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ORIGINAL PAPER

Implementation of the challenge-based learning approach in Academic Engineering Programs

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Abstract

In a world that changes very fast, it is necessary that educational models evolve at the same speed and that teachers are increasingly prepared and open to deal with current problems. *Tecnológico de Monterrey* has implemented the *Tec21* Educational Model based on four fundamental pillars: (a) *Challenge-Based Learning* (*CBL*); (b) flexibility; (c) trained, inspiring teachers, and (d) memorable, integrated educational experiences. The purpose of this study was to evaluate the results of the implementation of *CBL* experiences in two engineering areas within the campus, namely, Mechatronics and Biotechnology. In this article, we first present how a group of teachers adopted *CBL* as a teaching technique, and second, we describe the implementation of flexible education with external training partners using *CBL* in "*FIT*" (Flexible Technology, Interactive) courses. We also analyze various ways to assess the impact of digital technology tools like CANVAS, REMIND, ZOOM, and eLUMEN on competencies. The results of this research indicated that students acquire more knowledge in *CBL classes;* however, the teachers require an adequate training program and must have previously designed proficiency assessment instruments. The testing of various evaluation instruments found that checklists and evaluation rubrics were the most suitable, objective, and transparent in CBL classes, according to the surveys of teachers and students.

Keywords Tec21 Educational Model · Challenge-based Learning · FIT courses · Educational Innovation · Higher Education

1 Introduction

In a world that is evolving with increasing speed, it is necessary to have educational models that evolve at the same speed, and teachers who are increasingly prepared and open to face current challenges through continuous training so that they can keep up with the technologically active and voracious students in the acquisition of knowledge [1]. The traditional educational models, based on face-to-face lecturing of subject content, are being replaced because they have ceased to be effective in the face of technological and pedagogical innovations that have emerged due to the social and economic changes that student and teachers are facing in the twenty-first century. Now educators are challenged to search for holistic, endogenous, and sustainable educational models. The first experimental educational attempts to deal with changing reality in the last decade of the twentieth century and the first decades of the present did not yield the expected results. In a globalized world where there are problems such as climate change, the United Nations has issued its seventeen *Sustainable Development Goals* (*SDG*) and has defined transversal objectives. It holds education accountable for communicating knowledge that will be necessary to solve challenges of great magnitude [2]. In this, the construction of knowledge and the role of science play fundamental roles.

Since the summer of 2013, The *Tecnologico de Monterrey* has been implementing the *Tec21* Educational Model, which aims to provide students with comprehensive

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training that prepares them to face the challenges of our changing and uncertain world and ensure the international competitiveness of its graduates [2, 3]. There are four fundamental pillars of the model: (a) Challenge-Based Learning (CBL); (b) flexibility; (c) trained, inspiring teachers, and (d) memorable, integrated educational experiences. In the *Tec21* Educational Model, there are two categories of competencies to be developed: *disciplinary* and *transversal.* The former refers to all the knowledge, skills, attitudes, and values that are considered necessary for professional practice [4–7]. The transversal competencies are the "soft skills" developed throughout the process of the formation of a student in any discipline; they are useful for the life of the graduate and directly influence the quality of the exercise of the profession.

CBL shares characteristics with *Project-Based Learning (PBL)*. Both approaches get students involved in real-world problems and make them participate in the development of solutions to specific problems. However, these strategies differ in that *CBL* offers general, open issues from which students will determine the challenge they will address, instead of receiving a problem to solve [8]. PBL presents a problem to solve and often uses scenarios of fictitious cases. On the other hand, in *CBL*, the objective is not the solution to the problem itself but the process of developing competencies; the final product may be tangible or a proposal for a solution to the challenge [9, 10]. The differences between these techniques have been reported [11].

CBL is rooted in Experiential Learning (*EL*), which has as its principal fundamental that students learn better when they actively participate in experiences of open learning than when they participate in a passive way in structured activities. Therefore, *EL* offers opportunities to students to apply what they learn to real situations where they face problems, discover by themselves, try solutions, and interact with other students within a certain context [12]. *EL* is an integrative, holistic learning approach that combines experience, cognition, and behavior [13].

There are already agreements between universities and training partners where students are interns at the facilities of the training partner, but often the experience of interactions is limited to the students doing work of little demand and usually outside of a challenge. One of the first priorities of the *Tec21* Educational Model was for the University to establish agreements with the training partners that fit the objectives of the educational model. This, of course, implies an understanding on the part of the training partner that the principal goal is the development of competencies through the resolution of the challenges that the training partner wants to solve. On the other hand, the university commits to respect at all times the confidentiality of the process, the intellectual property of the resolution of the challenge, and the guidelines of both the school and the training partner to come to an understanding how the students can develop competencies through the *CBL* experience [11].

