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Use of Virtual Reality to Improve Learning Experience on a Lean Manufacturing Course

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Abstract

The application of technological tools in engineering courses has been extensively studied, yet the integration of Virtual Reality (VR) in Lean Manufacturing courses remains a relatively unexplored area, particularly for its potential in addressing challenges related to real-world exposure for engineering students. A case study conducted at Tecnologico de Monterrey within the "Design of Innovative Processes" course showcases the use of VR to simulate a manufacturing process known as the Virtual Factory. This research highlights the effectiveness of VR in enhancing Lean education, providing students with a hands-on, visual experience in a controlled environment. Results indicate a significant 7.5-point improvement in student performance post-VR exposure, coupled with positive perceptions of ease, enjoyment, and immersion. The proposed methodology offers educators and practitioners a valuable avenue for enriching Lean Manufacturing learning experiences, with implications for broader applications. Furthermore, the study suggests the potential extension of such VR environments to other engineering courses, emphasizing the importance of thoughtful VR tool design in improving learning outcomes.

Keywords

Virtual Reality, Higher Education, Educational Innovation, Lean Manufacturing

Introduction

It is foundational for Lean Manufacturing to sustain continuous improvement with workforce cooperation and involvement [1]. When Lean is referred to as an improvement toolkit, but leaving apart the human factor, it is not possible to achieve a sustainable growth of improvement rate, nor to generate a deep impact into organization' KPIs [2]. Therefore, it is crucial for engineering students to get involved in the complexities of interacting with people when implanting Lean, to correctly develop their skills in continuous improvement.

However, a common limitation for students that are learning Lean Manufacturing is the lack of exposure to real situations in which Lean is being implemented, such as practices in laboratories, participation in real-world experiences or access to available processes, where implementing lean tools and measuring the impact on KPI's is taking place [3].

Attending this urgent need of students to participate in real life process, in Tecnologico de Monterrey, we have designed a course named "Design of Innovative Processes", in which Industrial Engineering students learn concepts such as Value Stream Map, Pull vs Push Flow, Visual Management, Poka Yoke, Manufacturing Cells, Kanban, and SMED. In this course, students develop a continuous improvement project, using the learned tools, within a real company that allows them to analyze the process and collaborate with workers. Nevertheless, due to this course only having four to five weeks available to work with the company, the actual implementation of these tools is not performed completely, so the students don't see the results.

Recognizing these challenges, this paper explores an innovative use of virtual reality to simulate a manufacturing process and to implement Lean tools within a controlled environment. The aim of the study is to assess the impact that performing lean projects in Virtual Reality has on the students' comprehension of lean implementation methodologies.

Literature Research

Lean Manufacturing is a corporate strategy aimed at eliminating waste in the production process to enhance the value of a product or service [4]. This approach focuses on identifying and efficiently eliminating waste in operational activities to improve efficiency during the production process [5]. Regarded as a revolutionary methodology, Lean Manufacturing aims to increase resource utilization while minimizing waste. Studies have shown that it significantly enhances plant efficiency and reduces processing times in key manufacturing operations [6].

Its implementation improves organizational performance with benefits like increased flexibility, profitability, and efficiency. It leads to continuous process improvement, lower production costs, higher customer satisfaction, advanced just-in-time production (JIT), improved ergonomics for employees, and more reliable products. This success suggests that Lean is universally applicable and not a passing trend. Recent research also highlights Lean Manufacturing as a foundation for developing new technologies like Industry 4.0 [7].

Previous studies about the training in Lean Manufacturing of engineering and business students have shown that implementation phase on projects is a key factor for the success of improvement initiatives [8]. However, participation of individuals in proper training and the attitude towards learning is strongly related to the perception of usefulness, the perceived benefits [9] and the integration of fun features in the education programs [10].

