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Challenge-Based Learning Strategies Using Technological Innovations in Industrial, Mechanical and Mechatronics Engineering Programs

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Our university has implemented the Tec21 educational model, based on four fundamental pillars: Challenge-Based Learning (CBL), flexibility, inspiring trained faculty, and a memorable educational experience. The purpose of this study was to evaluate the results of CBL implementation experiences at the beginning of undergraduate engineering programs using technological innovations such as 3D printing, DC motors, and microcontrollers. Three challenges were designed: Rube Goldberg, Cable Car, and Mini Drag Race. The challenges were implemented during at least two years where over 1,000 engineering freshmen took part. The challenges were evaluated by quantitative and qualitative methods. Overall, students enjoyed the learning experiences, learnt new technologies, and developed disciplinary and transversal competencies. Students were also more engaged and motivated to pursue their engineering academic program. These strategies challenged the students with the basic characteristics of the new Tec21 educational model. Finally, faculty involved in the implementation of these challenges expressed they required to get out of their comfort zone, learn new technologies, and change their traditional role to become a coach.

Keywords: challenge-based learning, higher education, innovative education, digital technologies, active learning

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INTRODUCTION

The cov19 pandemic brought a space for deep reflection to education. It evidenced the need for educational models that evolve at the same speed, and faculty members that are increasingly prepared and open to face current ethics (Caratozzolo et al., 2021; Chand et al., 2022). It also suggested the evaluation of the level of continuous training of faculty, and a challenge for them to keep up with new technological tools and facing voracious students in the acquisition of knowledge (Meyers & Jones, 1993; Fahadi & Khan, 2022). Traditional educational models, based on sequential subject content, are being replaced because they are no longer effective in the face of technological and pedagogical innovations that have arisen due to the social and economic changes in this 21st century. Now educators are challenged to seek holistic and sustainable educational models (Caratozzolo et al., 2021). In a globalized world facing problems such as climate change, the United Nations has issued its seventeen Sustainable Development Goals (SDGs) and has defined cross-cutting objectives. For this reason, professors are responsible for educational strategies that sensitize new generations about current problems and establish plans to solve large-scale challenges (Hernández-de-Menéndez et al., 2019). In this, the construction of knowledge and the role of science play fundamental roles. Major changes in curriculum content knowledge and competencies, as well as instructor training, is required (Al Kandari & Al Qattan, 2020).

Since the summer of 2013, our university has been gradually implementing the Tec21 educational model, which aims to provide students with comprehensive training that prepares them to face the challenges of our changing and uncertain world and ensure the international competitiveness of its graduates (Hernández-de-Menéndez et al., 2019). It consists of four fundamental pillars: a) Challenge-Based Learning (CBL); b) flexibility; c) empowered and inspiring faculty; and d) comprehensive and memorable educational experiences. In the Tec21 educational model, there are two categories of competencies to be developed: disciplinary and transversal. The first one refers to all the knowledge, skills, attitudes, and values that are considered necessary for professional practice (Nichols & Cator, 2008, 2016; Johnson et al. 2009; Giorgio & Brophy 2001). The transversal competencies are the "soft skills" that are developed throughout the training process of a student in any discipline. They are useful for the life of the graduate and directly influence the quality of the practice of the profession. The workforce demands graduates prepared with the skills and knowledge to face current challenges. Therefore, there must be a close connection between companies and universities to develop academic plans and learning innovations to prepare young professionals that meet job requirements of the digital transformation (Loc et al., 2022; Nakhleh & Hanini, 2022).

