in the industry, encouraging students to develop strategic planning and resource management skills. The incorporation of AR/VR lessons Berglund (2023) adds an immersive dimension to the learning experience, allowing students to explore virtual factories, conduct virtual inspections, and interact with digital twins of industrial systems. This technology enhances engagement and provides deeper insights into system operations and problem-solving techniques.

Keywords: Higher education, Educational innovation, Gamification, MIX reality

1. Introduction

In 2019, prior to the COVID-19 lockdowns, a need was identified to create learning experiences more closely aligned with the realities of daily operations in a manufacturing company. This was to enhance the impact of learning on students, ensuring it extended beyond purely theoretical knowledge. The TEC20 academic model was designed to transition from a project-based and knowledge-assessment model to a competency-development model. At the core of this new model was the development of challenges, defined as problem-based scenarios designed by a "partnering stakeholder" (an external agent from outside the university). These stakeholders, in collaboration with professors, establish the framework for competency development that enables students to solve the challenges.

2. Development

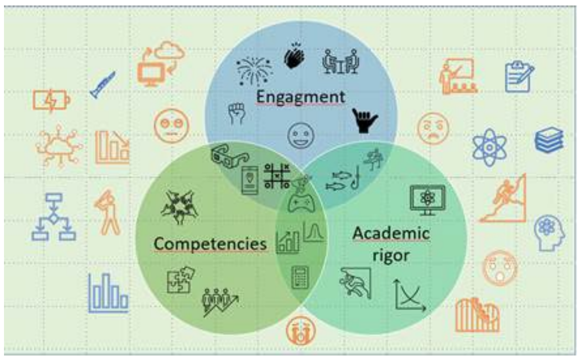
In 2019, engaging with companies for facility visits, process analysis, or securing real-world or realistic projects was challenging. Limitations included space constraints (visits capped at 15 students for groups of 35) and process confidentiality. Consequently, professors often resorted to adapting cases for instructional purposes. Industrial Engineering, a field integrating techniques and methodologies from mathematics and statistics, equips students to identify, modify, and manage parameters for operational excellence in manufacturing. However, some Industrial Engineering topics become theoretical and lack practical application due to the absence of real-world problems or lab-based experiential learning. This can lead to student disengagement, distraction, and loss of interest, necessitating a blend of active, realistic, and captivating exercises. The Department of Industrial Engineering and Systems at Tecnológico Campus Querétaro initiated two key strategies. First, an "Integrative Workshop" was implemented at the end of each semester, involving multiple departmental classes in a day-long project. Second, a board game was developed to simulate processes within an assembly company, from customer order placement to final product delivery. The game, designed to be flexible and adaptable to individual professor's classes, centered on assembling a Meccano car within fifteen minutes to allow for sufficient learning iterations. Gonzalez et al (2022)

2.1 Impact of Confinement

The COVID-19 confinement accelerated the need for virtual assembly and manufacturing labs and plants. However, the initial months revealed a noticeable decline in learning outcomes across both educational models. Previously undetected restrictions emerged, including student isolation, stress from lack of social interaction, boredom, excessive screen time, and workload. Summer 2020 saw a hybrid development combining the Tec21 car assembly with a digital environment using augmented reality (AR) on the EON XR platform. However, material explosions, line capacity calculations, and statistical process control/forecasting were conducted in Excel and Minitab. While providing a robust learning platform, this approach overwhelmed students, leading to negative perceptions of the lesson. Learning occurred, and the AR platform was accessible; however, student confinement hindered teamwork, transforming multidisciplinary projects into aggregated individual efforts with fragmented learning. This context led to the development of the Tec21 virtual car assembly plant: an online computer game simulating professor-designed scenarios using a Meccano car assembly. This platform integrates AR and virtual reality (VR) practices for the modeled assemblies, incorporating gamification for individual or team-based problem-solving. Prior to the summer, the R&EIT educational innovation research team employed undergraduate research fellows. Despite their talent, these students exhibited a tendency for distraction through mobile phone use. Some professors perceived technology as a distraction rather than a learning tool. A survey in Summer 2021 assessed students' weekly gaming hours and classroom gamification activities. Recognizing the emotional impact of student confinement and the potential of gamification in simulators and virtual plants, R&EIT explored readily available AR lessons. EON XR lessons were adapted to the board game models. Concurrently, projects were launched to create proprietary VR/AR lessons based on the physical Meccano car models, which were being 3D-modeled in Autodesk's Fusion 360 platform.