In previous communications, it has been reported that the main conditions that promote effective experiential learning are:

- The learning experiences are selected and designed to involve reflection and critical analysis, and they include synthesis activities.
- The learning experiences are structured to encourage the student to take the initiative, make decisions, and be responsible for the results.
- The student actively participates in the questioning and the solution to the problem and is creative throughout the experience.
- The student engages intellectually, creatively, emotionally, socially, and physically.
- The faculty and students may experience success, failure, uncertainty, and take risks because the results of the experience may not be very predictable.
- The teacher recognizes and promotes spontaneous learning opportunities.
- The teacher's responsibilities include explaining the approach to the problem, establishing limits, facilitating the learning process, giving support to the students, and ensuring their physical and emotional integrity.
- Learning outcomes are personal and are the basis of experiences and future learning.
- The relationships of the student with himself, the student with other students, and the student with the world are developed throughout the experience.
- The challenges are always multidisciplinary, which implies the participation of more than one teacher, and the constant is to request the participation of experts outside the challenge.

This research article reports the results of implementing the *Tec21* Educational Model in two engineering programs, Mechatronics and Biotechnology, during the past two years; this includes the analysis of two flexible courses with challenging experiences and collaboration with external training partners. In this study, a very thorough evaluation of different assessment instruments was carried out to determine which one best suited the needs of the different *CBL* activities; the rubrics and the checklists resulted in having the greatest objectivity, according to the surveys applied to the teaching professors and students who completed a semester under the CBL didactic technique.

2 Methodology

The general purpose of this research was to investigate the first results of the implementation of the *Tec21* Educational Model. The *CBL* courses were established, and the skills assessment tools were designed to verify their development [7, 8, 14, 15]. A group of professors from the mechatronics and biotechnology engineering programs were trained to change their teaching styles and transform the content of their courses to a *CBL* format. In addition, they were trained in different digital technological tools such as CANVAS, eLUMEN, and REMIND. Also, the evaluation instruments were designed and applied to assess the course content. The *CBL* experiences were carried out inside and outside the school premises during four different semesters. To assess the degree of flexibility, the research team analyzed the results of specific, synchronous online courses (*FIT* courses—Flexible, Interactive, and Technological) for four consecutive semesters. Specific skills assessments were conducted, each based on rubrics, subject lists, knowledge tests, or learning assessments associated with the resolution of the challenge through written progress reports and oral presentations. These assessments covered the development of challenge solutions and competency skills, such as oral and written expression, teamwork (collaboration), ethics, critical thinking, abstract thinking, and problem-solving skills. In addition, student satisfaction surveys and anonymous opinion polls were conducted to evaluate all the courses. Teachers' opinions about their transformation process toward *CBL* were also collected. Finally, the opinion surveys of 20 professors and 179 students about the instruments used to evaluate the learning acquired through the experience were analyzed.

2.1 Data collection and statistical analysis

Data from the surveys were acquired through *Google Forms*. The collected data of the tests were analyzed with the Student's t-test with a p-value of 0.05. In the statistical test, when the p-value is lower or equal to 0.05, the null hypothesis is rejected, and then the alternative hypothesis is accepted with a 95% interval of confidence. As the surveys were applied anonymously and all personal data was kept confidential, an ethics protocol for data handling was not required.

3 Results and discussion

A recent survey of engineering students who have dropped out of school indicated that a very common reason for leaving school is that their studies had no relevance in their lives, that is, they studied in a classroom a very abstract subject whose application remained in the classroom [14]. Increasingly, employers value and assess not the amount of knowledge that the students have acquired in the classroom but the skills and competencies that they have to join the workforce, which needs to remain competitive in a global market [14, 15]. The *Tec21* model responds to this need by focusing not on the grades and classifications of the exams but on involving the students in work and activities that are relevant to real-life [15–20]. The key is in the design of the pedagogical model of *CBL* that leads students to solve problems inside and outside the classroom [15, 17] to direct the course of their learning, and puts the faculty in the role of coach and guide [5, 6].

3.1 Experimental design

3.1.1 Faculty

Professors assigned to the Mechatronics and Bioengineering Departments, specifically those belonging to Sustainable Development and Biotechnology Engineering programs, were trained in the *CBL* application. As shown in Table 1, all the concepts were explained in work sessions, including: (A) content development, (B) definition of the challenge, (C) the challenge in the teaching–learning process. (D) *CBL* and its relationship with other teaching techniques (Project-based or Problem-based), (E) establishment of the learning module session calendar, (D) student follow-up activities and the role of the teacher, (E) evaluation mechanisms for competencies, (F) use of CANVAS, REMIND, and eLUMEN.