CBL looks like but it is not Project Based Learning (PBL). Both approaches engage students in real-world problems and involve them in developing solutions to specific problems. However, these strategies differ in that CBL offers general open questions from which students will determine the challenge to tackle, rather than receiving a problem to solve (Gaskins et al., 2015). PBL presents a problem to solve and often uses scenarios of fictitious cases, not real or where appropriate, controlled by the teachers. On the other hand, in CBL, the objective is not the solution of the problem itself, but the process of developing competencies; the final product can be tangible or a proposed solution to the challenge (Larmer, 2015; Lovell et al., 2013). The differences between these techniques have been previously reported (Membrillo-Hernández et al. 2019). CBL has its roots in experiential learning (EL) whose theoretical basis states that students learn better when they actively participate in open learning experiences than when they participate passively in structured activities. Therefore, EL and CBL offer opportunities for students to apply what they learn in learning modules to real situations where they face problems, discover for themselves, test solutions, and interact with other students within a given context (Moore, 2013). CBL and EL are an integrative and holistic learning approach that combines experience, cognition, and behavior (Akella, 2010). The role of technology in CBL and EL is fundamental for the soon-to-be engineers to develop the competencies demanded by the workforce, including problem-solving, critical thinking, self-learning, creativity, innovative thinking, and lifelong learning. Industry 4.0 technology helps not only decision support, but also continuous learning and knowledge enhancement, enabling formal and informal learning and opening opportunities for adaptive learning and a personalized learning path with asynchronous time for learning activities (Tvenge & Martinsen, 2018). Technology being less of a shock to students gives potential to design new learning experiences to produce skilled learners who can be innovative graduates (Kintu et al., 2017). Engineers must develop a learner mindset to adapt easily to the world transformation, acquiring and updating the necessary knowledge and skills to be competent in this constantly changing environment (Chakrabarti et al., 2021).

Hernández-de-Menéndez et al. (2020) recently published a review of the state of the art regarding technologies that are transforming engineering education, including 3D printing, Robots, Drones, the Internet of Things, Virtual and Augmented Reality, Wearable Devices, Holograms, Virtual Laboratories and Blockchain. Incorporating technologies in the learning process makes education exciting and flexible, allowing students to develop their competencies and higher order thinking skills, and acquire knowledge at their personal pace and at convenient times (Hariadi et al., 2022). The role of the professor must also evolve to a “Teacher 4.0” approach to involve these technologies in the learning experience and promote competencies development (Peredrienko et al., 2020). Teachers must be up-to-date and incorporate learning innovation and technologies to make learning more effective and efficient, motivate students to learn actively to improve learning outcomes and help them to retain longer what they learned (Situmorang et al., 2022).

The objective of this study is to test whether experiential learning within the first semesters of higher education in Engineering can develop competencies that are useful for later semesters. On the other hand, we also intend to test whether the CBL technique is suitable for first-year students skills development and the student's experience with the engineering area. The students participated in three different challenges during their "Introduction to Engineering" course, each one is analyzed in detail, and CBL from the beginning of the career is essential for a better acquisition of lifelong skills.

METHOD

The engineering programs at our university comprise nine semesters. During the first semester, there is a course named "Introduction to Engineering" and it has two main goals: (1) get to know the university and its services for an enhanced university experience, and (2) learn about the chosen engineering program and its applications. In this course, students become familiar with the educational model taught at the university and get to know the different opportunities they have for their professional and personal development during their studies. Regarding the engineering program, the purpose is that the students discover the potential and the different applications, understand the skills and competencies they need to develop and confirm their choice of engineering program. Having these two goals in mind, freshmen students were involved in three different challenges: Rube Goldberg, Mini Drag Racing, and Cable Car. Each challenge presents its own analysis in terms of students' experience and competencies development, and their experimental settings are described in this section.

Subjects and Survey Instruments

Each academic period, undergraduate students participate in the Institutional Opinion Survey to evaluate different aspects of the institution, but mainly their courses and faculty. This instrument provides feedback for improvement of the faculty performance and improvement in relation to the course and its teaching-learning method. The feedback provided is both quantitative and qualitative (with students´ comments).

The survey´s questions and comments considered for this analysis correspond to the academic periods August - December 2017 and August - December 2018. Most students start their engineering program in the fall semester; therefore, groups were more populated in these terms. Table 1 shows the number of students enrolled in the Introduction to Engineering course, per academic program.