A possible way to achieve an educational structure in which application is perceived as fun and palpable is the integration of active, experiential learning to Lean Manufacturing training, in which students put in practice the conceptual framework by performing actual improvement activities [11]. Unfortunately, this kind of approach often requires investment in infrastructure and facilities to experiment Lean tools, which make necessary to look for new content delivery techniques that allow both, the conceptual and technical frameworks of Lean, to be learned [12].

Literature shows that the conjunction of technology quality, availability, consistency, and accessibility are crucial for effective learning. However, it's important to note that technology alone doesn't ensure desired learning outcomes. The interaction between humans and technology, along with the design of educational tools, significantly impacts students' learning results and engagement [13]. The fast growth of technology has contributed to eliminating distances among people to ease the learning process; hence, educational sectors are certainly motivated by the capacity and efficacy of digital learning [14].

In the contemporary digital landscape, the integration of technology in education is imperative. Students must possess a set of essential skills crucial for success in an increasingly interconnected global environment. These skills encompass social and personal responsibility, critical thinking, visualization, decision-making, planning, creativity, cross-cultural understanding, strong communication skills, effective presentation, interpersonal competence, and the ability to discern when and how to select and utilize technology and tools that are most suitable for a given task [15].

Hence, the purpose of integrating technology into the teaching and learning process is to enhance productivity, improve the effectiveness of current practices, and introduce pedagogical changes that benefit education. This incorporation of technological tools fosters increased interaction between teachers and students during the teaching and learning process. To successfully implement technology, educators and teachers must carefully select and apply the right technological tools, creating an environment that is more innovative for the students [16].

One of the newest methodologies that has transformed education is Virtual Reality. Its implementation in the educational field has been proven in several contexts, offering countless advantages for both students and teachers. One of the most outstanding benefits lies in its ability to provide immersive and realistic experiences [17], making it significantly easier for students to understand and retain complex concepts and methodologies. This technology allows students to explore and experience virtual environments that would otherwise be inaccessible or dangerous [9], thereby significantly expanding learning opportunities and enriching the educational experience [12].

Another key advantage is its encouragement of active, hands-on learning. Students can interact with virtual environments, manipulate objects [18], and engage in hands-on activities, which stimulates critical thinking, problem-solving, and experiential learning. This active interaction with educational content increases students' engagement in the learning process and enhances their understanding and application of concepts.

In addition to the above-mentioned advantages, the use of virtual reality in education increased intrinsic motivation and engagement of the students. They believe that they are more active, can keep their attention better and enjoy the experience of relevant situations in a virtual environment [19]. The immersive nature of virtual reality captures students' attention and motivates them to actively participate in the learning process.

When referring to Lean training and education, simulators are often used. These can take the form of desktop games, computer simulations, or full-scale simulators [20]. The advancement of virtual reality (VR) technology has created new opportunities beyond the realm of video games [21]. Some innovations rely in platforms for creating simulation environments using VR and artificial intelligence (AI) techniques. The combination of VR and AI enables the development of complex and realistic scenarios, including the introduction of fictional characters and interactive obstacles. This kind of solutions offers specialized training companies a versatile tool to generate their own content, thereby enhancing productivity by delivering training experiences that are realistic and close to reality. For example, previous studies that incorporate VR into 5S training found that students enthusiastically embraced the incorporation of this technology into the teaching of engineering methods, valuing the innovation it introduces to learning. Students identified as the greatest advantages of educational games being a non-traditional means of experiential learning. Moreover, students perceived that the interaction with virtual reality equipment that is not normally available in conventional educational contexts may substitute experiential learning that requires actual physical resources to be performed [22].

Therefore, developing a methodology that incorporates VR in a Lean Manufacturing course is justified by multiple fundamental reasons. VR enhances content retention through immersive experiences, allows the practical application of Lean concepts in simulated environments, reduces risks and costs associated with real physical settings, and facilitates accessibility and flexibility in learning. Additionally, it stimulates interest and participation, enables effective performance evaluation, caters to diverse learning styles, aligns with technological trends, and fosters collaboration with the industry, thereby improving educational competitiveness. These benefits support the need to leverage VR to enhance Lean Manufacturing training.

