OPMITISING LEARNING IN INDUSTRIAL ENGINEERING; IMPROVING SKILLS THROUGH XR ENHANCED LEARNING SCENARIOS

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ABSTRACT
Extended reality facilitates better learning in less time while optimising resources. This paper explores a student-centric course experiment rooted in the application and practice of a recently developed educational platform, the Tec21 educational model, which is based on the development of disciplinary and transversal competencies. For this purpose, the design of educational innovations is fundamental. In recent years, the design of virtual simulations has rapidly increased in number as well as in sophistication. Virtual laboratories based on virtual reality and augmented reality have experienced exponential growth, which has led to the creation of new platforms for lessons based on XR technology. Although present research has presented several examples that showcase virtual environments designed for students to learn from, platform independence is growing, allowing users to experience different learning formats with minimal disturbance as technology strives to reach further seamless solutions. This research presents the results from specific learning scenarios through so-called design-build-test (DBT) exercises for different groups of industrial engineering students. The students were introduced to the MxREP simulator and the TecXR platform, which offer augmented guideline design tracking, intuitive support, and virtual reality design scenarios that allow students to repeat physical DBT exercises in a timely manner to gain deeper understanding of stepwise design parameters. The specific course exercise was designed to emphasise life cycle educational activities originating from the lecture design objectives, instructions, and activities, as well as the definition of educational objectives. Also, the design of simulator parameters and the interface with virtual and augmented reality lessons are used to achieve three essential objectives: development of skills, learning, and engagement. The findings showed that students greatly appreciate utilising XR as part of their learning. The variation of the platform noted that the more fixed VR process enables it to focus more on process-related design steps, whereas augmented support increased co-design engagement among student cohorts that participated.

Keywords: XR reality, gamification, simulator, higher education, educational innovation

1 INTRODUCTION
Adversity fosters creativity, and Tecnologico de Monterrey's Educational Innovation remains constant. As distance learning gained momentum, academics worldwide were compelled to design and develop virtual laboratories, with extended reality emerging as a leading technology. Tecnologico de Monterrey stood out in this global shift for its unique approach. While transitioning to a new educational model, TEC21, where the central process revolves around challenges provided by external partners, the institution had to accelerate its distance learning efforts. This involved supporting students in tackling real-world problems, with knowledge transfer occurring in the classroom through competency development, problem definition, and solution proposal, all encapsulated in a project [1].
This document shares the lessons learned from the design, development, and classroom application of virtual laboratories supported and enhanced by practices based on XR technology, mainly virtual and augmented reality, as a learning complement for our students. Utilising XR to enhance the learning environment, providing enriched depth through immersive scenarios, has been explored and deemed critical to gain important professional skills recognition. This collaboration, together with Mälardalen University, Sweden aims to improve the learning experience of Industrial Engineering students. [2].

2 METHODOLOGIES

The first step involved forming a task force group responsible for designing learning activities focusing on specific industrial engineering topics. The training unit IN2006 – Project Feasibility Analysis with a Systemic Perspective was targeted, running at module three, during fifth semester. A problem situation was identified regarding the teaching-learning process. This problem aimed to enhance students' understanding of the process of determining the capacity of a production line from a systemic perspective, where various factors such as machinery and equipment performance, supplier training, material quality, assembly process, and materials management throughout the product supply chain influence the outcome.

The R&EIT (Research and Educational Innovation Team from Tecnologico de Monterrey) employed two support methodologies to construct the academic activity. The first methodology is based on Design Thinking and Design of Experiments [3] to identify the measurement factors of the activity's efficiency in the teaching-learning process and its corresponding levels. The second methodology utilises soft systems to define the problem and the activities that are necessary for designing an academic activity [4].

The training unit comprised two DBT groups: 501 and 502 in the five semester, third period. The first group (course 501) consisted of 29 students, and the second group had 23 students. Both groups had the objective to develop and determine the capacity of a production line, first group used the simulator while the second group would rely on traditional classroom methods for learning. Both groups would undergo two tests, one before and one after the activity for group 501, and one before and one after the class for group 502. The exams would consist of 15 items drawn from a database containing 40 questions related to the learning topic.

The hypothesis under research aims to confirm whether there is a significant difference between groups 501 and 502 concerning learning, and the utilisation of the activity designed for learning this topic. To assess this, the paired t-test will be employed.

3 DEVELOPMENTS

The initial step involved applying soft systems methodologies to analyse the problem related to learning about line capacity, define the problem, and commence generating solution ideas utilising the chosen methodology. This methodology was employed to design academic activities based on Design Thinking and Design of Experiments. [3].

Figure one illustrates the enhanced rich picture, which is based on soft systems methodology enhancement by R&EIT [4]. This figure depicts the problem situation and the system restrictions, enabling a focus on realistic solutions. It consists of two frames: the first frame explains how the four thinking ways (Systemic, Prospective, Resilient, and Concurrent Thinking) contribute to problem definition, while the next frame delineates the restrictions or guidelines for the activity, including the assembly process, statistical process control, quality plan, syllabus, and competencies. Within the red line lies the problematic situation, represented by a diagram connecting actors and elements and describing the workings of the activity design.