Table 1
Number of enrolled students in the course per academic program

Academic Term	Mechanical Eng.	Mechatronics Eng.	Industrial Eng.
Fall 2017	181	124	210
Fall 2018	158	118	220

The survey has 8 questions for each course plus students' comments. From the 8 questions, the following three were selected to be analyzed in this study since they are strongly related to CBL in terms of the learning experience, the evaluation system, and the intellectual challenge for the student:

- Question 2. Regarding conceptual comprehension in terms of their practical application (I solved cases, projects, or real problems, performed laboratory practices or workshops, visited companies or organizations, or interacted with professionals applying the topics seen in class).
- Question 4. Regarding the evaluation system (a set of tools was used to receive feedback about my strengths and weaknesses in the course based on specific criteria and policies defined in a timely manner)

- Question 5. Regarding the level of intellectual challenge (I was motivated and pushed to give my best effort and meet the defined goals with quality benefitting my learning and personal development)

Additionally, a student satisfaction survey was applied to a sample of students (n=200) that participated in these challenges during different academic terms. The survey asked them about their preferred challenge in the Introduction to Engineering course as well as their perception of competencies development.

CBL Implementation

Rube Goldberg

A Rube Goldberg machine is a device with several steps in a chain reaction to accomplish a usually simple task in a complicated manner. The main elements of a Rube Goldberg machine are the six classical simple machines: lever, inclined plane, wheel and axle, screw, wedge, and pulleys. These elements are combined to build compound machines. Having the main task of the Rube Goldberg machine in mind, the design of the machine starts usually at the last step and goes backward step by step to complete the device. The machine is built using common household items such as dominoes, marbles, plastic cups, strings, magnets, books, balls, and toys, among others. The machine is set up step by step and adjusted to work perfectly, learning from each run to improve it and have more precise movements.

The analysis of the implementation of the Rube Goldberg challenge was carried out during five consecutive semesters (spring semester of 2017 to the spring semester of 2019), involving 1,326 engineering students from different disciplines: mainly Industrial Engineering, Mechanical Engineering, and Mechatronics, and some students from Innovation and Development, and physics programs. The challenge was measured by: (1) Performance during the challenges and (2) Student satisfaction. The challenge was implemented in two stages: (1) pre-recorded video and (2) live stage. During the first stage, students got familiar with the Rube Goldberg Machine. At this stage, each team of students had to design and implement a device to throw a ping-pong sized ball into a household bucket machine, having at least 8 steps, including one reversing action, using material they had at home and being able to use the space of a common bedroom. There was no restriction regarding time to complete the task or limited space and resources. As deliverables of this first stage, students prepared a report and a video as evidence of their work. The report must include the description of the device and how it meets all the required design specifications, a schematic sketch of the device, the link to the video that shows the machine running, and the challenging learning outcomes. The video should present the set up before the run, a one-shot video of the machine working as planned, and a few bloopers. For the second stage, the task of the Rube Goldberg machine was the same: to throw a ping-pong-sized ball into a household bucket. However, this time there was a time constraint (set up and running in less than 10 minutes), a space constraint (fit the device on a given table), and include a magnetically actuated action, and a heat actuated action. Electronics, motors, and batteries were welcome but optional. On this live stage, different teams participated simultaneously to set up and run their machine, while a judge and an audience observed.

Mini Drag Race

The objective of the Mini Drag Race Challenge is for a team of students to design and build a car and race it along a straight-line track in the shortest possible time. Each team uses a direct current (DC) motor, a switch, and a 9 V battery as its main energy source. The maximum accepted dimensions of the vehicles were 15 cm long x 15 cm wide. The track has a central guide of 8 mm and a total length of 4.8 meters. The challenge was also presented at the beginning of the course. Along the semester, workshops were offered to students with the goal of gaining basic skills needed for the challenge.