Methodology

This research uses a quasi-experimental design with pre and posttests, involving 22 Engineering Students of sixth semester, in Tecnologico de Monterrey. The study was performed in three phases taking place during a week, as shown in Figure 1:

Phase 1: After students attended to traditional lessons about Lean Manufacturing, on day 1 of the experiment they were asked to solve a 12 question test about Lean Tools and it implementation. This test corresponds to the Pre-Test of the study.

Phase 2: Students were asked to explore a Virtual Reality manufacturing process. This phase had a duration of three days, in which students had to perform the process taking the role of operators, collect measurements, and redesign it into a Pull-Flow. During this phase, students had to perform a current and future state VSM, calculate key measurements such as WIP, Lead Time, Takt Time, Cycle Time, and Yield. Then, they had to implement at least four lean tools to pursue the future state, and to compare the key metrics under the new operation conditions.

Phase 3: Finally, on day five, students were asked to answer two surveys: a multiple-choice quiz related to lean tools implementation methodologies and practical issues. This test was similar to the initial test and corresponds to de Post-Test of this study. The second survey was a perception test to measure the acceptance of students towards Virtual Reality after its use.

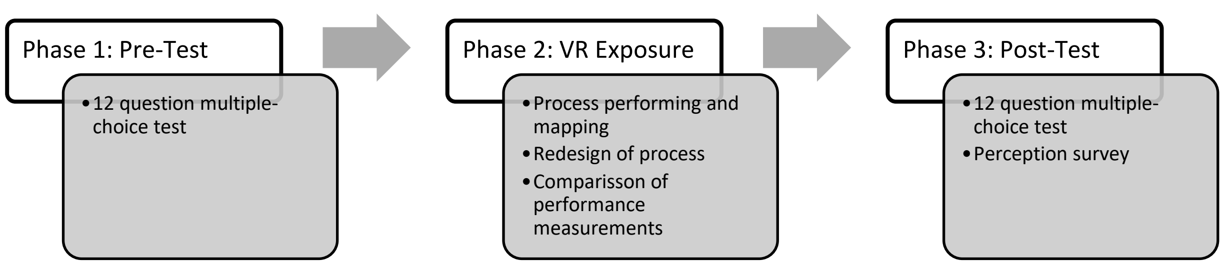

Figure 1. Phases of the study done with the students at Tecnologico de Monterrey

Prior to the execution of the experiment, we designed a virtual factory in which the students could implement Lean Tools and Techniques during Phase 2. We decided to use the metaverse called Framevr.io, due to its easiness of use, for both, creators of the space and users; and because of the possibility of using cost-free environments for the students.

As shown in Figure 2, the design of the virtual factory could be done without any significative effort due to the interface of the metaverse. Default shapes and 3D objects were added into an already available space, creating a virtual factory with working tables, delimited spaces, and the minimum information necessary for students to understand the nature of work to be done in the facilities. The focus of the design was to develop a process that required operations existing already in the metaverse, instead of designing the simulation of a specific manufacturing process.

Figure 2. Images of the virtual factory designed in Framevr.io

The virtual environment context was a factory of geometrical shapes. This type of products responds to the fact that Framevr.io includes this object as part of the basic library, and because of the different characteristics that could be modified in order to make them unique. Under this assumption, students were expected to execute 5 operations to be able to fulfill a demand of shapes with different sizes, colors, and combinations. The operations involved, in order of execution, were:

1. Shape Creation: The students had to import a shape from the library of Framevr.io. The imported shape had a standard size, color, and name; characteristics that would be modified in further operations.
2. Labeling: The students had to modify the name of the shape according to the time in which the operation was performed. This operation allowed the traceability of items.
3. Scaling: The students had to modify the size of the shape according to the standard. Every kind of shape had a different scaling factor.
4. Paint: The students had to change the color of the shape according to the standard. This operation was particularly difficult because the color had to be selected from a continuous color palette.
5. Assembly: Students had to cluster specific shapes in groups of three, according to the provided demand.