2.2 Theoretical Framework

According to Alex Games (2014), play is the primary mode of learning, involving experimentation, iteration, and pattern recognition within a trial-and-error loop to develop winning strategies. Addressing concerns about student emotional well-being, academic quality, and competency development (transversal and disciplinary), a methodology was implemented. This methodology proposed by Gonzalez et al (2021) combined design of experiments and design thinking to identify a "success zone" in design, defined by the intersection of three key variables: engagement, competency development, and learning. Abstract concepts were mathematically represented as measurable variables to pinpoint the optimal learning environment. Designs were then focused on achieving results within this zone, ensuring gamification success (Figure 1).



	Outstanding	Solid	Basic	Incipient
	100	80	70	60
High	a	a	a	a
	b	b	b	b
	c	c	c	c
Medium	a	a	a	a
	b	b	b	b
	c	c	c	c
Low	a	a	a	a
	b	b	b	b
	c	c	c	c

Figure 1: Design Thinking and Design of Experiments Methodology for academic lessons

Education often conflates gamification, serious games, and game-based learning. This confusion stems from serious games and game-based learning utilizing games as a foundation for motivating learning. Gamification in education strategically incorporates game design elements to enhance learning within a specific discipline. Key elements include immediate feedback, points systems, motivation to win, recognition, and the freedom to make mistakes and retry. (Deterding 2011) (Kim 2015) Serious games are technology-driven designs with a defined learning purpose beyond mere entertainment. They are intentionally designed for educational objectives, encompassing our simulators and VR/AR practices for modular learning in Industrial Engineering (Figure 2).

Serious games can be described as purposeful games aimed at addressing real-world problems in controlled, life-emulating environments. While they can be enjoyable to boost engagement, entertainment is not their primary goal. (Wouters et al 2013). Game-based learning uses games as instructional/learning tools, representing learning through games within a professor-designed educational context. These are typically existing games with defined rules, designed to balance entertainment and player skill in retaining concepts. (EdTec Review 2013)

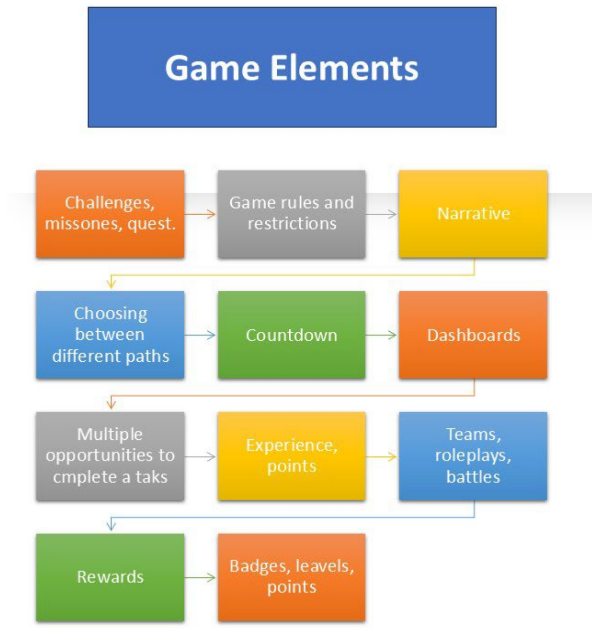


Figure 2: Game elements used in the MxREP Simulator

3. The MxREP Simulator Development Process

The MxREP simulator facilitates learning across Industrial Engineering disciplines using a Meccano car assembly plant that replicates ERP system processes. It leverages a robot ("Chencho") to optimize variables across departments for maximum company profits. The simulation is accessible online and supports teamwork. Existing manufacturing process simulators often lack product visualization. Emulating SAP processes is easier with products using three or four row materials, which doesn't expose students to the complexities of real-world bill of materials management in car manufacturing. VR/AR lessons bridge this gap, providing students with the experience of visualizing car assembly component by component.