Table 1 Elements of Teachers' transformation to the CBL model

From: Content-based model	To: New educative CBL model
Curriculum based on subjects and contents	Curriculum based on the development of competencies through challenges
Subjects are the basic element for curricular design	Challenges are the basic element for curricular design
Evaluation of knowledge in each subject	Evaluation of competencies through challenges
Sequence of courses	Modularization of contents and flexibility of use
Professors with multiple roles	Roles separation based on the context

The teachers were trained and evaluated by the *Center for Educational Development and Innovation* (*CEDDIE*). A satisfaction and feedback survey indicated the following eight main points (ordered by frequency of the responses):

1. It is very difficult to change teaching habits after 25–30 years.
2. The proposed evaluation systems require practice.
3. The resolution-of-challenges approach implies that the teacher may not be an expert and will require the help of other faculty.
4. There is doubt that the students will obtain all the knowledge of the subject.
5. The implementation of CANVAS, eLUMEN, and REMIND requires more time to understand their scopes.
6. There is no clear difference between projects and challenges.
7. Team teaching is not suitable for a basic sciences undergraduate course.
8. How to structure a strategy to solve a challenge is not clear.

According to the *Tec21* Educational Model, in *CBL*, faculty are transformed from being passive "blackboard" to active teachers who may not be experts in the challenges they are solving or have had a special preparation for them so that they will need to team up with other faculty in order to combine experiences. Therefore, *CBL* teachers become learning collaborators who also seek knowledge and solve the challenges together with the students, creating different learning habits, and developing new thinking and strategies that are multidisciplinary. One of the teachers' fears, according to the comments expressed in the surveys, was that the students are not prepared for this type of active education, a process that in itself is a challenge, due to the difficulty in transforming the students into participatory, purposeful beings who learn through the experience.

3.1.2 Students

One hundred and seventy-nine students of the Mechatronics, Mechanical Engineering, and Bioengineering academic programs were the subjects of study in the establishment of *CBL*. During the transition from learning traditional content to CBL, the characteristics and benefits of CBL were discussed, the commitment required by students, the responsibility they have for an active education where they seek knowledge and solve the challenge in question, and they see the teacher as a mentor who will accompany them in solving the challenge, inside and outside the classroom. In addition, the students were informed of the evaluation systems to be used and the weightings of each one. Additionally, the students were trained in the use of digital supports such as CANVAS and REMIND so they could have both the control of all the deliverables of the courses as well as communication with the teacher 24 h a day/7 days a week.

To evaluate the flexibility of courses (one of the four fundamental pillars of the *Tec21* model), four groups (83 students) were involved in four FIT courses (Flexible, Interactive, Technology), where students were trained in the use of digital tools such as ZOOM, REMIND, CANVAS, and eLUMEN to be able to have a more interactive and digital vision of their courses and teachers.

It is important to note that the use of CANVAS gives students and the teacher a platform where students can upload their exercises, assignments, or reproduce recorded classes online, and it allows them to plan the deliverables ahead of time; this gives a very strong to boost to improving the teaching–learning process. The use of REMIND sets up constant communication through text messages, and ZOOM gives students a visual communication tool that allows the FIT courses to be flexible. These digital tools promote the development of both disciplinary and transversal competencies by giving students a way to discuss topics in-depth with their peers more personally, thus aiding the development of competencies such as critical thinking, collaborative work, problem-solving, ethics, and the use of digital tools.

3.2 CBL in Bioengineering

The general purpose of this part of the research was to implement a course in CBL format with Biotechnology students. To do this, we established the challenge of determining the origin of the entry of influenza viruses in Mexico. Fifteen students were subjected to a period of 14 weeks where they had not only teachers from Tecnologico de Monterrey but also an external training partner, and as a team, they established the challenge to be solved in different stages. The resolution of the challenges developed in students' transversal competencies, such as Ethics, Collaborative Work, Problem-Solving and Critical Thinking, and disciplinary competencies, such as the identification of specific sequences of influenza viruses, phylogenetic analysis, genome comparison, and establishment of mutation rates.

It was very interesting that the professor in charge of Ethics, having to solve the strategic challenges of CBL, found a successful way to comply with teaching all the contents of the subject that corresponds to the appropriate semester. Teaching through ethical dilemmas developed in the Professor a more intelligent and efficient way of transferring the knowledge to the students in a close way.