The layout of operations was not optimized, as it can be seen in Figures 3 and 4, and it was specifically designed to generate problems during operation. In other to achieve this, the virtual space was full of waste and improvement opportunities, such as space unused, unnecessary items in shop floor, long trajectories between operations, unbalanced activities, excess of inventory, suboptimized movements to perform the operations, noise, pollution, and distractors.

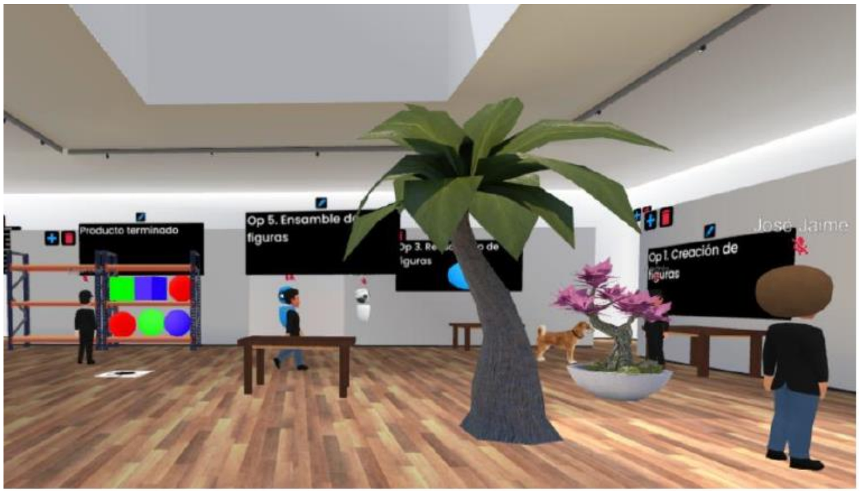

Figure 3. Students interacting with the virtual environment in Framevr.io

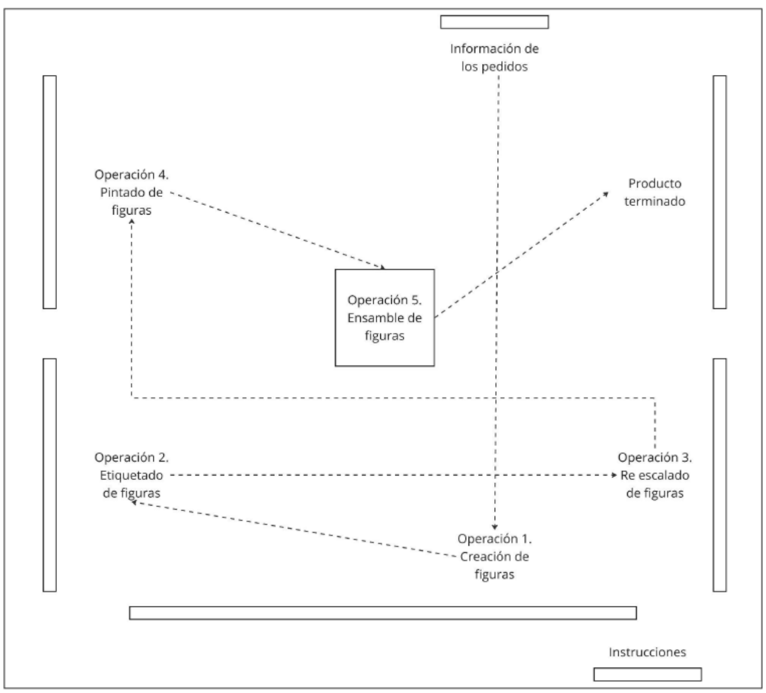

Figure 4. Layout of the virtual factory

During Phase 2 of the experiment, to improve the current configuration and operations of the space, we asked students to create a VSM of current state, analyze it, and generate a map for the future state, as shown in Figure 5. Students were expected to apply at least four lean tools to modify the process, however, as they would play as operators as well, they had to be convinced that suggested modifications would improve the overall process and their individual performances.