3.1 XR Technologies

Augmented reality (AR) overlays digital information onto physical environments, using devices like smartphones. Given the widespread smartphone ownership among engineering students, AR is a democratizing technology for delivering educational content. Virtual reality (VR) immerses users in digital simulations where they can manipulate objects and interact with the environment. VR's educational limitations include the need for specialized equipment (VR labs) and a focus on collaborative rather than individual work due to time/space constraints. Mixed reality (MR) combines AR and VR, projecting digital environments onto the user's real-world surroundings via devices like headsets. A PwC study, "What does virtual reality and the metaverse mean for training?", investigated post-COVID-19 employee training and learning challenges. The study highlights the dilemma of remote and hybrid work's impact on upskilling: "Employers are facing a dilemma: Their workforce often needs to learn new skills, upgrade existing capabilities or complete compliance training. Yet the new reality of remote and hybrid work has made traditional, in-person upskilling more challenging. Online and app-based courses can fill in some gaps

but not all. So how can employers deal with this challenge?" The PwC study indicates that VR training enables employees to learn four times faster, feel 275% more confident in applying their knowledge, and experience 3.75 times greater emotional connection to the learning process.

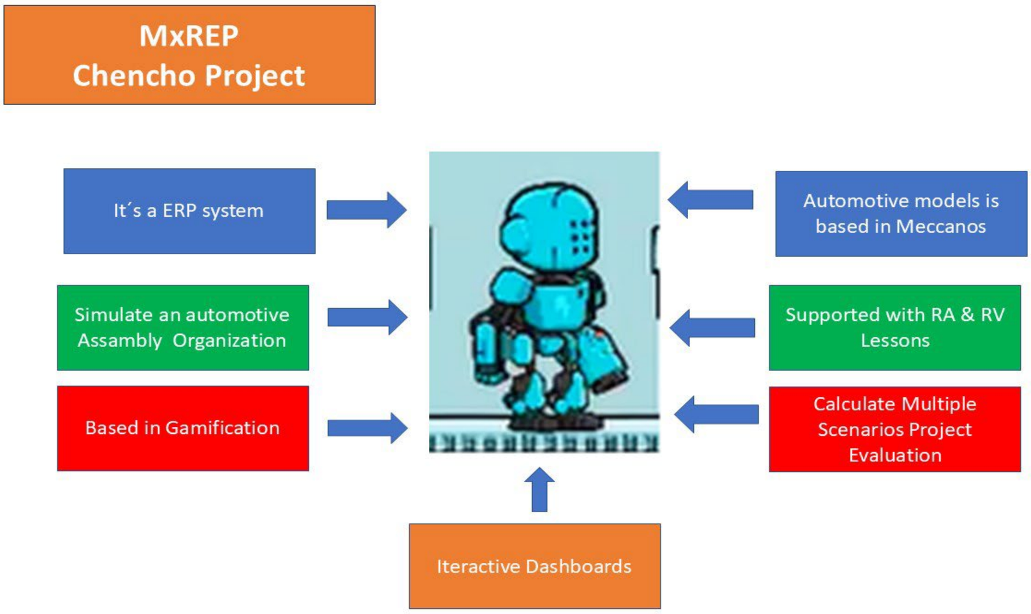


Figure 3: The MxREP Futures deployment in the simulator rounds

3.2 How MxREP Works in the Industrial Engineering Learning Process

The MR REP simulator (Figure 3) aims to accelerate the learning of complex engineering topics through lessons designed for three learning domains:

- In-depth product knowledge (geometry, bill of materials, mechanical interactions)
- Layout design, material flow definition, assembly strategies
- Quality principles through problem-solving lessons using the 7 quality tools or DMAIC.