3.3 CBL in Mechanical and Mechatronics Engineering

It was recently reported the importance of having leading international companies in their business as training partners [11]. This report analyzed four different challenges presented to 33 students of Mechanical Engineering and 28 of Mechatronics Engineering who were involved in CBL with first-level training partners such as Boehringer Ingelheim, Covestro, and Becton Dickinson. The challenges that they took on during three semesters were related to manufacturing processes, digitalization, and the automation of processes and energy efficiency. In each case, the learning gain, measured by the Hake formula, was evaluated [21]. It is noteworthy that many of the situations evaluated were related to the management and safeguarding of sensitive information for the general population, information that could determine the development of a public policy that could restrict the rights of the inhabitants, or it could trigger an immediate reaction to an impending outbreak. It is important to mention that ethical competencies were a fundamental pillar in the development of the challenges in this experience.

A team of expert biotechnology professors from Tecnológico de Monterrey designed the teaching modules to support the resolution of the challenge in Biotechnology and Epidemiology. The evaluation using rubrics indicated that the students managed to develop competencies and obtained the knowledge necessary to solve the challenges presented. Figure 1 shows the schematic for solving the challenges used in this and all the programs presented in this report.

3.4 FIT courses

One of the fundamental pillars of the *Tec21* model in addition to *CBL* is *flexibility*; for this, the *Flexibility, Interactive, and Technology* (*FIT*) courses have been established, which are courses that allow the students to take synchronous classes online from any place. Students and professors are trained in the use of CANVAS (http://www.canvas.com) and the eLUMEN interfaces (http://www.elumen.com) for skills assessment, and in the use of the ZOOM tool (http://www.zoom.us), which is the form of synchronous communication with the students. There are real-time sessions twice a week to solve the challenges.

Four different courses are analyzed in this study. It is important to note that the challenges were selected together with the assessment instruments in such a way that the courses were designed to solve two challenges per semester; one was related to the electromagnetic spectrum and the other, the evaluation of a solid waste management system. We did the study for four semesters with face-to-face groups, and in *FIT* mode, so we further evaluated the impact of having a flexible *CBL* course or a face-to-face *CBL* course. As shown in Table 2, on average, the students who solved challenges in FIT mode had better performance. This is in line with previous studies [22, 23].

As a control experiment, three parallel groups were analyzed with face-to-face classes that were developed by content in a traditional scheme with partial and final exams. As Fig. 2 shows, in all cases, the learning gain was higher when *CBL* was used. This is clearly consistent with previous publications [22–24]. In the challenges-resolution process,

Table 2 Objective Measurements of Learning: Course Grades (Maximum 100) and Withdrawal Rates (SD was less than 20% in all cases, and it is omitted for clarity). The table shows the average of 15 courses: 10 face-to-face classroom courses and 5 FIT on-line courses

	Classroom Teacher	FIT Teacher
First Partial	84.73	96.38
Second Partial	83.70	91.38
Final Grade	88.49	92.04
Withdrawal rate (%)	4	3

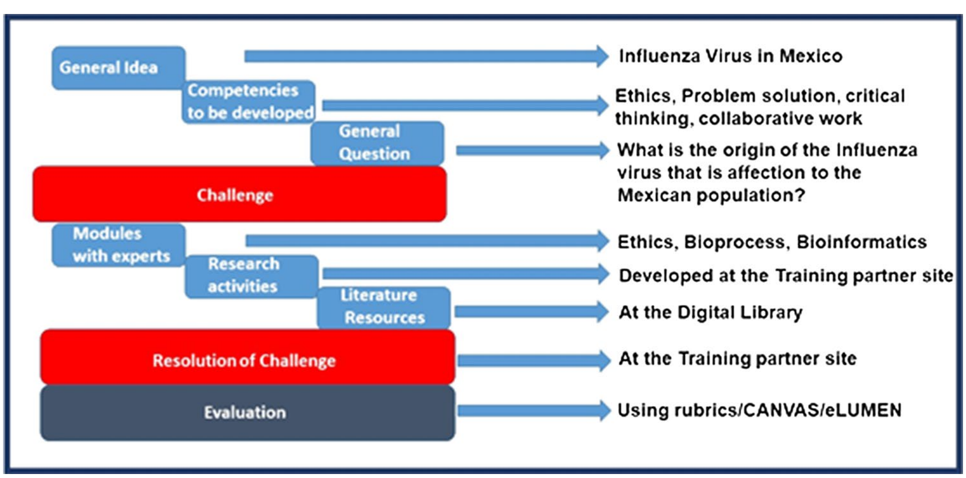
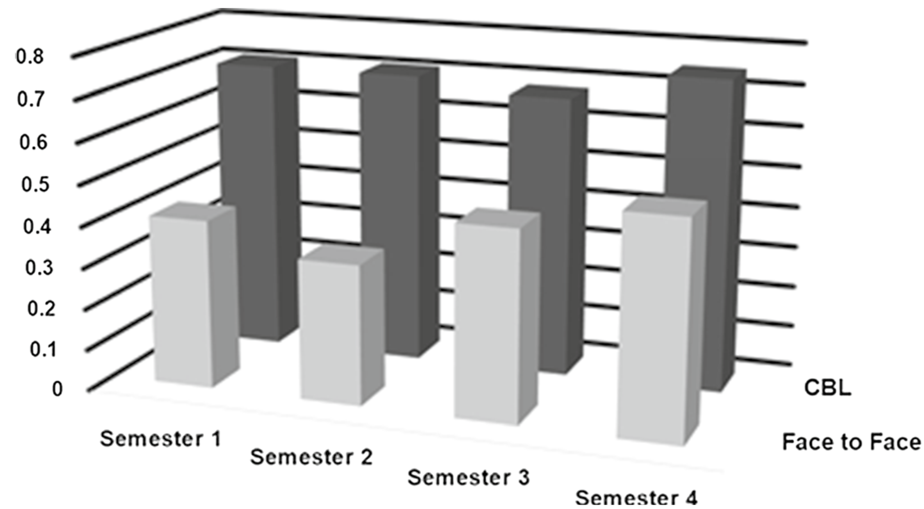


