Gamification for the Development of Competencies in Tec21 Based on Mixed Reality

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Abstract: Currently, university students expect to obtain not only valuable knowledge about their majors, but they also want to develop different skills that will allow them to develop and stand out in the highly competitive world of work in which we find ourselves. To achieve this, Tecnologico de Monterrey implemented the Tec21 model, a challenge-based learning system focused on the development of both disciplinary and transversal competencies. Among the innovative tools used to promote these competencies we can find, after our research, the gamification: a technique that uses the resources of a game to promote student learning in an unconventional way, resulting in an excellent means for the development of the competencies. At the beginning of the pandemic, educational institutions reinvented themselves through innovation to make distance learning efficient. At Tecnologico de Monterrey, we have sought to develop problem-solving competencies through the implementation of two gamification strategies: an Enterprise Resource Planning (ERP) simulator that emulates the processes of a scale car model manufacturing line and a role-playing game in which students solve problems through a scenario. Three important factors were considered for gamification: engagement, academic rigor, and the development of competencies, all this has been enhanced with the use of emerging technologies such as immersive, augmented, and virtual reality, which allow students to have access to Laboratories at a distance and at any time. The theoretical concepts used, the situations or problems selected, the dynamics of the game, and the use of technological elements such as augmented reality and the use of the Tec Virtual Campus, have made this project an enrichment experience for the users, since the students spent an average of 32 hours of practice per week, improved their confidence in the application of problem-solving methodologies and developed teamwork, problem-solving, and information analysis skills. One of the greatest achievements, additional to the academic aspect, was the increased emotional stability of the students, which had been affected by episodes of depression derived from the confinement.

Keywords: Innovative education, gamification, problem-solving, higher education

1. Introduction

The Tecnologico de Monterrey has been characterized by constantly working to find academic excellence. Over the years, it has made various modifications to its syllabus with the aim of preparing professionals who are capable of adapting to the changing needs of society and facing the new challenges that arise. In this way, we have witnessed an important change in its educational model with the introduction of Tec21, a flexible model based on challenges that seeks to enhance transversal and discipline-specific skills.

However, the sanitary conditions caused by Covid-19 changed the world completely. In the educational field, both, the students and the teachers, were forced to use a virtual modality to which they were not accustomed, also, this fact represented difficulties in implementation: the students did not feel motivated by the way in which the topics were being presented causing a null participation in class, in addition the distractions were constantly manifested and, since most teachers were based on the tasks to promote learning, the students were saturated by the large number of activities, reaching the point to show signs of mental exhaustion and emotional disorders such as stress, anxiety, and depression.

The problem was clear, and an innovative solution had to be found, because if it continued like this, the students would not be involved in the activities that seek to promote the development of the transversal skills necessary to function in the professional world. To do this, different proposals were developed at the Tecnologico de Monterrey that, together, will represent an advance in an educational model based on a virtual implementation that faces the challenges caused by the health lockdown by covid19. Thanks to 30 years' experience in the design and teaching of digital education programs, in just one week of preparation and the suspension of academic activities for students, the institution resumed classes on March 23 through a Flexible and Digital Model designed to ensure educational continuity for more than 90 thousand students and 10 thousand professors.

The simulator itself, for students, is a very good learning tool, but in the context of confinement due to Covid-19, it was difficult to coincide with classmates at the same time, it was always seen as one more activity. On the other hand, one of the reasons why gamification was considered as a good tool to achieve engagement with students is the large amount of time young people spend playing games on different devices such as phones, computers, and consoles. Since the confinement, the popularity of video games increased as people turned to them to spend their free time. The research interns were able to notice this behavior because they were part of this group, and these observations allowed the teachers to consider gamification as a key element in gaining students' attention. It was in that moment that the leading teachers of the development involved the students in an empathy exercise and firstly added virtual augmented reality lessons, augmented and later inversive, achieving a learning addiction when the simulation was modified.

