PROBLEM SOLVING RACE: GAMIFICATION TO SOLVE INDUSTRIAL ENGINEERING PROBLEMS IN THE DISTANCE AND CLASSROOM LEARNING

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ABSTRACT
In the Tec21 educational model [1], one of the core competencies is problem-solving, which is also one of the most requested skills by companies for hiring candidates. Solving problems is a priority competency in training the Tecnologico de Monterrey students. This paper describes the academic experience of a gamification design using problem-solving in a role game.
The objective was to redesign the primarily theoretical course to be more empathetic to the confinement situations of students during the pandemic, leveraging available educational technology using gamification. Thus, we created a board game called Problem-Solving Race (PSR), which has evolved into an online game students can play to develop this and other competencies for the graduation profile that we seek in our students. The university's "Virtual Campus" platform (using virtual reality technology) facilitated the gamification for a practical experience that highly engages the students.

Keywords: Gamification, educational innovation, problem-solving, higher education

1 INTRODUCTION
Design is everything. Structuring a class to share learning with students requires a well-planned design process. Before the COVID 19 health emergency, course designs were primarily aimed at classroom exposition or workshops. Few university teachers were prepared to conduct their classes 100% in a remote modality, generically termed "distance learning."
Since 2003, the School of Engineering and Sciences of Tecnologico de Monterrey has been seeking ways to combine the theoretical topics of industrial engineering classes with practice laboratories. This gave birth to a weekend experiential workshop, once during the semester, where students enrolled in "Design of Experiments" and "Design of Work and Statistical Quality Control" attended an integrative six-hour workshop to solve a fun and playful challenge in which the teachers ensured that the students put into practice their classroom learning. The workshop aligns with the Tec21 educational model [1] that migrates traditional learning to challenge-based learning to acquire competencies through practice activities that simulate real scenarios.
In 2008, Meccanos [2] were integrated to solve these challenges, which allowed designing activities to do in the class; in 90 minutes, the students could combine practice and theory. In 2013, the virtual plant was born where the first attempt was made to gamify all the processes of a car assembler and expose the best practices of industrial engineering techniques. Teams competed to assemble cars with the most competitive profits and meet the production, management, and quality standards of a current car manufacturer.
Gamification alone makes students very competitive. Specific training unit strategies and tactics applied in the classroom allow students themselves to seek through indirect learning the best techniques and practices that permit them to win. Board games are popular among students of all ages because they develop the ability to work individually and as a team. In that competitive and relaxed environment, learning is attained more individually, according to Ocanto 2009 [3]; in neuroscience, it is known that enthusiasm and total attention to the activity results in more irrigation of blood throughout the brain. This oxygenation creates the necessary conditions for more extended-duration learning.
When the university closed and students went home due to the pandemic's confinement, the interactive face-to-face learning and socialization were broken. Techniques and design knowledge had to fit

distance learning platforms that allowed student interactions and gamification experiences. Managing and resolving how to promote learning had to consider a factor not conceived before the pandemic and as time pass by the relevance of emotional stability increased.
The main purpose of the design focused on making an online simulator for the virtual plant. The project had a release time of 15 months, therefore, concurrent strategies had to be established. One of them was to solve small challenges through knowledge capsules in a board game called *Problem-Solving Race*. The research development process and results are detailed in this scientific essay.