Fig. 1 The methodological framework of Challenge-Based Learning used in the Bioengineering experience (based on [19])

Fig. 2 The learning gain analyses of the CBL experiences for Mechatronics and Mechanical Engineers student. The light grey bars show the results with classroom classes using traditional teaching strategies. The dark bars show the learning gain average of the parallel CBL experiences



it is noteworthy that the expert professors of Tecnologico de Monterrey had a process of adaptation to the teaching based on challenges; the training partner previously explained the challenges to the teachers, and that facilitated the development of the solutions. The interaction between professors from different areas was an essential factor in achieving the development of skills in the students. Engineering professors in sustainability, climate change, renewable energy, design thinking, sustainable use of water, and engineering projects worked together on a multidisciplinary strategy with clearly satisfactory results, despite the initial reluctance of teachers to develop this type of education based on challenges, which forces the students to move from their comfort zones and make additional efforts to acquire knowledge.

3.5 Evaluation

The evaluation is defined as a systematic and planned process of gathering information through multiple strategies, techniques, and instruments, which allows judgments to be made and evaluate if the students have achieved the expected learning, with all the dimensions that are implied: knowledge, skills, attitudes, and values, and to what extent [25].

As the *CBL* is a novel technique at the bachelor's level, much has been studied and proposed on how to evaluate it. Perhaps that is the most difficult point on which to reach a consensus among teachers. Historically, the evaluations have consisted of the application of a written exam certifying the acquisition of knowledge, and it seems to be objective; however, it is not the most appropriate tool when it comes to assessing soft competencies such as those pursued by the *Tec21* Educational Model being implemented at Tecnologico de Monterrey [25].

Educational evaluation is a process having multiple facets and dimensions in the process of assessing student learning. It does not just concern whether the students assimilated the course contents imparted to them acquired and developed knowledge and skills, adopted new attitudes, and assumed new values. Educational assessment is a multi-faceted and multi-dimensional process of assessing student learning. It is not only about the quantification of what the students assimilated from the course, the knowledge acquired and the skills they obtained or the new attitudes adopted and the new values practiced. It goes further and is linked to other human components, such as teaching performance, the actions and omissions of school and educational authorities, the degree of participation and co-responsibility of parents or guardians, the quality of interactions at school, the presence or absence of learning environments and, materially, infrastructure and its sufficiency or insufficiency to meet the needs of students, the conditions of safety and inclusion that must be guaranteed in the school, among others.

The three functions of the evaluation are:

1. **Diagnostic**: These evaluations allow all interested parties to know to what extent certain learning has been acquired before starting to work with it.
2. **Formative**: These evaluations guide the decisions on the teaching strategy and the adjustments necessary to achieve the learning objectives, based on the progress and difficulties of the students during the learning process.
3. **Summative**: These evaluations are generally applied to finished processes and consider multiple factors to which are assigned numerical values.