The simulation lets the users manage and control a virtual manufacturing company, being in control of the different inventory, processes, employees and orders. Taking a hands on approach to optimizing the construction and completion of the orders in a safe and test-focus environment.

Starting with the simulation the users can find themselves in the first area where they can manage the raw materials used for the construction and assembly of the vehicles.

3.2.1 Raw material

Users will be able to manage their resources, order materials from different suppliers and manage their inventory. This will enforce the strategizing abilities and their organization; maintaining the necessary logistics of all the materials needed for the production of different products. With this, the users can plan the logistics of the different orders, maintaining the necessary stock and reducing costs or having excess inventory.

3.2.2 Employees

To create all the necessary products, the user can't do it on their own, so getting some help is essential to finish all orders in time. To do that there is a panel to hire and manage employees, assigning them to different areas or phases in the production line. This generates a cost, time implication and essential workers that needs to be taken into account when planning orders and managing production.

3.2.3 Fixed assets

The last panel is for managing fixed assets. These will help the user acquire certain tools that will help them improve productivity, quality or increase production. Creating a goal for the user to grow and increase the efficiency of the company as much as possible and be able to generate lots of money while cutting costs.

3.2.4 Production flow

The simulation gives the opportunity to manage orders for different products with an expected delivery date. For that reason the player should be ready with all the materials necessary prior assembly, or order them as soon as possible to avoid delaying the delivery (Figure 4). Followed by the activation of the production lines necessary to process the raw materials into the finished product and get a return of investment with profit. This will conform the basic flow of actions a player must follow on an everyday basis analogy, but progress is key to maintain entertainment and investment of users, so the fixed assets available for purchase and the always improving efficiency of the factory will be making the player come back into the simulation and use the topics learned in class to optimize the production and increase earnings as much as possible.