The study of the race car challenge includes 6 consecutive semesters (fall semester 2016 until spring 2019) for four engineering programs: Mechatronics, Mechanical, Industrial, Electrical and Automotive Design. A total of 570 freshmen had the drag race car challenge experience. It was measured by: (1) critical thinking and (2) problem-solving. The challenge included four phases: (1) workshops, (2) design, (3) prototype, and (4) team competition. During the first phase, several workshops, such as soldering, CAD (Solidworks), 3D printing, electric tools, and materials, were offered to students to learn the basic set of skills needed for the challenges. In addition, there were visits to multiple labs at the campus so that students would get familiar with the equipment that was available for their projects. For phase 2, students designed a basic mechanism to transmit the rotational movement of the motor shaft to the wheels of the car. As the main goal is for the vehicle to register the shortest run time, the car should be lightweight but at the same time robust enough to complete the track. As mentioned before, students learned Solidworks during the semester and for this challenge, it was optional for them to design a piece and 3D print it. Some teams chose this approach. Phase three consisted in building the prototype. The prototype must be an original design. It was not allowed to use prefabricated models, such as toys and scale designs. It was forbidden to use any type of energy besides the electric power from the batteries to help the mobility of the device (no photovoltaic cells or compressed gas cans). The vehicles had to include an on/off switch, and a maximum guide of 8 mm wide. For phase 4, all teams had to register their prototypes and be validated by a judge to ensure that the vehicle followed the rules. Each team had a 5-minute turn and the opportunity to run the vehicle three times; the best time was recorded.

Cable Car

The Cable Car challenge aims to design and manufacture on a small scale, using CAD software and 3D printing. The cable car must move along a cable in the shortest possible time. The cable car uses the following components: DC motor, 9 V battery, and switch. The design must consider that the cable car must adapt to a cable already fixed at both ends, which has a diameter of 0.48 cm, in addition to considering that it must be light, it must also be robust enough to complete the route. The maximum allowed for the cable car is 8 cm long, 8 cm high, 8 cm wide and a maximum wall thickness of 1 cm. The challenge is presented to the students at the beginning of the course so that they can take courses and workshops and have their CAD design on time.

The analysis of the Cable Car challenge comprises its implementation during 6 consecutive semesters (fall semester 2016 until spring semester 2019), involving a total of 570 engineering students. The age range of the students who participated in the challenge was between 17 to 19 years old and from three different engineering programs: Mechatronics, Mechanical, Industrial, Electrical, and Automotive Design. The challenge was measured by: (1) collaborative work and (2) intellectual curiosity and passion for learning. The challenge comprises four stages: (1) Learning workshops, (2) 3D design and prototyping, (3) Component integration, and (4) Team competition. In the first stage, students take practical workshops to learn the basics of how to strip a wire and how to use a soldering iron, as well as the basics of an electrical circuit that connects a battery with a motor and a switch. They also have access to eCourses for a free online certification for Solidworks CAD software, then receive a session to familiarize themselves with the software. For the second stage, students have an instructor-led training session in CAD software, in which they learn the basic steps, as well as answer their questions while working on the design of their own cable car. At the end of the session, the students will know the requirements so that the CAD file is ready to be 3D printed correctly, after this the students send their STL file, they receive their 3D printed cable car after 4 weeks. During the third stage, students adapt the switch, the battery, the motor, and the basic mechanism designed to transmit the rotational movement of the motor shaft and thus achieve the operation of their model, for which they need the knowledge acquired in the workshops that they were taught in stage one. Finally, in stage four the competition takes place, in which each team has 3 opportunities to run their cable car and get it from one end of the cable to the other in the shortest time possible. The cable has 5 marks along with it, so in case the team does not complete the full length of the cable, the team can get certain points based on the performance that was obtained.

FINDIGS

Specific results per challenge

Rube Goldberg

In the first stage of the Rube Goldberg Machine Challenge, the evidence was recorded and there was no limit on time or number of trials. Therefore, all the machine designs worked sooner or later. Some of the lessons learned at this stage were: to avoid complicated steps such as projectile motion, put water or clothes within the bucket to prevent the ball from bouncing out, have a reference mark to control the initial force for more controlled movements, and short and straight dominoes lines are preferred, plan the machine with its steps and materials, communication among the team, patience, learn from the mistakes and change the initial plan if something is not working.