2. Previous work

Since 2015 the investigation group of the Tecnologico of Monterrey has been developing different innovations based on gamification and since 2019 they opened space for research assistants for engineering students with the aim of fully developing the empathy phase of *Design Thinking* by collaborating with the development of the educational innovations and the design of methodologies. It is in this way that the authors of this research are incorporated into all gamification initiatives that were being developed and as mentioned above, the MxREP simulator is the result of all the gamifications carried out in the area of industrial engineering since 2008. Gamifications have promoted the realization of 10 papers, of which this one stands out for presenting the results obtained with the implementation of this strategy in the new tec21 model.

2.1 Research approach

According to *Design Thinking* and Design of Experiment Methodology proposed by González, Lule and Caballero (2022) three factors were defined as the most significant in the research: the quantitative variable is defined as academic rigor, that means the learning of the techniques and methodologies in the industrial engineering. The qualitative variables were defined as competencies and engagement: the first one obeys to the development of disciplinary and transversal competencies in the Tec21 Model (reporte 2019- 2020), while the second one explained by the interest shown by the students in the class. Their relation can be seen in figure 1. To define the research variables, a form was applied to the students about their feelings about the health situation and distance learning.

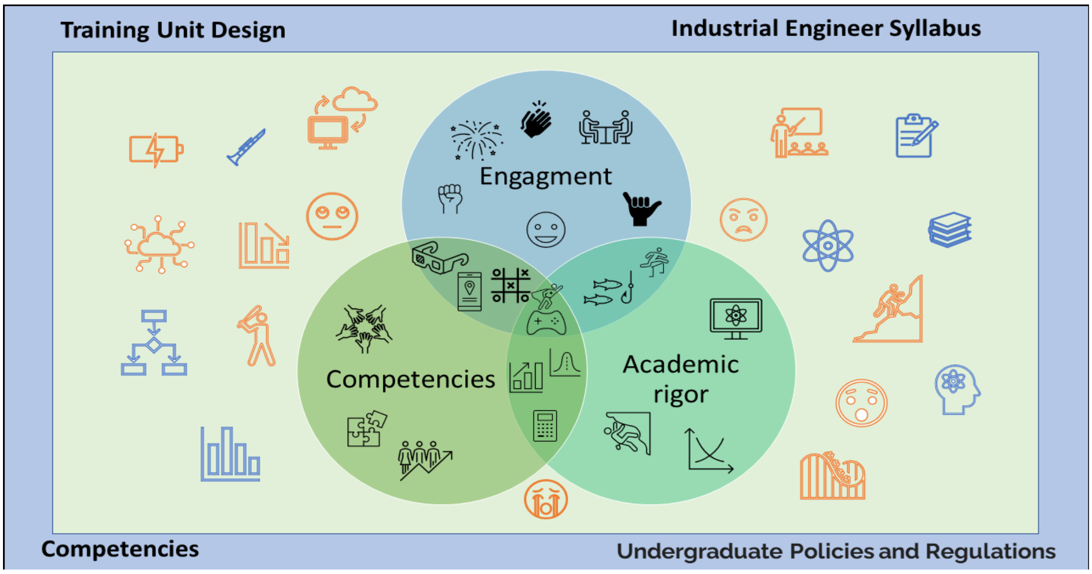

Figure 1: Design of the variables of interest through the DT & DOE methodology

In order to confirm that these three variables are met at the time of implementing the simulator, it was necessary to determine a research protocol in which the following was studied the veracity of the hypothesis that gamification increases the quality of learning.

A complete group of 36 students belonging to the course Improvement of an Organizational Process with Statistical Methods was selected. Two exams will be applied focused on the practice (topic) of which we want to measure the knowledge acquired by the students. The first test will evaluate the knowledge previous to the use of the virtual plant (VEP) and the second after having carried out the practice to measure if there is greater learning and that it is statistically significant.