In the case of the implementation of the new *Tec21* Educational Model, challenge-based learning is a complex process of detection, delimitation, research, proposal, execution, and analysis of the probable responses or solutions to the proposed challenge. Obviously, the evaluation mode is

Table 3 Moments of the Evaluation

Initial assessment	Continuous or procedural assessments	Final assessment
Is done in the classroom at the beginning of each learning situation. Various instruments collect information about the situation and the initial context, which allows future changes to be generated by defining possible and desirable goals. At the end of the process, it allows us to assess whether there was progress and to what extent	Assessment of student learning is done continuously, based on the collection and systematization of information and the interventions made by the teacher. The purpose is to make improvement decisions as the challenge is being solved	It consists of assessing the information collected at the beginning and during the implementation of the process and linking this with the results of the closure, in order to identify the extent to which the goals established at the beginning were met

determined by the engineering area involved in the evaluation. However, the evaluation moments do not change, i.e., Initial, Continuous (progress evaluations), and Final (Table 3).

3.5.1 CBL evaluation

What evaluation instruments can be used in *CBL*? Knowing that the teaching technique of *CBL* is being applied in all the engineering curricula courses and that the challenges are multidisciplinary, how are they evaluated? Another consideration is that the challenges in many ways are variable in their levels of complexity and length.

In the evaluation of all *CBL* programs, we first detected the following characteristics that are shared by all the *CBL* experiences [11, 15, 17, 22, 23, 26, 27]:

(1) All the challenges are multidisciplinary.
(2) The challenges with training partners are more complex than the domestic challenges that are resolved within the University's facilities.
(3) The most important thing in the development of the *CBL* experience is not the challenge to be solved but the process and development of student competencies. In other words, whether the challenge is resolved or not, it does not affect the students' grades.
(4) The teachers responsible for each module (support session, review of concepts, strategies, and work plans) can use assessment instruments according to the characteristics of their module.
(5) The competencies and the level of development of these should be clearly established at the beginning of the experience, not during or at the time of the evaluation.
(6) One of the properties of the challenges is the level of uncertainty, so it is difficult to plan the evaluation instruments at one hundred percent.
(7) When there are expert personnel from companies, industries, or other organizations functioning as training partners involved in the evaluation, they will have to carry out training appropriate to the evaluation objectives.
(8) The transversal competences to be evaluated in all *CBL* experiences are Ethics, Collaborative Work, Oral and Written Expression, Problem-solving, and Critical thinking.
(9) The Evaluation of the development of competencies must be collegial and consensual with all the teachers involved.

3.5.2 *CBL* evaluation instruments tested

Once the characteristics of the CBL experiences have been defined, we considered that both quantitative and qualitative evaluations should have to be used. Both methodological approaches are important for the evaluation of competencies [28].

On the one hand, *quantitative* evaluations need to create controlled situations to measure student performance or achievement in relation to the expected learning. It is reflected in numerical results that allow comparing the student's performance with certain established criteria (defined, observable, and measurable), which allow translating the performance into a numerical grade [29–37].

On the other hand, *qualitative* evaluations focus attention on the activities, forms, means, and dynamics in which learning occurs. To achieve this, they use nominal and hierarchical scales, such as categories, characters, and attributes, among others. Several instruments should be used to corroborate the results to eliminate doubts about its validity and reliability.

To obtain the data that allow students to be evaluated at the beginning, during, and at the end of a *CBL* experience, the teachers of this study tested different *evaluation techniques and instruments*. It is important to mention that *evaluation techniques* are the procedures used by the teacher to obtain information about student learning. Each evaluation technique is accompanied by its own *instrument,* defined as a resource that is used to collect and record information about student learning and the teaching practice itself.

In the framework of higher education, the definition of competencies is based on a consensus of what employers, society, and global conditions require. So, Tecnologico de Monterrey defined certain transversal competencies that should be developed in the courses by the teachers, and therefore, it is also necessary to make a judgment regarding these and validate the changes that occur in the students.

To build an instrument, one will need to know what kind of knowledge or actions will be evaluated.

The *techniques* used in the experiences were those that favor the development of formative evaluation, namely:**

Self-analysis of teaching practices.
Free trials.
Surveys
Direct observations.
Notebook Reviews.
Corrections of activities.
Preparation of the draft resolution.
Development of study techniques.
Implementation of reinforcement program.
Use of teachers' and students' diaries.
Student interviews.
Analysis of ethical dilemmas.

For these, the techniques of the *formative evaluation instruments* that were used were the following:**

Observation scales.
Checklists.
Tests or test exercises.
Rubrics.
Evidence portfolio.
Laboratory guides.
Questionnaires.
Schemes.
Maps.
Oral, plastic, or tangible production (device, prototype).
Solution implementation activities.
Oral and written statements of the proposed solution.
Explanatory videos in support of the proposed solution.
Debates with experts from the training partners.