The second stage had limited time, limited space, several teams participating simultaneously, and a judge per team and audience watching. Given these conditions, it was harder to achieve the main task. Analyzing the performance of the students, in average, 85% of the teams set up and ran their machine during the 10 minutes. Though, only 59% of the devices completed the task of throwing the ball inside the bucket. Most of the teams (94%) included a heat-operated action, generally a candle. Eighty-three percent of the machines had a magnetic action and only 13% of them included the use of electronic devices such as switches, sensors, and actuators.

The applied surveys showed that 93% of the students enjoyed the challenge and 94% perceived it as an innovative learning experience. Students mentioned it was a great satisfaction to see the machine working and completing the task. Some lessons learned from this stage were: each team must plan and design the machine beforehand, it must be run many times to adjust the device, each team member must know his tasks and responsibilities, time management, and keep calm and work under pressure.

Mini Drag Race

The Mini Drag Race Challenge was evaluated with three indicators: (1) performance, (2) final report grades, (3) and student satisfaction. Performance stands for how well the vehicle did during the competition within the three opportunities, if the vehicle completed the entire track with no problems, best time recorded, etc. For the final report grades, each team gets graded based on the prototype performance in the competition and the final report. For this indicator, the average of the final report grades is considered. For the final report, the team must submit a report with the following: challenge description, materials used, design process, final design proposal, photo of the final mini drag race vehicle prototype and team members, results of the competition (best time), major incidents during the entire process, video as evidence of their functional prototype and conclusion. Figure 1 shows some examples of the vehicle prototypes ready for the competition.

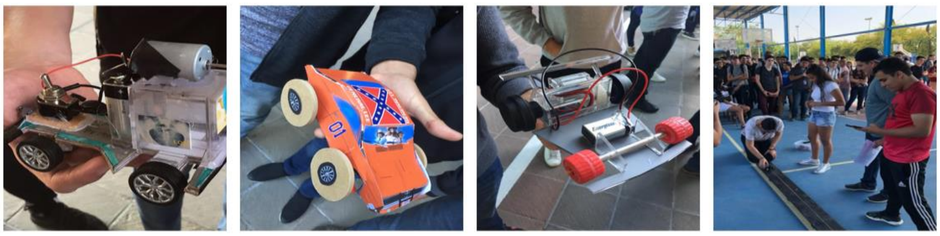

Figure 1
Examples of mini drag race vehicle prototypes

The third indicator is the results of a survey that was applied to the students to identify if the challenge had an impact on the student's learning process and to recognize if there is any difference with the challenge´s restrictions and their relationship with the competencies that were defined, critical thinking and problem solving. The outcome of the survey showed that 67% of the students considered that they developed both competencies during the Mini Drag Race Challenge. 24% of the students think that they developed only problem-solving competencies and 5% only critical thinking. Only 4% of the students think that these two competencies were not developed with the activity. It is relevant to mention that this is a course that students take during their first semester at the engineering graduate program of Tec de Monterrey. Even though the use of Solidworks and additive manufacture was not requested in the Mini Drag Race Challenge but mandatory on the Cable Car Challenge, the survey showed that 99% of the students consider that the use of a modeling CAD software and additive manufacturing (3D printing) is beneficial for those type of projects where prototyping is needed. In addition, students agreed on the relevance of developing these hard skills for their future professional life as engineers. With these types of challenges, students can reinforce their decision to become Mechanical, Automotive, or Mechatronics engineers.

Cable Car

The cable car challenge was measured by two indicators: (1) Performance during the competition and the average of the final report grades, and (2) Student satisfaction survey at the end of the challenge. Students get the grade based on performance during the competition, which means that the cable car must work, that is, it can complete the entire length of the cable and how fast it is, etc. On the other hand, the final report is based on documenting all the experience by describing the challenge, the justification of why that specific design was selected, as well as the entire list of materials used in it, the image of the prototype that was made, team members picture, performance during the competition (best time and description), a link to the video as evidence of the functional prototype, and the learning outcomes that were achieved based on this challenge. Figure 2 shows some examples of Cable Car prototypes.