In the solution proposal, factors contributing to poor learning of the topic in the classroom are identified through brainstorming, weighted numerically, and subjected to Pareto analysis. This analysis identifies the three critical factors to be addressed through a design of experiments, employing three levels for each factor to determine the appropriate parameters for an optimal academic activity aligned with our academic objectives. The three factors to be analysed are:

- A Skills Development.
- B Learning.
- C Student engagement in the activity.

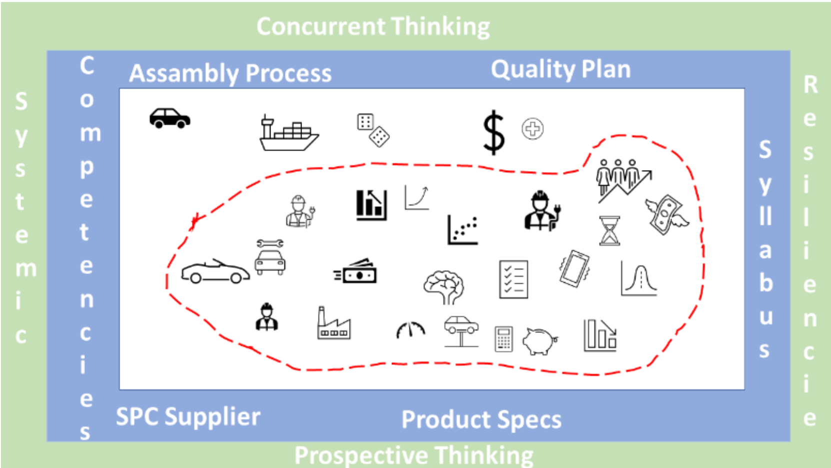
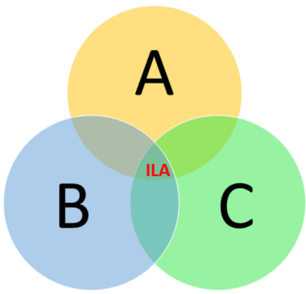


Figure 1. Soft Systems Methodology applied to explain the challenge and design process activities

Three levels will be used for each factor, and the parameters of these levels will be determined through Anova analysis to obtain the learning results. Figure 2 illustrates the interaction between the three factors, while the table delineates the zone for an ideal learning activity.
For factor A, competencies, the design incorporates four levels: Excellent, Solid, Basic, and Incipient [1,4]. These levels denote the development of student competencies, which is assessed using a rubric applied to learning evidence.
Factor B pertains to learning performance, with the minimum passing grade for a class unit set at 70, and the scale ranging from 10 to 100. Excellent performance for a student is defined as achieving a grade between 90 and 100.
Factor C delineates the level of engagement among students and the learning activity, measuring the degree of teacher performance creativity in storytelling, which serves as the front end for student engagement.

Engineering Thinking Model and Design of Experiments Matrix



	Higher				Medium				Down			
	100	90	80	70	100	90	80	70	100	90	80	70
Exeptional												
Solid												
Basic												
Incipient												

Figure 2. Engineering Thinking Model and Design of Experiments Work Matrix

The academic activity aimed at achieving the learning objectives is based on the utilisation of an Enterprise Resource Planning (ERP) system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment [5, 6, 7, 8]; The academic activity aimed at achieving the learning objectives is based on the utilisation of an ERP system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment. The academic activity aimed at achieving the learning objectives is based on the utilisation of an ERP system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment.

4 IMPLEMENTATIONS

The implementation strategy revolved around designing the storyline (academic case) that students would engage with, facilitating team application, and preparing Meccano kits to replicate the manual process. This approach allowed students to learn about the parts and subassemblies supported by augmented reality on their phones and tablets.

The second phase unfolded in the VR Zone of the Campus, known as Mostla, which translates to "Tomorrow" in the Nahuatl language. Here, students utilised virtual reality lessons in teams to enhance the assembly process and determine assembly time for calculating the line's capacity. They encountered challenges such as the quality sum of tolerances to the motor gears, which they solved and provided a solution for. Finally, they completed a knowledge test.

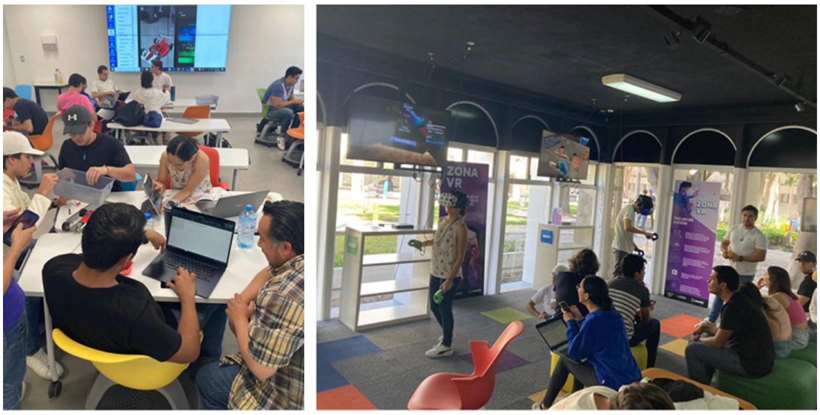


Figure 3. Implementation using AR (left) and VR (right)

5 RESULTS

The implementation strategy was centred around designing the storyline (academic case) that students would encounter, facilitating team application, and preparing Meccano kits to replicate the manual process. This approach allowed students to learn about the parts and subassemblies supported by augmented reality on their phones and tablets.