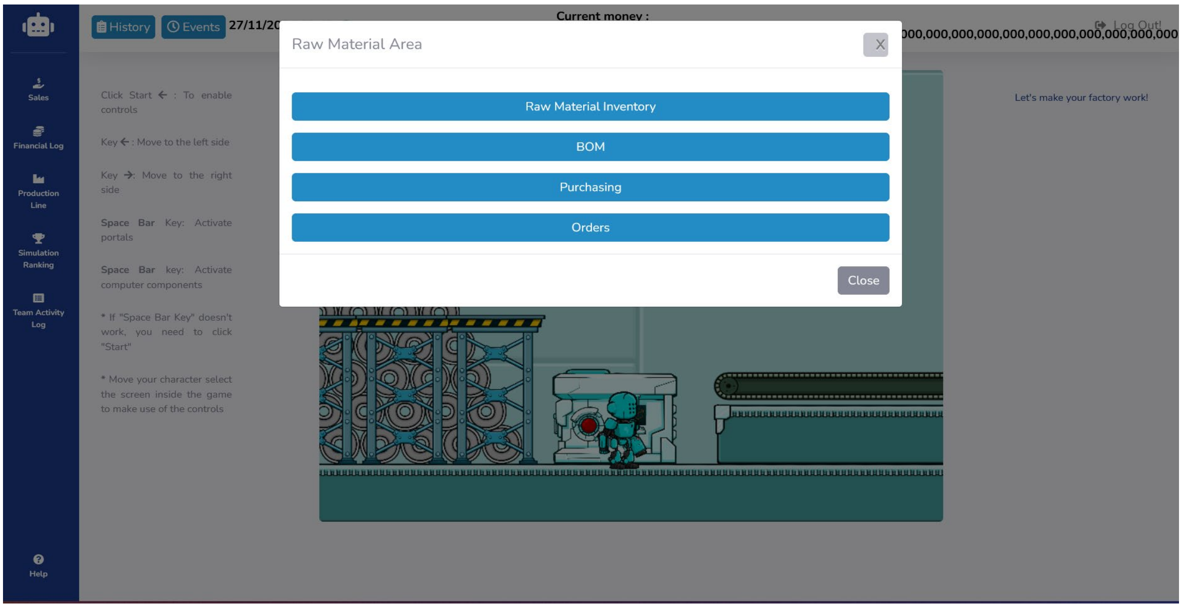


Figure 4: Raw Material Area menu with inventory management options

3.2.5 Sales

In this tab, users are able to view and manage their product sales data. The interface will show a table with various entries, which include data such as the product name,cost, and the final price, allowing the student teams to monitor their revenue performance and make strategic business decisions based on product profitability. Just as in real life scena.

3.2.6 Financial Log

The Financial Log tab gives the user detailed visibility into their organization's cash flow activities. The user is presented a structured data table with filtering capabilities that allow users to segment financial records by transaction type (Expense) and status (Purchasing Raw Material), alongside a date range selector (November 1-30, 2024) for temporal analysis. The main data display is designed to present transaction details across multiple dimensions, including Type, Status, Date, Before Amount, Amount Expense/Income, and After Amount, effectively tracking the financial impact of each operation within the simulation. The user can also toggle between a data table view and a graphical representation, supporting both detailed transaction analysis and trend visualization to help student teams make informed financial decisions and manage their simulation budget effectively (Figure 5).

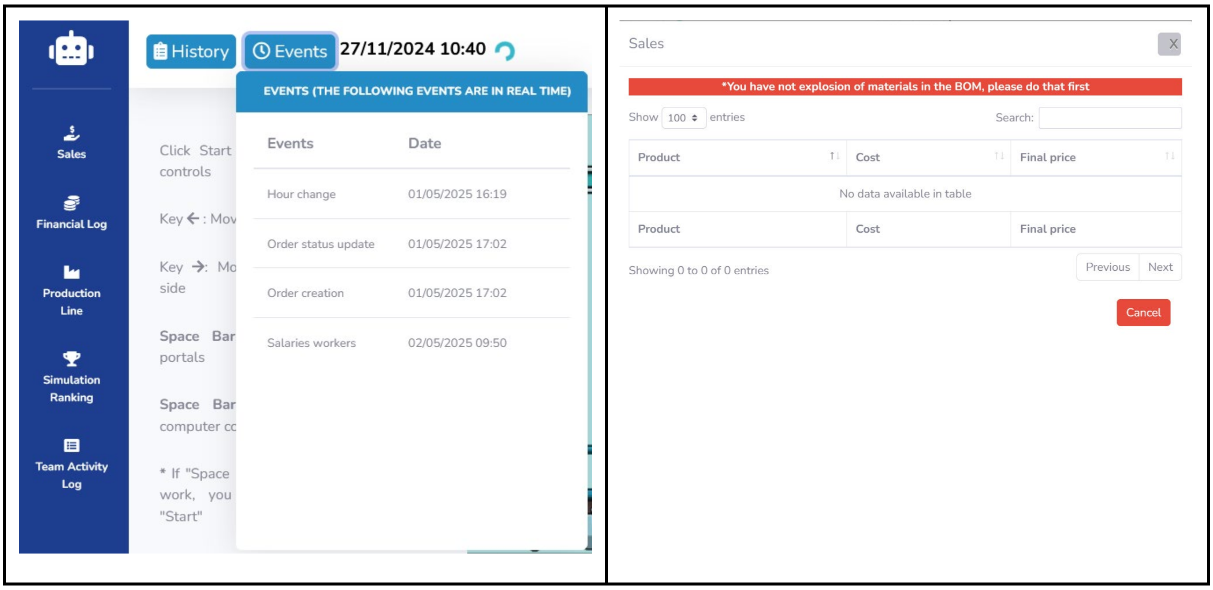


Figure 5: a) and b) Real time events calendar with upcoming factory operations and sales tables awaiting BOM