Figure 2
Examples of cable car prototypes

Finally, an anonymous satisfaction survey was applied to the students to detect the relationship between the development of competencies, collaborative work, and intellectual curiosity, concerning the challenge of the cable car. Forty percent of the students considered that they were able to develop both skills during the cable car challenge. By contrast, 30% considered that they only developed collaborative work, while 18% indicated that they only developed intellectual curiosity and passion for learning. Only 12% mentioned that they did not develop either of the two competencies during the challenge. Overall, the students enjoyed the challenge and obtained positive results, as, according to the survey, 76% shared that they liked the learning experience, in addition, 99% of the students indicated that Solidworks software and 3D printing are useful tools that prepare them for their professional life.

Performance during the challenge

Each semester, the first-year engineering students took part in the three different challenges along the semester in the following order: 1) Rube Goldberg, 2) Mini Drag Race, and 3) Cable Car. Students received an academic grade per challenge considering the technical report and the team performance during the challenge. Table 2 shows the average of the academic grades per challenge per semester. The Rube Goldberg challenge was their first experience with CBL and the uncertainty it involves. It was a great experience to help students to get organized, communicate, plan ahead of time, integrate as a team, and learn to deal with uncertainty and work under pressure. Then, the Mini Drag Race involved compulsory electric components that required students to get training in basic electrical circuit concepts and soldering techniques. Finally, the Cable Car challenge integrated the Mini Drag Race electric circuit with additional technological elements such as CAD modeling and 3D printing and a mechanism to move the prototype along the cable. Even though the Cable Car was a more complex challenge than the previous two, students showed in general an improvement in their grades. For the Cable Car challenge, students had to plan the entire design and model the 3D part with anticipation to have it printed before the deadline and have enough time to conduct prototype tests and adjustments. As a result, cable car experience performed better than the mini drag racing cars during the competition.

Table 2
Challenge academic grades (average per semester)

Semester	Rube Goldberg	Mini Drag Race	Cable Car
Spring 17	90.00	87.50	100.00
Fall 17	93.71	89.02	95.16
Spring 18	88.22	91.00	84.00
Fall 18	98.38	73.89	98.57
Average	92.58	85.35	94.43

Student satisfaction survey

At the end of each semester, students participated in a perception survey. When students were asked which challenge, they liked the most, Rube Goldberg was preferred by 40% of the students, Mini Drag Race by 35%, Cable Car by 21%, and Mini Splash by 4%. The Mini Splash challenge was a pilot, similar to the Mini Drag Race but with the twist that the prototype had to float and perform on the water at a fountain at the campus. It was decided that 4 challenges were too many for a single semester, so we kept the other three given the different technological elements and learning experiences they involve.

A pillar of the CBL didactic technique is the competencies development along the process. Some of them are critical thinking, problem-solving, teamwork, intellectual curiosity, self-learning, tolerance to frustration, resilience, and engagement. When students were asked about their perception of how much they developed these competencies during the Introduction to Engineering course (Figure 3), with a 5-point Likert scale, the top three responses were: Problem Solving (88%), Self-learning (86.4%), and Intellectual curiosity (85.3%). On the other hand, the lowest ones were: Tolerance to frustration (79.3%), Resilience (82.6%), Engagement, Teamwork, and critical thinking (84.8%).

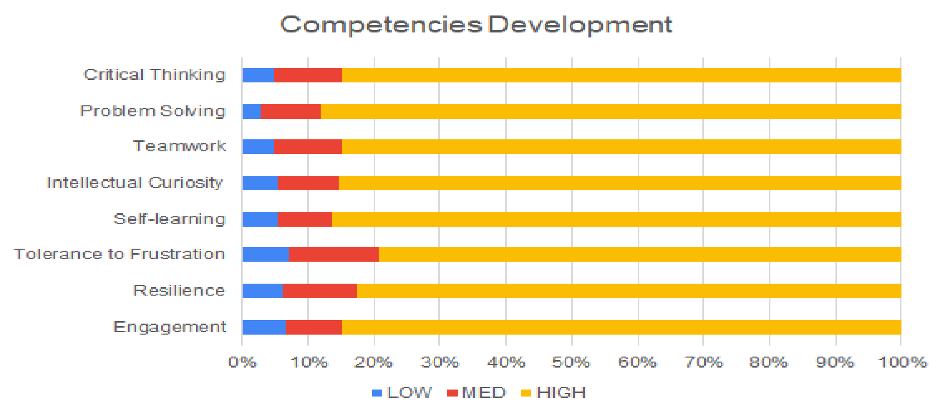

Figure 3
Students' perception of competencies development (n=200)