The second phase unfolded in the VR Zone of the Campus, known as Mostla, where students, working in teams, utilised virtual reality lessons to enhance the assembly process and determine assembly time for calculating the line's capacity. They encountered challenges such as the quality sum of tolerances to the motor gears, which they successfully solved and provided a solution for. Finally, they completed a knowledge test. The research protocol analyses four variables: two for the use of Innovative Learning Activity (ILA) and two for traditional learning. Table 1 presents the descriptive statistics for each variable.

Table 1. Summary Statistics for the two groups, before and after

Sample	N	Mean	Standard Deviation
T before A	29	63.97	16.33
T After A	29	86.9	11.05
T before C	23	66.52	13.27
T After C	23	71.52	13.52

Before the ILA application, students took a knowledge test on the capacity line theme. The mean score of students the 29 students in 501 group was 63.97 out of 100 for the 20 questions, falling below the minimum passing score of 70. Subsequently, students underwent the ILA process, first in the classroom and then in the VR Zone or Mostla Laboratory. Descriptive statistics reveal an increase in the average grade from 63.97 to 86.9. Figure 4 illustrates the boxplot depicting the distribution of scores between the “T before A” and “T after A” variables.

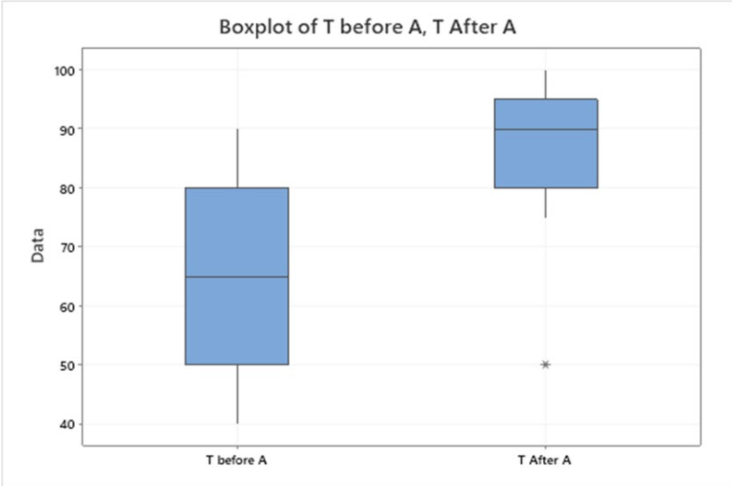


Figure 4. Box-plot between Test before and after ILA application

With a p-value of 1.1066E-07 and a confidence level of 95%, a significant difference exists between the mean grades for before and after the activity. Additionally, the confidence interval for the difference ranges between (-29.57, -16.29), indicating that, on average, the grades in the exam after the ILA application were higher than those before the ILA application. Please refer to Figure 5 for visual representation.

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference ≠ 0

T-Value	P-Value
-7.0767	0.000

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-22.93	17.45	3.24	(-29.57, -16.29)

μ_difference: population mean of (T before A - T After A)

Figure 5. Inference for the difference of before and after the ILA application

On the other hand, with the control group, a p-value of 0.154 and a confidence level of 95% indicate that there is no significant difference between the mean grades of before and after the activity. Moreover, the confidence interval for the differences ranges between (-12.02, 2.02), suggesting that the mean grades before and after the activity may be equal at a 95% confidence level. Please refer to Figure 6 for visual representation.

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference ≠ 0

T-Value	P-Value
-1.48	0.154

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for μ_difference
-5.00	16.24	3.39	(-12.02, 2.02)

μ_difference: population mean of (T before C - T After C)

Figure 6. Inference for the difference of before and after for the control group

6 CONCLUSIONS

The implementation strategy was based on designing the storyline (academic case) that students would engage with, facilitating team collaboration, and preparing Meccano kits to replicate the manual process.

This DBT approach enabled students to learn about the parts and subassemblies supported by augmented reality, accessible on their phones and tablets. The second phase unfolded in the VR Zone of the Campus, known as Mostla. In this VR Lab, students, working in teams, utilised virtual reality lessons to enhance the assembly process and determine the assembly time required to calculate the line's capacity. They encountered challenges such as the quality sum of tolerances to the motor gears, which they successfully addressed and provided a solution for. Students were highly engaged during the sessions and confirmed that it was more joyful to learn this way in comparison to traditional teaching. Afterwards, they completed a knowledge test with the highest mean values ever recorded. In summary, the TEC21 XR challenge is clearly impacting the skills development of students as well as creating a positive learning experience.

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