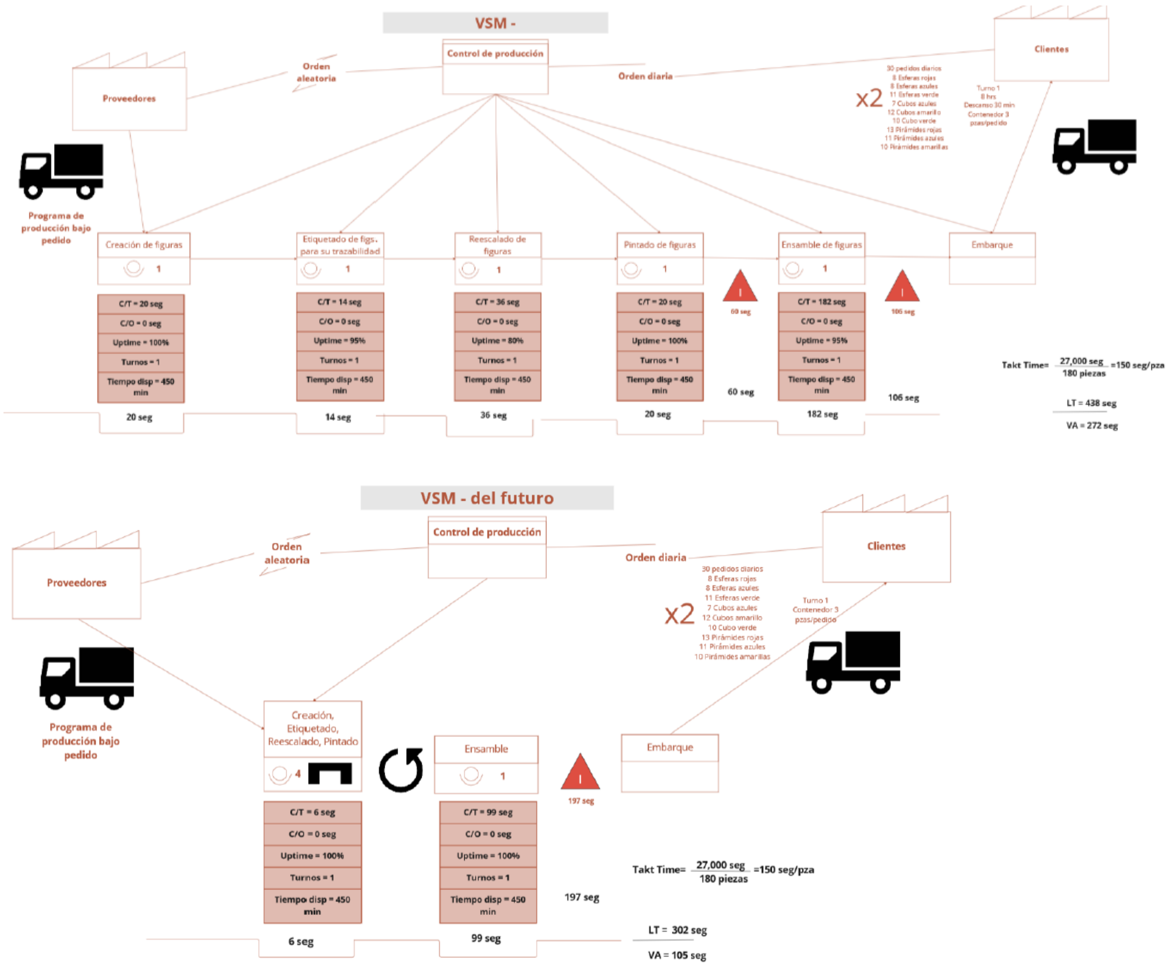

Figure 5. Value Stream Mapping of current and future states for the virtual factory

Process improvements done by students included change of layout, balance of operations, visual aids, standardization of operations and Poka Yoke. According to their delivered results, Cycle Time was reduced in 20%, Lead Time was reduced 25%, and inventories were reduced in 75%. Figures 6 and 7 show some of the modifications in the virtual factory.