2 DEVELOPMENTS

To develop this educational innovation, we conducted an immersive, empathetic exercise (from the students' perspective) involving the topics and subjects in which gamification would be applied. The methodology proposed by González, Saavedra, Caballero, Acuña, and Lule 2021 [4] of EPDE was its model in which the design of experiments is merged with *Design Thinking*, taking as the transcendental variables the involvement in class (*engagement)*, the learning of specific training unit topics (*learning)* and, finally, the development of transversal and graduation competencies.
Using thought engineering, we began to analyse the appropriate parameters for each variable. Based on *engagement*, we found that gamification was the most reliable technique. The first problem-solving activity designed for the online class with 329 students used mini-challenges that were solved using different platforms and software. For the variables of learning and competencies development, the objectives were achieved. However, the students expressed their annoyance in their comments because many hours were required to solve these challenges, and being a remote team activity, not all students were able to participate significantly under this modality.
A more profound empathetic study detected a variable that was not being considered, emotional stability. We found that the reason for this problem was that each student during confinement had a unique home and study environment that influenced the full development of their educational process. In 2020, the university began the implementation of a new educational plan. Its most crucial element, the challenge, was very much affected by the Covid19 confinement. The challenge had to be addressed collaboratively among the students, teachers, and external training partners, who open the doors of their facilities for students to solve real-world problems.
Each school semester is divided into five-week learning blocks in which students solve a challenge with the training partner. The topic modules provide the information and theory to support resolving the challenges. Due to the confinement, this educational strategy had to be modified for remote work and resolving the challenges without affecting academic quality.
We applied surveys at the beginning of each training unit to find out the appropriate parameters for the *engagement* variables. Exploratory questions aimed to find out the students' hobbies, sports, and extracurricular activities, their emotional state resulting from confinement and online classes, and what they do not like a teacher to do in distance learning.
Thus, we found that the classes should have multi-level gamification components [5] from a low level, using Kahoot, Socrative, and Mentimeter platforms to compete for the best responses, to activities designed for a role-playing game when in 90 minutes, the students solve the challenges with an adequate balance between playfulness and technique. Recent studies like the one presented by Welbers 2019 [6] have reached the same conclusions as ours.
As teachers, we create academic activities that help students learn and enjoy. What does the concept "Wow" mean in an educational lesson? Desmet, Porcelijing and Dijk [7] define that, in essence, "Wow" is nothing more than a simple verbal exclamation, so an academic *Wow Experience* is a combination of pleasant surprise, fascination, and increased learning. This work describes how we designed an academic activity using gamification to solve problems in a board game.
After making several prototypes and testing them in *focus groups* with students from different curricular programmes ("careers") and semesters, we created the *Problem-Solving Race (PSR).* It has four modalities, the board game with 21 and 42 stages and the virtual one with 21 and 41 stages. It is related to the philosophy of the marathon and a board game widely used by children in Mexico called Snakes and Stairs [8], a Western version of a game created in India in the sixteenth century called Gyan Chaupar or Leela. It was known as The Game of Knowledge and imparted the philosophical teachings of its culture.
For each class, depending on the specific topic that the teacher wanted to gamify, a problematic situation (not to be confused with a problem) and three key moments were designed when the work teams were

formed, and the problem was defined. The second stage, ideation, was oriented to information analysis and learning of specific topics. The third stage was the solution, where students presented their solutions to the problematic situations. Figure 1 shows different steps of the PSR using augmented and immersive reality as well the board table game.

Figure 1. Some steps of PSR using AR and IR, at the board table

The graduation skills developed during this activity are teamwork, critical thinking, problem-solving, and communication.

The most important competency that the PSR develops in the student is the solution of problems because it is focused on learning different methodologies and techniques, depending on the topic underlying the problematic situation that the student encounters during the activity.

For the problem definition, we relied on the Soft Systems Methodologies (SSM) proposed by Checkland [9] and the technique of Kepner and Tragoe [10]. Their proposal focused on considering a problem as a deviation between what *should be* and what *is*. Four questions were answered that ultimately helped frame the definition and the problem statement. It calls to mind Einstein's famous comment that by knowing the problem, you have 99% of the solution.

During ideation, students learn design-of-experiments techniques, statistics, and data science directed by specific problem-solving techniques such as Design Thinking [11], DMAIC, eight disciplines, and others that allow students to create feasible solutions. Students test their proposals and prototypes in the solution stage, adjust parameters, and present a final solution.

Each learning stage utilizes agile project management with different *springs* that allow students to have concurrent learning individually and as a team. For challenges focused on the aerospace and automotive industry, augmented and virtual reality practices potentiate learning in students by providing active experiences instead of passive theoretical learning. To explain the techniques and methodologies, we created short videos that students can consult and simple explanations in PDF documents.

After creating the PSR, the subsequent development challenge was to create the platform so that it could be used in remote classes. The first pilot runs of gamification were made through the Zoom platform with individual sessions where students solved specific challenges in their group activity placed in the CANVAS learning platform. The videos' PDF files were accessed through a Google drive.

Twenty percent of the activities in the stages were playful with no apparent connection to the problem situation or challenge. Nevertheless, these activities were to develop transversal competencies.

The lesson required at least two teachers and 3 assistants to attend the activity simultaneously, using a *script* with times that had to be followed rigorously to complete the gamification in 90 minutes. In November 2020, this immersive reality of the "Tec Virtual Campus" was introduced through the Virbela platforms [12], providing a metaverse world of possibilities. Students could interact as if they were in the classroom, completely engaged.