Based on the information gathered, a paired t student study will be carried out in which the following hypotheses will be studied:
H_0: $\mu_1=\mu_2$ The application of the simulator does not make a significant difference in learning.
H_1: $\mu_1\neq\mu_2$ The application of the simulator makes a significant difference in learning.

where:

- μ_1 is the population mean before the simulation
- μ_2 is the population mean after the simulation

2.2 Creative phase and first prototypes

One of the proposals to solve this issue was based on the development of a simulator of an ERP system focused on a car manufacturing company called, initially *Virtual Enterprise Planning* (VEP), but that after all the applied improvements and presentations it was considered that the most appropriate name would be *Mixed Reality Enterprise Planning* (MxREP), whose greatest strength is that it considers the company as a whole system and takes into account all the activities of the supply chain, unlike other simulators or activities that focus mainly on production planning. In addition, it contemplates the use of virtual and augmented reality, tools that give added value to students.

The algorithms of each process involved in the assembler were designed during the August-December 2020 semester, based on the Soft Systems Methodologies (SMM) for the definition the processes and the stakeholders involved (Checkland, P. B. (1989), and the Maltese cross (Wilson, B. 1980) was used to map the information flows for each process and then integrate it into a global ERP system. Concurrently, during this school period, a beta version of the simulator reinforced with augmented reality lessons that existed on the EON Reality platform (https://eonreality.com/) began to be used, specifically in the suspension of a car that was very similar to that of a racing car of the model 836560 104 111 multimodels of Meccano (Marriot, R. 2012) that are used in industrial engineering laboratories.

The first approach that the students had with the implementation of the virtual plant took place in the course of *Problem-Solving Methodologies IN3039*. In this, the learning obtained allowed them to observe several phenomena that were not considered within the conceptualization of the simulator, such as the emotional stability of the students during confinement, the frustration of not having real practices, as well as the time invested in the development of the activities and other considerations shown in Figure 2.

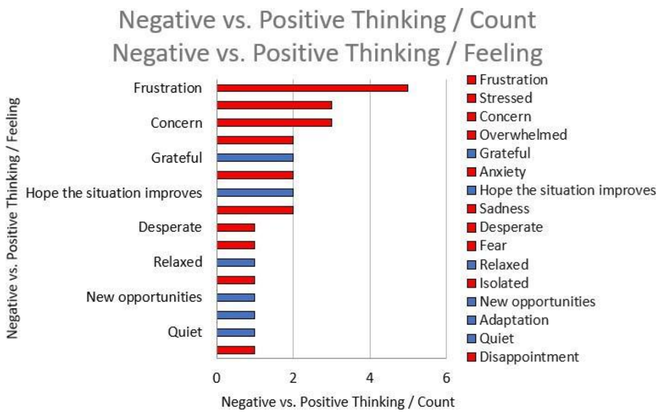

Figure 2: Students´ feelings of about the health situation

After the first implementation, a reflection analysis was made, and it found terrible results in the acceptance of students. The need for a redesign of the activity was imminent. The simulator was well designed but the activity should be transformed from tactical to strategic, in other words, do not focus on calculations and analysis with the use of different software, instead to design strategies to increase the company profits based on the teachings of industrial engineering topics.

The students were involved in the activities that allowed the idea for the VEP to be consolidated: from board games and car assembly in our statistics classes in the first years of the degree to gamification with virtual and augmented reality lessons. However, this development has not been an easy path and, as in any other project, problems were present at each stage from the conceptualization of the idea to the implementation of virtual tools. The concept and its objectives were clear, and it was even known what type of cars would be taken into account for the modeling. The Industrial Engineering department of the Querétaro campus of the Tecnologico de Monterrey had experienced working with Meccano assemblies in physics, like the one showed in Figure 3; the design of it, the total number of parts and their flexibility made them an attractive prototype to be considered as the model cars of our assembler. However, there was a significant delay in the development of the digital parts, lengthening the time for the tests to be carried out with the students. After solving this problem, up to five different models of cars and planes could be designed.