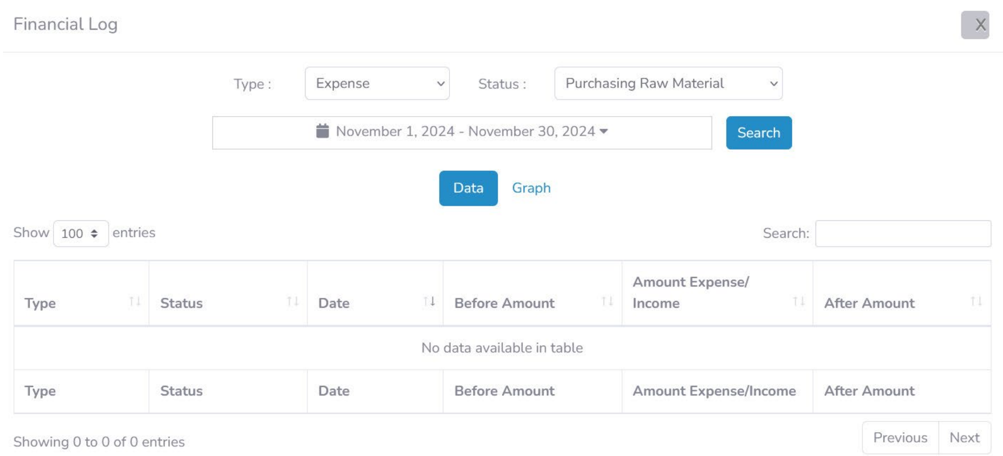


Figure 6: Production Line Tab, Six-step F1 manufacturing workflow interface

3.2.7 Production line

The production line tab (Figure 6) allows users to configure and activate different production workflows. The interface displays available production line templates (in this case F1, Buggy, and DRON) on the left, while the main section shows detailed configuration options for the selected template. For the F1 production line, the system has a six-step manufacturing process representing a complete vehicle assembly workflow. Users can specify resource allocation by defining quantities of both fixed assets (specialized control and marking machines) and human resources (employees) required for production operations. This production line tab helps student teams to make strategic decisions about production capacity, resource utilization, and manufacturing processes.

3.2.8 Simulation ranking

The simulation ranking tab is meant to increase competitiveness inside the simulation, improving the engagement the students have with this application. It provides users with a clear visualization of their team's standing relative to other participants. This is an important gamification element added to the learning experience.

3.2.9 Team activity log

The team activity log tab serves as a monitor system for the students, users can filter activity by the type (Simulation, Finance, BOM, Purchasing, Raw Material, Employees, Production Line, Sales, Ranking, and Orders) inside the left panel, select specific team members for a focused analysis in the center panel, and also view detailed timestamped activities on the right panel. This tab serves as both an accountability tool and a historical record of team operations (Figure 7). This collaborative transparency enables teams to coordinate their efforts, maintain awareness of actions taken by teammates, identify potential workflow bottlenecks, and analyze patterns in team member engagement.