Surveys were conducted on students who carried out *CBL* experiences, with or without training partners, asking what was the evaluation methodology that, in their opinion, most reflected a fair score of their performance and with which they were more satisfied to have been properly evaluated.

Seventy-eight percent of the respondents indicated that the *evaluation rubrics* and *checklists* were the clearest and most objective ways to be evaluated in their activities as participants of a *CBL* experience. When questioned about the other evaluation instruments, the most mentioned comments (41%) were that the questionnaires, the examinations or laboratory guides, or any pre-established instruments did not fit the changing reality of the challenge or the uncertainty of it.

Other comments from students (28%) had to do with the resistance to frustration for not solving the challenge either due to lack of time (71%) or because of its complexity (23%). The opinion by the students about their satisfaction that the concepts and the contents of the course were developed through the resolution of challenges was solidly positive (95%).

4 Conclusions

Implementing a new didactic technique through an innovative educational model always brings its consequences; on the one hand, there is a reluctance to change, not wanting to leave the "comfort zone," and the fear of updating to learn the use of digital tools. Faculty with more than 20 years of experience, as digital migrants, are often afraid of digital natives (the students) because of their skillful management of complex technological resources. A teacher who uses the challenge-based teaching technique:

- Proposes the challenge in conjunction with the students, other collaborating professors, and external experts.

- Ensures that there is a clear relationship between the learning objectives and the general idea of the challenge in all its stages.
- Integrates the key competencies to be developed by the students into the challenges that will be addressed.
- Guides the student to become responsible for his own learning, commitment, and involvement in the development of challenges.
- Is a facilitator during the development of the challenges, monitors activities, reviews team progress, and guides by asking trigger questions.
- Collaborates with faculty from different areas, working as teams of specialists to support the students.
- Advises or channels advice with other colleagues.
- Is a mediator with related associates and partners.
- Evaluates together with other teachers and external evaluators the solutions proposed by the students to the challenge and ensures that the evaluation is carried out through a previously elaborated rubric.
- Is a mentor in the entire learning process, seeks to guide the work teams, channels the efforts and the feedback of the students as they work toward the proposed solution.
- Promotes collaboration among team members to attain a common goal.
- Supports conflict resolution, negotiates resources, and spaces for the activity and provides advice to others.
- Motivates students to work on the solution of a real problem on a small or large scale.
- Encourages creative thinking associated with the assumption of risks in the experience.

According to interviews with professors who conducted *CBL classes*, the key points that clearly changed the way of teaching were:

The use of information technologies to interact with the students.

Giving up the usual control of the classroom in order to guide the students throughout the process of resolving the challenge.

Allowing the students to commit errors so that they could later discover them and correct them.

Becoming current in documentation when the students selected a topic that is not part of their total knowledge base or required technology that went beyond their mastery.

Knowing how to work collaboratively with colleagues from various areas since challenges are commonly multidisciplinary.

Making a greater time commitment (both the teacher and the students) as compared with most traditional academic teaching activities.

The interviewed students who studied under the Challenge-Based Learning didactic technique expressed that:

(1) They achieved a deeper understanding of the issues.
(2) They learned to diagnose and develop their creativity.
(3) They became as involved in defining the problem to be approached as in the solution they developed to solve it.
(4) There was more professional interaction with the faculty.
(5) It was a real-life experience, which they do not normally have in college.
(6) It improved personal communication.
(7) At first, they felt uncertain about being able to learn, but by the end of the challenge, they had acquired the desired knowledge.

The results of this research indicate that adequate training of the teachers and previous design of the evaluation instruments for the competencies are required, and, in addition, the relevant and correct use of technological tools such as CANVAS, REMIND, eLUMEN and ZOOM is necessary. The role of training partners is essential to increase the degree of uncertainty of the challenges that are to be solved in the development of this ambitious program promoted by *CBL*. Finally, it is clear that every semester a comprehensive evaluation of the application of this model must be made to adapt it to the circumstances of the world's educational reality. At this moment, we are at a point of transition to a new, unique educational model in our institution. New challenges await us to face the daily reality of managing the transmission of knowledge to our students in a more appropriate way to help them face their environment. That is really the principal challenge; we are convinced that we will achieve success through pedagogical techniques such as *CBL*.

It is important to delve a little into the instruments that impressed the students positively so that they felt comfortable with the assessments they received. The rubric is an instrument of authentic evaluation of student performance. They are tables that break down student performance levels in given aspects, each with specific performance criteria.