Figure 3: Digitized Meccano model

On the other hand, in order to establish a clear structure through a Bill of Materials (BOM), each of its parts was renamed and cataloged according to its nature, supplier, region and country of origin.

These elements were sufficient to define the *Stock Keeping Unit* (SKU) of each part of the models, which is a code that allows the management of parts and their traceability in the supply chain as it is used in reality with the aim of making the user experience more enriching.

3. From an efficient simulator to an exceptional gamification

As of February 2021, the research group focused on transforming an ERP simulator in which the students had a good learning experience into an educational innovation where the three research variables had the highest values, i.e., they were able to enter the success zone shown in figure 4. This was achieved by gamifying the simulator in an online platform that could be accessed from anywhere the student was and that would record their progress and the time spent to obtain the best results.

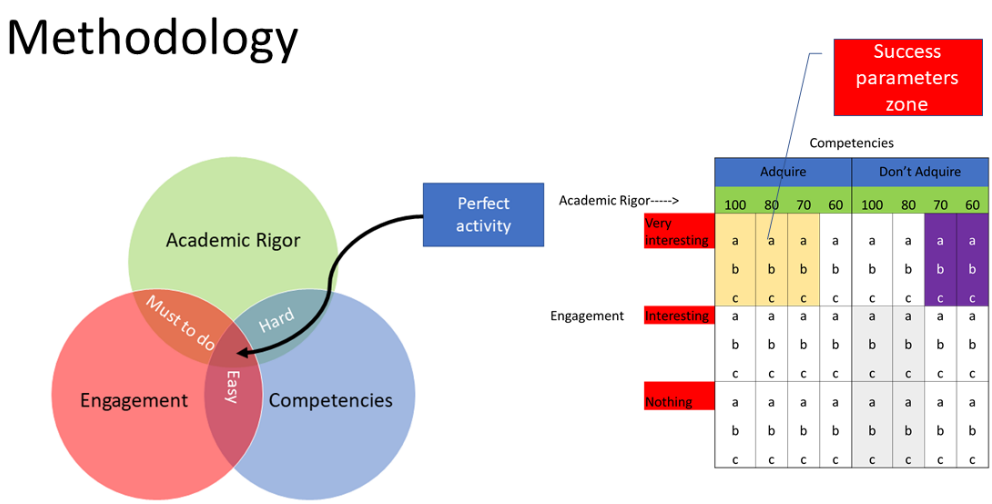

Figure 4: Factor to achieve success in an activity

With the use of the simulator, the most significant processes of a car assembly plant were represented (Figure 4), starting with the customer, who is the one who generates a purchase order that finally reaches the buyers of materials. This is where the productivity index should be consulted, since if the purchase order is for 40 cars, it would be a mistake to buy the spare kits for that amount of product if the productivity index suggests buying more to counter design problems and quality that may arise during the process.