However, when students were asked which competency, they developed the most with these challenges, the top three responses were: Teamwork (25%), Resilience (18%), and Engagement (15%). The competencies less voted were: Critical Thinking (2%), Self-learning (7%), and Problem Solving and Intellectual Curiosity (10%) (Figure 4).

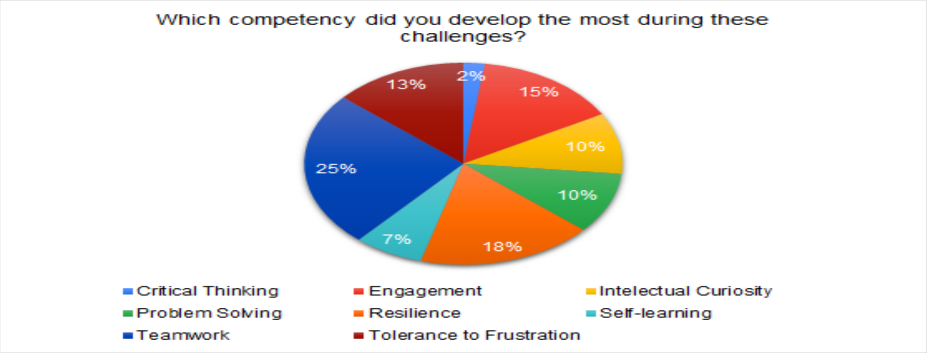

Figure 4
Most developed competency (n=200)

Overall, students were satisfied with the Introduction to Engineering course. Eighty-two percent of students mentioned that they enjoyed the course a lot and that they recommend implementing these challenges with future freshmen generations.

Institutional Opinion Survey

The Institutional Opinion Survey is a continuous improvement instrument in which students evaluate their courses and faculty each academic period. This instrument provides useful feedback to improve the teaching delivery, the learning experience, and faculty performance. The feedback provided is both quantitative and qualitative (with students´ comments). Table 3 shows the results for academic terms Fall 2017 and Fall 2018, in a scale of 1 to 10, where 10 is the highest score. Overall, students evaluated the course with high scores, which agrees with the results obtained in the students‘ satisfaction survey.

Table 3
Institutional survey results for academic terms Fall 2017 and Fall 2018 (Scale 1-10)

Engineering program	Academic Term	Q.2	Q.4	Q.5
Mechatronics	Fall 17	9.42	9.52	9.23
	Fall 18	9.87	9.59	9.47
Industrial	Fall 17	9.35	9.25	9.15
	Fall 18	9.16	9.33	9.20
Mechanical	Fall 17	9.29	8.98	9.11
	Fall 18	9.58	9.16	9.37

Feedback comments to faculty followed a common process of analysis: (a) review of comments in total, (b) category assignation according to related topic, (c) frequency of comments according to affinity, (d) comments related to challenges. Table 4 describes the comments categories. Each comment was analyzed and subdivided if it described more than one topic. At the end, the frequencies were considered, and the percentage of the total number of comments found for related topics (Table 5). As it can be seen, the greatest impact on students is linked to the faculty's performance in the course, followed by the impact on the dynamics of the course, and the least mentioned topic was the effect on students of the activities carried out. Considering that the question is directly related to the professor, it is interesting to find that almost 30% of the students' comments were related to the dynamics of the class, the challenges they developed and the impact on their motivation related to their discipline.