Figure 6. Modifications done in the layout of the virtual factory

Figure 7. Visual Management tools included in the virtual factory (highlighted in yellow)

Analysis of Results

The research involved a pre-test and a post-test applied to students in phases 1 and 3 of the experiment, respectively. Each of the tests contained 12 questions related to implementation of Lean tools and was graded in a 100 points scale. Obtained results clearly show an improvement in student's performance. In Tecnologico de Monterrey, the minimum score necessary to credit a test is 70, and as shown in Figure 8, only 50% of the students obtained a score greater than 70 in the pre-test, while 75% achieved that score in the post-test. Moreover, in the pre-test there existed lower outliers, representing students with a score considerably below the rest of the group. However, variance of scores in the post-test decreased, with a symmetric distribution with a mean of 75.

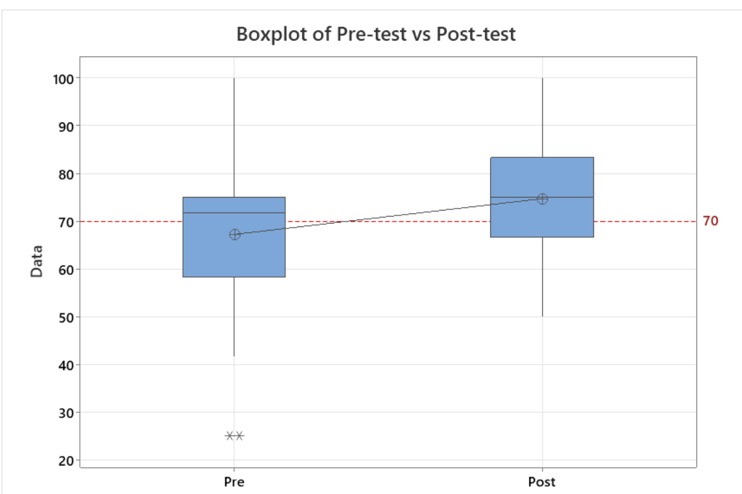

Figure 8. Distribution comparison of the pre and posttests results

However, to verify the improvement of individual students, we used a 95% confidence interval for difference of paired means. We found a significant positive impact in the test performance after the VR activity, with a p value of 0.021, as shown in Table 1. This result may imply that the activity allows students to better understand technical concepts and application methodologies of Lean. Nevertheless, this improvement may be conditioned to the perception of students about the use of technology. To verify it, we applied to the student a perception test which measures three main components: Ease of use, Enjoyment, and Emotional immersion [23].

Table 1: Statistical test for the paired means difference between pre and post - test

Null hypothesis	H_0: μ_difference = 0				
Alternative hypothesis	H_1: μ_difference > 0				
Mean	**StDev**	**SE Mean**	**95% Lower Bound for μ_difference**	**T-Value**	**P-Value**
7.47	18.94	3.52	1.49	2.12	**0.021***

μ_difference: population mean of (Post - Pre)
**Significant to a 95% confidence level*

As seen in Figure 9, there is a strong correlation between VR perceptions of students. Students who consider that the virtual environment was easy to use perceived a better emotional immersion, similarly, those with a deeper immersion in the activity perceived a more enjoyable experience. These results point out the importance of using a friendly VR interface for delivering contents and promoting the acceptance of students.