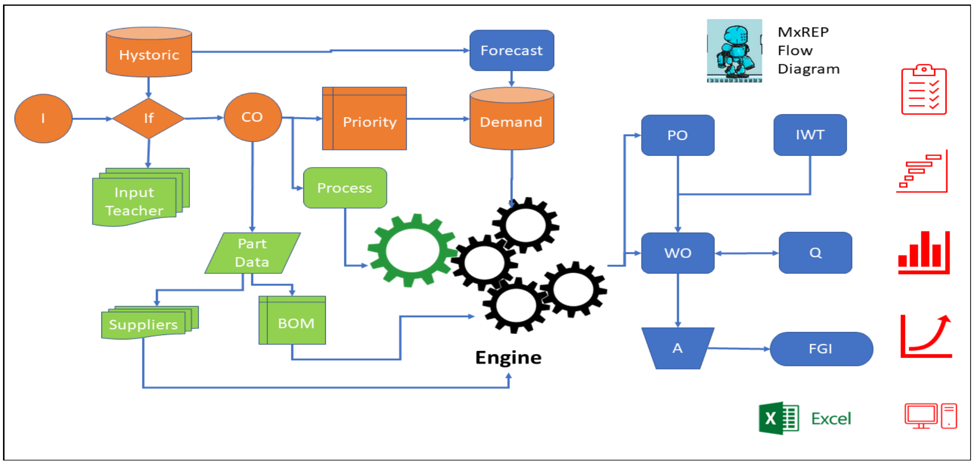

Figure 5: Simulator system design based on an ERP model

The incorporation of these different elements and modalities is very important for this project because we know that there are other systems that are similar to MxREP, but that lack points that give added value to our learning. In accordance with González et al (2021) at recognized universities such as MIT use "the beer game" to explain the fundamentals of supply chain management or the "Fishbank", a simulator that focuses on resource management, while Harvard students learn via the *Operation Management Simulation: Balancing Process Capacity* and the *Global Supply Chain Management*. The drawback that all these tools have in common is that they focus on a few specific areas, while MxREP, fostering systems thinking, considers the entire supply chain.

At this point, this simulator meets two of the variables (skills and academic rigor) of the *Design Thinking*, so to achieve student engagement, gamification is used, which “allows students to engage, improve their learning, and focus on learning objectives”. Its design is based on a model where they have challenges, objectives, and achievements in such a way that the user learns while having fun. This involves game elements such as prizes, competition between students, teamwork, and progress and scoring tables to drive engagement (Holloway, 2018).

For the simulator to be successful, it was placed on a 2D platform to create a gamification with graphic animations, this is because the nature of the human being is to be competitive, and gamification make attractive for the student to use the simulator, which allows him in a fun and educational way to manage and put learning into practice in the classroom.

Virtual and augmented reality modules were added so that the student could visualize all the components of the car and could make the virtual assembly, thus enhancing learning and we could emulate the practices both in the laboratories and in the training centers. manufacture of forming partners.

Studies have shown that VR and AR experiences have increased student motivation and helped them acquire research, critical thinking, problem-solving, and communication skills through collaborative exercises. The benefits of VR and AR technology are reflected in our students' results as learning achievements, better learning outcomes, increased motivation, and more positive attitudes. They demonstrate emotions of happiness as they "learn through the game" (Gonzalez et al, 2020).

According to Gartner Inc. (2008), there are various significant emerging technology trends. I have highlighted the technologies that will significantly affect companies, society, and people in the coming years. These include technologies that enable businesses and society to regain confidence in technology. AR technology is booming exponentially because its use in innovative educational applications in the classroom is increasingly prevalent, allowing students and teachers to "interact" more thoroughly in their activities and the teaching-learning process. In an institutional way, in Tecnologico de Monterrey, we are using the Flexible and Digital Model (Modelo Tec21, 2022). It is a challenge-based learning model that integrates innovative teaching strategies and cutting-edge technologies. The model proposes a flexible and digital learning experience that emphasizes content, interaction, learning activities, technological tools, and evaluation.

Various research studies in the educational environment by Akçayır (2017) have shown that experiences with emerging technologies such as AR and VR have resulted in the following parameters (in descending order): learning advantages (43.75%), motivation (31.25%), ease of interaction (15.63%)), collaboration (18.75%), low costs (12.5%), learning (12.5%), just-in-time information (12.5%), in-place learning (9.38%), student-centered (9.38%), student care (9.38%), enjoyment (9.38%), exploration (12.5%), increased capacity for innovation (6.25%), positive attitude (6.25%), awareness (3.13%), anticipation (3.13%), and authenticity (3.13 %).