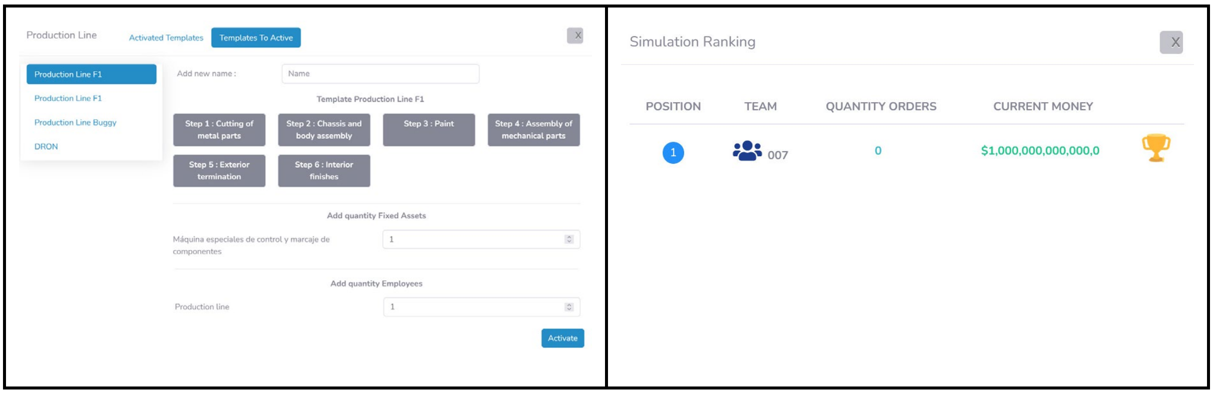


Figure 7: a) and b) Financial Log Tab, financial transaction tracker with type/status filters. Simulation Ranking Tab, team leaderboard showing position and assets

3.2.10 Collaboration

This simulation allows and promotes team building and collaboration of different users to complete all tasks in the factory, allowing for specialization in certain areas, community and a common goal that can bring people together, or allow for friendly competition amongst a classroom. This is not only to improve social and communication skills, but to create a share experience environment, letting the students help each other on different topics.

4. Results

Over the past 5 years, we have implemented the virtual plant an average of 9 times per year in different learning units (UF) within Tecnológico de Monterrey, every UF has two groups, every group average 31 students. In the last 3 years, we have introduced various improvements, such as distribution centers for the logistics module and more products that can be assembled (e.g., drones), which has increased our capacity to impact a larger number of students. For this research, we present the results implemented in the latest learning unit for the Industrial and Systems Engineering program, involving two groups of 26 and 29 students. Both groups had to solve a problem-based scenario focused on designing a drone manufacturing plant, requiring them to learn how to calculate line capacity and design the plant layout with the total number of machines and employees.

A pre-test was developed, consisting of 20 questions randomly selected from a pool of 50. Subsequently, the students completed the entire exercise, which included hands-on practice with physical drones, followed by using the simulator and accessing the virtual and augmented reality lessons. The results are presented below Figures 8 and 9.

Statistics

Variable	Total Count	Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Range	Mode
Pre Test	25	67.60	16.78	45.00	50.00	70.00	80.00	95.00	50.00	45, 50
Post Test	25	92.20	9.58	65.00	85.00	95.00	100.00	100.00	35.00	100