Elements of a rubric:

- Evaluation criteria: these are the factors that will determine the quality of a student's work. They are also known as indicators or guides. They reflect the processes and content that are considered important.
- Performance levels: represent the categories in which the quality of a student's work is classified.
- Quality descriptors: provide a detailed explanation of what the student should do to demonstrate their effi-

ciency levels and achieve a certain level of mastery in the desired objectives. These definitions should be provided to the students.

The other CBL instrument worth delving into is the *checklist*. When we read or hear the name "checklist," surely what we think of is a series of elements that will be qualified as success or error, done or not done, or perhaps in a CBL experience, a list of "things to do." A checklist is actually a list of words, phrases, characteristics, statements, and questions to ask in order to achieve something. In didactic strategies, they are instruments "to observe the performance of the students through tangible products" [38]. These observation listings divide student performance into two categories: adequate or inadequate [36]. They can also indicate the presence or absence of some determined characteristic. Some of the uses of checklists are necessarily associated with processes, procedures, or activities carried out sequentially that describe in detail these results:

- That the student identifies the results that he/she expects of himself/herself.
- That the student verifies his/her own learning process.
- That the teacher or evaluator verifies each of the elements of a process.
- That both the teacher and the student identify deficiencies or failures within a process or product.

A checklist can be an effective aid in the learning of some mathematical procedures; in fact, students can participate in the process of preparing the sequence statements, providing a space for reflection, and, thus, fulfilling one of the evaluation functions, which is to provide the space for student learning. In fact, a participant teacher in a CBL experience can prepare the checklist in advance, but also build one with the students to have an opportunity to contrast the omissions when compared to the checklist created by the teacher. This exercise also allows the student to "understand" the process and how it will be evaluated; thus, the student moves toward self-direction and self-regulation, one of the pillars of the educational model and challenge-based learning.

The learning moments in which the use of an instrument like this is usually recommended are [38]:

- In works whose format is novel for the group (model, delivery of drawing or prototype, a portfolio of evidence) because it allows the student to know what this learning product should contain.
- When a process is about to be learned (to face a situation that involves multiple disciplines for the first time, to operate a machine, to carry out a procedure to obtain something, a laboratory procedure, a program, or a specific methodology).
- If you want students to learn how to do something (maps or essays, for example) where it is prioritized that a process will be followed. This may be the case of essays, where you intend to evaluate the argumentation that the students make.

The checklist is NOT recommended when self-assessment and co-evaluation are practiced on a job that entails a series of steps. In fact, the checklists are used by evaluators when certifying process competencies, as in the case of the use of parcels and applications, where they make sure that the assessor follows the process that they are verifying step-by-step. Therefore, the use of this instrument functions as a tool for self-direction in learning and, used for self-assessment, is functional to develop self-regulation.

In addition to the general sequences that were previously identified as what we want to evaluate (objective: development of competencies through the resolution of a challenge) and what is important to demonstrate (evidence of compliance with competency development specified by clear criteria), the following requirements for actions are needed to build a checklist:

The actions are part of a process or a procedure.

The actions are sequential.

Preferably, each action is described in the form of an assertion.

Each action is unique; the assertions avoid mixing elements that give rise to partial or imprecise responses.

The first two elements above are essential characteristics in the construction of a checklist, while the other two are elements required in the evaluation instruments [31, 36–39].

CBL is a didactic strategy that brings students closer to the world of work and a real environment with challenges that not only make them develop disciplinary and transversal skills but also bring them closer to the new principles and emerging technologies of the next industrial revolution, Industry 4.0. This can lead to a very interesting approach to interactive techniques for solving challenges in Industry 4.0 where virtual and augmented reality experiences, automation, machine learning, robotics and model-based design could be designed. To provide these new skill sets, universities must provide educational patterns that allow combining technology, principles of modern industry, but at the same time must be rooted in communication, personalized, collaborative and relevant to the needs of society. CBL will be a very useful tool to achieve this goal. Learning with interactive technology can maximize students' academic experience in fast-growing areas of interest to Industry 4.0 at all levels of global education.

An important task yet to be done is the development of an appropriate evaluation methodology for the CBL technique. It is difficult to have a single form of evaluation, and this becomes more complicated when there are training partners involved in the teaching process. Therefore, in addition to homework and assignments, the analyses of deliverables such as bibliographical searches, presentations with detailed rubrics, or observations of competencies (using eLUMEN) can be used. New and improved evaluation methods may have to be developed for assessments of CBL. Other authors have reported the use of deliverables such as written reports, examinations by training partners, and skills tests [24, 39–41] as assessment items. In any case, what has been reported in this research will serve as a basis for future studies of *CBL*.

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