According to Gonzalez et al. (2021) the defined scope of the simulation was an assembly company of scale cars built with Meccano parts and those suggested by the EON XR platform for the Willys and Wrangler Rubicon Jeeps, as well as the engine and suspension assembly lessons. A final assembly plant and four sub-assemblies were conceptualized that will be in different cities, processes of the different areas of the company will be simulated and the students will have the role of consultant, where the company will inform them of a problematic situation, they will have to define the problem and intervene in the areas of the company involved to generate a solution proposal.

The design of attractive dynamics that keep the students' attention is an interesting challenge for the teacher (Kuo & Chuang, 2010), with the help of Meccano as a basis to generate these dynamics, it has been possible to make complete simulations of manufacturing processes that involve the analysis of the systems internal departments, such as design, purchasing, product engineering, quality, logistics, testing, finance, information systems departments, to name a few, and external systems that are regulations, standards, sources of financing, suppliers, clients, carriers, etc. where the student through role-playing using event cards and dice emulates the day to day of the manufacturing center (Holloway, 2018).

Using tablets, telephones, and computers, they can monitor the progress of the other departments in real-time. The purpose of the activity is teaching based on competencies, rather than the theoretical learning of a subject and that the student gets hooked through the game, assuming different roles and challenging their creativity and resilience. Using the simulation of a planning process, it is possible to optimize the whole supply chain in one model. The goal or target of this workshop version, this leads to dramatic cost reductions and improved customer satisfaction (Davis & Comeau, 2004).

Gamification by itself generates a feeling of competitiveness in the human being, in education it generates that same competitiveness focused on winning in academic activity through the development of strategies that allow the student to obtain points, and the development of said strategies is the assimilation of the concepts seen in class.

When we play a board game, we are motivated to win, this sense of competition makes it attractive to spend hours and hours in this activity. Transforming methodologies and problem situations into fun challenges we manage to engage students in the learning process. According to Gonzalez et al. (2020) the advantages of gamification are:

- Make learning fun and interactive
- Generate learning addiction.
- The student has the opportunity to see a real utility to the theory seen in traditional class.
- Provide immediate feedback.
- Gamification enhances the learning experience.

If gamification is the *front end* of a simulator that shows in a simple and fun way the information transaction between the entities of an organization, enhances student learning and forms a special connection between students and the teacher, but the trigger that makes a total engagement is the use of mixed platforms, such as virtual, augmented and mixed reality.

4. Results

Recently, the implementation of the simulator was carried out in the class of *Improvement of an Organizational Process with Statistical Methods*. A test of previous knowledge was applied so that, once the run is finished, we can compare the results based on two variables: learning before (A MxREP) and after (D MxERP) running the simulation, all this through an analysis of experiments. A sample of 36 students was considered, and the data obtained by our survey is shown in Table 1:

Table 1: Descriptive statistics

Statistics										
Variable	N	N*	Mean	Standard error	Standard deviation	Minimum	Q1	Median	Q3	Maximum
A MxREV	36	0	81.22	3.22	19.31	13.00	79.25	87.00	100.00	100.00
D MxREv	36	0	97.472	0.870	5.218	87.000	100.00	100.00	100.00	100.00

The mean obtained before the activity in the simulator was 81.22. It should be noted that, on average, learning with the traditional classroom method is fine. However, we see a large difference between the maximum and minimum ratings obtained; before performing the activity, the minimum grade was 13 and this value increased to 87.

A student's t-test with two paired samples was done to validate that there is a significant increase in student learning when using the simulator, that is, the research protocol has been followed.

The hypothesis to be checked is that the average of the grades obtained in the exams, which for the study will be called "knowledge gain", is different between the two exams.
H_0: $\mu_1=\mu_2$ The application of the simulator does not make a significant difference in learning.
H_1: $\mu_1\neq\mu_2$ The application of the simulator makes a significant difference in learning.

where:

- μ_1 is the population mean before the simulation
- μ_2 is the population mean after the simulation

It is desired to reject the hypothesis Null H_0, which will be able to demonstrate the veracity of H_1 and validate the assumption that students improve their academic performance using the simulator in industrial engineering topics.