Table 4
Comments categories

Topic	Description
Classroom dynamics	Challenges that generated enjoyment, interesting activities considered excellent activities, captures attention in class, fun class.
Impact (effects) on the student	Motivates the student to work hard, generates excitement for the engineering program, motivates to develop a life and career plan.
Performance as a course faculty	Commitment to the students, resolves doubts, cares about the students, very experienced, provides information, shows passion for his /her course.
Performance as a person (faculty)	Nice person, flexible, in a good mood, willing to help.
Role of an academic program director	Supports students, resolves doubts about the academic program, gives good advice.

Table 5
Analysis of student comments by category

Category	Mechatronics	Industrial	Mechanical	Total
Classroom dynamics	20.00%	15.69%	18.18%	16.88%
Effects on the student	4.00%	15.69%	9.09%	11.88%
Performance as a course faculty	40.00%	44.12%	51.52%	45.00%
Performance as a person (faculty)	16.00%	10.78%	15.15%	12.50%
Role of an academic program director	20.00%	14.71%	6.06%	13.75%

DISCUSSION

In the Rube Goldberg challenge, some students were creative enough to introduce the use of sensors, actuators, and microcontrollers in their designed devices. For the Mini Drag race and the Cable Car challenges, the use of technology was not optional. In both challenges, students used a DC motor, batteries, and a switch to make a simple electrical circuit for their prototype's motion. Additionally, in the Cable Car challenge, students learned how to model basic designs in CAD software and then print them in 3D. In general, with these challenges, the first-year students worked with electrical circuits, microcontrollers, CAD design, and 3D printing, which are some of the technologies that are transforming engineering education (Hernández-de-Menéndez et al., 2020). To help students with the use of these technologies, the teaching team offered basic courses on electrical circuits, CAD design, and 3D printing. We also involved the ASME (American Society of Mechanical Engineers) student chapter to help with these courses and to be judges.

This research on the use of academic challenges at the beginning of undergraduate engineering programs aims to confront students with the basic characteristics of the new Tec21 educational model that is based on CBL. Despite our previous studies on the implementation of these challenges (Lara-Prieto et al. 2019; 2020, Arrambide-Leal et al. 2019), the analysis of more semesters applying it and studying the comments of students and professors gives more general usefulness to this course. It should be noted that the experience of learning "by doing" provides the student with a dynamic of participation that motivates him to continue his path at the level of the engineering career. This generates a positive expectation of the model.

It is also very relevant to discuss Challenge Based Learning from the perspective of faculty. As professors, we see the benefits of implementing CBL in this course: students have learning experiences outside the classroom, collaborative work, experiential learning, challenges linked to the engineering discipline in an active way, student engagement, and motivation with their engineering. The program, direct feedback from students throughout the process, among others. However, there is a cost to the teaching staff compared to traditional educational methods. First, professors need to get out of their comfort zone and do things differently. Our experience implementing these challenges taught us to work as a team, which is not so common among faculty members (Membrillo-Hernández et al., 2021). The implementation of these challenges implies a large amount of work in the logistics of each of them, for example, planning, the definition of the rules of the challenge and the instruments for its evaluation, the definition of date and time, reservation of a space for the challenge. place, organize the teams, set up the corresponding tables, track or cable, invite the judges, etc. (Membrillo-Hernández and García-García, 2020). Professors spend more time in their role as coaches of the teams and in the general implementation of the challenges. Overall, we are convinced that the benefits outweigh the costs and that, with practice, professors will learn to implement CBL more efficiently.

Finally, this work was limited to engineering freshmen to study competencies development through CBL and the incorporation of technological innovations. For future work, we want to study student´s disciplinary and transversal competencies development along the different stages of their engineering academic programs. The ultimate goal is to prepare well trained young professionals to meet the needs of the Industry 4.0 workforce and with the ability to keep up-to-date in the lifelong learning journey.

CONCLUSIONS

Experiential learning at the beginning of undergraduate engineering studies proved to be, at least in this study, a trigger for students' curiosity and rapid acquisition of skills such as critical thinking, collaborative work, complex reasoning, and problem-solving. We can conclude that the didactic technique of CBL is an adequate way to promote the development of both disciplinary and transversal competencies. It is no longer just learning by doing, today it is learning by reasoning and acquiring skills that will serve for lifelong learning.

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