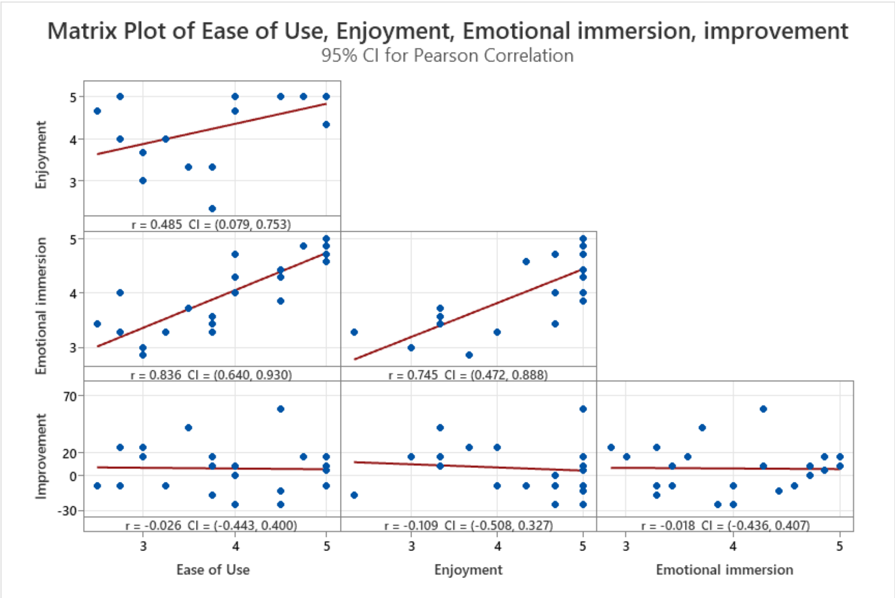

Figure 9. Scatterplots of the ease of use, enjoyment, emotional immersion and improvement of the students after the use of the Virtual Factory

Nevertheless, the correlation between students' improvement with any of the dimensions of the perception questionnaire results to be non-significant. We can infer that the student's development within the proposed methodology is not conditional to the level of acceptance towards the technology, but it is the result of the practical implementation of course topics in a simulated reality.

Conclusion

The exploration of Virtual Reality (VR) integration in engineering courses presents a compelling avenue for transformative learning experiences. The study, exemplified by the application in Lean Manufacturing education at Tecnologico de Monterrey, underscores the potential of VR to address challenges in real-world exposure for engineering students. The broader implication is that VR can be a valuable pedagogical tool for enriching engineering education, offering hands-on, visual experiences within controlled environments. As technology continues to advance, the thoughtful integration of VR holds promise not only in Lean Manufacturing but across diverse engineering disciplines.

The results of this research show that use of Virtual Reality for practicing implementation of Lean tools under a controlled environment provides significant positive impact in students' performance, with an average improvement of 7.5 points over 100 when comparing a pre-test with respect to a post-test performed after VR exposure. Moreover, most students perceive virtual reality as a tool that is easy to understand and that provides pleasurable, interesting, and highly immersive experiences within learning.

These findings support the idea that the implementation of Virtual Reality can be beneficial in achieving a deeper and more effective understanding of the principles and tools of Lean Manufacturing. The hands-on and visual experience provided by Virtual Reality can contribute significantly to a better understanding of improvement project implementation.

Two limitations of this study should be acknowledged. On one hand, the generalizability of the findings may be constrained due to the single-case design focused on Tecnologico de Monterrey. While the results showcase the efficacy of Virtual Reality (VR) in Lean Manufacturing education within this specific context, variations in institutional settings, student demographics, and course structures could impact the applicability of the proposed methodology elsewhere. On the other hand, the relatively short duration of the study, spanning only a week, may not capture the long-term effects of VR integration on students' retention and practical application of Lean concepts. A more extended study duration would provide a more comprehensive understanding of the sustained impact of VR on Lean Manufacturing education.

We believe that our proposed methodology can be used by professors interested in enriching the learning of students, in topics related to Lean Manufacturing, and practitioners interested in creating learning experiences for employees and training sessions. Further research will include the use of Virtual Reality in other contexts to verify the impact in the students' learning process.

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