With the support of Minitab software, a student's t-test with two paired samples was done to validate that there is a significant increase in student learning when using the simulator, that is, the research protocol has been followed. The results are shown in Table 2.

Table 2: Results of the Test

Test	
T value	P-value
- 5.31	0.000

With the results of the student's t-test with two paired samples it can be proven that with a p-value of 0 and 95% confidence level H_0 can be rejected; therefore, it was found that the two means were different. Consequently, it can be concluded that learning acquired by students is greater when the simulator is applied.

In figure 6 we can see a boxplot compares the academic performance before an after the simulator. It is very clear that the variability before the activity is higher, and the grades seems to be lower in comparison with the ones obtained after the simulator.

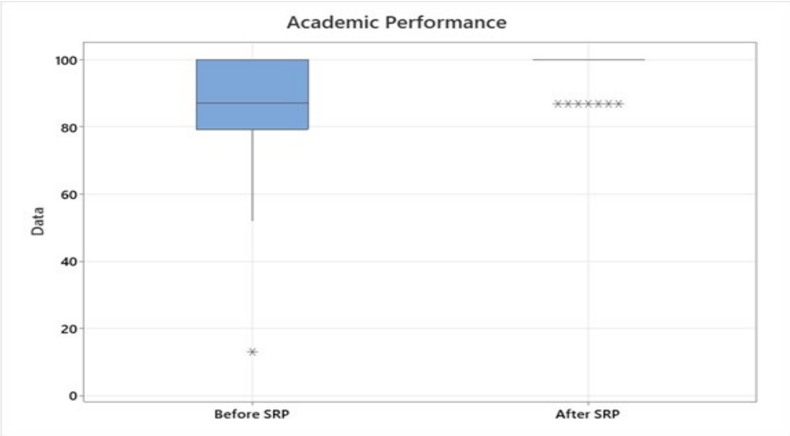

Figure 6: Boxplot before and after applying the simulator

In addition to the results presented above, non-quantifiable differences in the performance of this activity could be observed. It was possible to see the clear participation of all the students, even in some of the teams there were discussions about what was the best strategy to obtain the greatest benefits. Despite the fact that their involvement was noted, it was observed that they treated this activity as if it were another one, that is, there was a lack of emotion, which arrived at the moment of explaining how they would do the same activity but through the simulator.

5. Conclusions

Although the sole use of gamification in teaching shows good results, the use of the ERP simulator increases the student's engagement using virtual and augmented reality. Besides, the characteristics of the MxREP make it a useful tool for a diverse variety of courses since it integrates topics from Industrial and Mechanical Engineering.

Gamification causes an addition to the platform, and indirectly, the student begins to develop knowledge, moving from passive to active learning. We observed an improvement in the student's emotional stability, and satisfaction with the course is also observed.

As students, it has been a pleasure to collaborate in the design of improvements to the simulator. Our vision in two educational ways, as gamers and students, allowed us to provide feedback to teachers on design improvements. Before the research group opened its doors to assistants there was a disconnect between what the student expected from their classes and what the professor offered. The research interns became that liaison that changed the channel of communication and allowed for better learning. It should be remarked that this development was carried out under the auspices of the Institute for the Future of Education of the Tecnologico de Monterrey.

It is clear that the development of this simulator does not end here. Future objectives are to design cars, add data science and machine learning to create predictive models, making it a unique simulator in the market that could be used in other Universities. In addition, the research group plans to continue to allow the collaboration of students as assistants so that educational innovations can continue to develop with the valuable feedback they provide.

Acknowledgements.

The authors would like to acknowledge the financial and the technical support of Writing Lab, and Tecnologico de Monterrey, Mexico, in the production of this work.

The authors would like to acknowledge the financial support of NOVUS 2020, ID 199 an initiative of Tecnologico de Monterrey, Mexico, in the production of this work.

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