On this platform, we replicated the stages of each activity or adapted them to the different Tec Virtual Campus scenarios. The students began by entering a reception in a *Conference Hall* for the time of definitions. Before the activity, the students were trained to use the platform installed on their personal computers; then, they designed their avatar and personality to use in their group. In this definition stage, a high-performance work team was formed, also having unique characteristics. Through the screens and walls, the students obtained the problematic situation information; they could also see it on their CANVAS platform.

After the reception in the Conference Hall, the students moved to an *Exhibit Hall* where, concurrently, there were videos with detailed explanations of the problem situation, techniques, methodologies, and

augmented reality lessons [13]. Thus, students learned as a team together and not individually, sequentially, optimizing research times.
After defining the problem, the students played on the *Soccer Field* and the *Beach*, where they found clues in the speedboats while having fun as if they were really at sea, collecting and learning indirectly from knowledge capsules, and then moving to the *Lighthouse* where the ideation stage took place in a very relaxed scenario and a view of the sea.
After this creative process, another playful moment took place on the beach stage, where the students had to do a group choreography to music selected by the teacher. This crucial stage strengthened teamwork and coordination among the members, preparing them to move to the prototype test and final presentation in the conference room.
All this and the physical and virtual gamification through Zoom followed a rigorous time *script* to pass through all the stages and finally solve the defined problem.

3 RESULTS

The research protocol was divided into two parts, the quantitative variable that measures the learning of the topic and subtopics presented during gamification and the qualitative variables of student *competency development* and *engagement*.
We applied an individual student knowledge test in each group before the gamification and another exam after it to measure the learning variable. The *paired student's t-test* was used to compare both exams. The null hypothesis declared that the average score of each test was statistically the same, and the alternative hypothesis that it was different, so it could be inferred that gamification produced significant learning among the students.

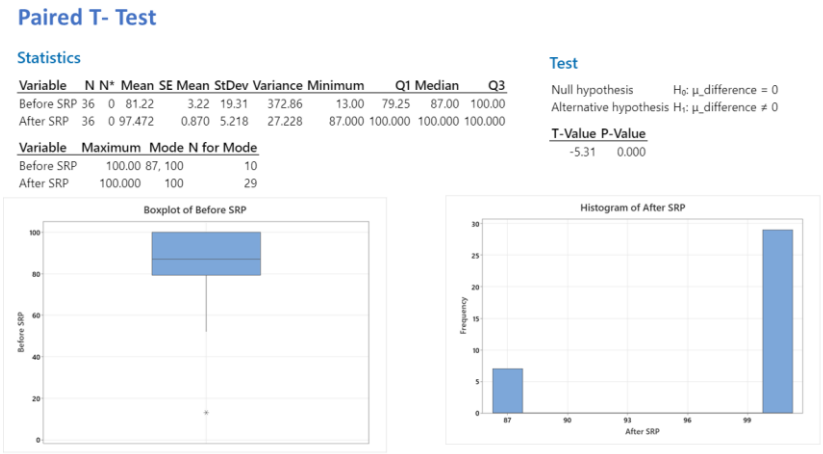

Figure 2. Descriptive statistics and paired T-test

Figure 2 shows the results obtained for the Systems Dynamics class, which used a PSR game about generating electrical energy through hydroelectric sources; the students had no previous experience or knowledge in this area. The before-gamification exam result was a mean of 81.22 out of 100 points, which increased to 97.47 after applying the gamification. The paired T-test produced a statistic of -5.31 with a sample of 36 students, so we could infer at 95% of confidence level that the gamification did have a statistically significant difference for the students' learning variable: since the p-value was 0.000.

4 CONCLUSIONS

The gamification of challenges or problems designed in lessons within the Tec Virtual Campus platform managed to create a different experience for the students, motivating them to participate and to engage, as indicated by the improvement in the learning variable. Gamification generated highly significant learning, allowing the students to apply their semester knowledge in real cases in a funny way.
Competing in a sporting event or contest motivates and leads to an excellent result. Gamification also motivates, but for positive results, a high dose of creativity and social commitment is necessary for the students.

If we call this a "Wow" experience, the equation would be:
Wow= Experience (Gamification + activity + creativity) ^ Virtual Campus
Where gamification, activity, and creativity are summed and mounting it on the virtual campus potentiates it, so the experience becomes unique.

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