Variable	N for Mode
Pre Test	4
Post Test	12

Figure 8: Descriptive statistics of the Pre Test y Post Test escenarios

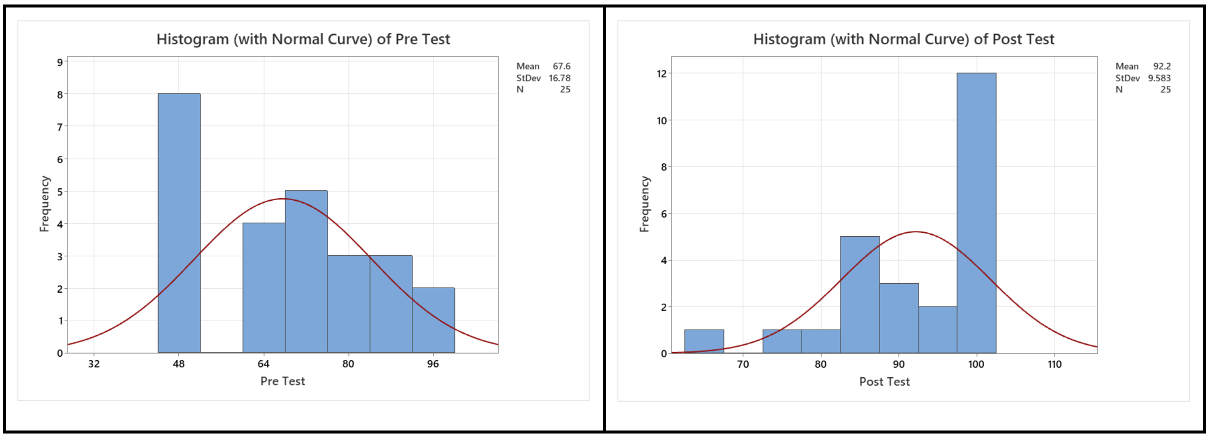


Figure 9: Distribution comparison between Pre y Post Test

The statistical results are shown by applying a pre-test on knowledge of line capacity analysis to students from the G1 of the UF IN3001B Design of a Smart Organization. As seen in Figure 8a, most of the data are skewed to the left with a low average; 8 out of 25 students scored 45 out of 100. The exam consists of 20 items generated from a database of 50 questions, aiming to minimize the risk of copying or having identical exams. After conducting the Simulation Session, it can be observed in Figure 5b that the vast majority of students, 12, achieved a maximum score of 100 on an exam consisting of 20 questions using the same database of 50 as in the pre-test. The paired t-test shows that the hypothesis that traditional learning and learning based on immersive technologies with an ERP component are the same in students is rejected. A t-value of -9.78 indicates sufficient evidence that immersive learning based on the MxREP simulator, combined with XR technologies in a stressful environment generates better knowledge among students.

5. Conclusion

The theoretical model underpinning the MxREP simulator and the augmented and virtual reality lessons allows us to highlight the robust design of this learning ecosystem. Its primary focus is on developing disciplinary and transversal competencies, but it has the potential to be scaled to industrial applications, transitioning from a serious game to an exclusive ERP platform. The experience gained in the initial years of implementation enabled a redesign of the simulator towards gamified learning. This shift facilitated a rapid acquisition of industrial engineering concepts and, crucially, enhanced the retention of key concepts. It also motivated students to engage in competition through immersive learning, compelling them to refine game strategies based on operational excellence in the car assembly process.

Having a digital twin of the product, encompassing the various car models, provided students with a comprehensive experience akin to being in a manufacturing plant. This approach not only fostered disciplinary learning but also cultivated essential life skills, such as problem-solving, analysis under pressure, teamwork, critical thinking, and, above all, confidence in their acquired knowledge. From a design perspective, incorporating students from computer technology programs allowed for a balance between learning objectives and optimal learning methodologies. This resulted in heightened student engagement with the simulator and the lessons developed within it, as well as in the virtual and augmented reality lessons. Budgetary constraints were addressed through a modular design approach, similar to assembling Lego bricks, where components were connected as soon as they were ready to form the simulator's core, utilizing interfaces. This aspect of project management is noteworthy, as it required implementing the four types of thinking for educational innovation projects—systemic, concurrent, prospective, and resilient—for each team member.

Across these five years, more than 25 research protocols applied during the use of the MxREP simulator have consistently demonstrated a significant improvement in learning outcomes when comparing traditional instruction of industrial engineering concepts with lessons based on emerging technologies like AR, VR, and process simulators. Future work will focus on compiling the data generated from the various simulations to derive knowledge using artificial intelligence. This will enable us to identify patterns and obtain results that enhance the quality of demand forecasts, for example, or suggest workstations and/or parts where errors causing low organizational productivity may be located. And these concepts, which can be complex, are learned in an immersive and enjoyable way through the design of serious gamification.

Acknowledgement

The authors would like to acknowledge the financial and technical support of Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, in the production of this Work. The authors would like to acknowledge the financial support of Novus Grant with PEP No. 190 and 263, TecLabs, Tecnologico de Monterrey, Mexico, in the production of this work.

Ethics Declaration: The authors declare that this research was conducted by ethical standards for publication. This research, involving the development and implementation of gamified learning experiences using virtual and augmented reality, adhered to ethical guidelines for educational research

IA Declaration: No use of IA was made in the redaction of this article. IA was used only for translating some paragraphs

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