A Novel Model of Challenge-Based Learning for the Development of Skills of the Future

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***Abstract*—One of the growing problems faced by small, medium, and large companies worldwide is finding human resources with the necessary skills. Employers have already set a warning signal for higher education institutions to prepare their graduates with today's and future skills. Several didactic schemes have been tested within Experiential Education that require students to be exposed to natural and multidisciplinary problematic situations, where they develop disciplinary and transversal competencies. In higher education, challenge-based learning (CBL) has been the most popular teaching technique for training the most competitive professionals. Here, we analyze the implementation of a novel CBL system using several training partners (companies) in a multi-challenge experience that requires discipline, communication, and knowledge transfer between the actors of the experience. Our results indicate that competencies can be developed in different challenges simultaneously in the same group and with several training partners. Attention was paid to the competencies to be developed and the knowledge to be disseminated. On the other hand, experimental planning was carried out by mentors and expert staff from the training partners. Finally, the evaluation was carried out with a strict competency development rubric. Questionnaires given to students at the end of the experience suggest that replicating this experience in their careers will help them become more competitive. Here, we report a scheme that establishes a new model in CBL, where a course is not only governed by a particular challenge, but through the resolution of more than one challenge within the group, the discussion is enriched, and all topics are strengthened and the designated developed competencies.**

***Keywords*— Challenge-based Learning, Experiential Learning, Higher Education, Educational Innovation, Tec21, Engineering Education**

I. Introduction

A. Challenge-based learning (CBL)

For many students, the future represents a source of uncertainty and concern [1]. All are fueled by the challenges presented by the current world, including a world that is increasingly less sustainable and with risks of new environmental, social, and economic situations [2]. Preparing undergraduate students better to meet employers' demands is a joint dynamic mission of teachers, collaborators, students, managers, and pedagogical architects. It must be remembered that perhaps the knowledge and competencies acquired today may soon no longer be valid or have the same value or priority in the future.

Various teaching models have been used to generate the necessary competencies that employers demand; several educational institutions have adopted the challenge-based learning (CBL) model as the most appropriate method to develop these competencies ([3] and references therein). Specifically in Engineering Education, CBL has flourished in the last ten years. Several studies have suggested that CBL has the potential to educate and prepare students for their future careers by combining knowledge acquisition and application, developing disciplinary and transversal competencies, taking control of learning toward students, and developing what is known as experiential learning [4][5].

B. Commitment to Stakeholders (employers)

Developing the right competencies in graduates is a problem that causes employers to lose millions of dollars. A recent European Community and developed countries report describes three significant economic challenges for the EU industry in 2024 and 2025: **labor and skills shortages**, inflation, and the need to make it easier for EU companies to do business. Small and Medium-sized Enterprises (SMEs) are currently facing structural difficulties in recruiting staff with the right skills due to the growing mismatch and shortage of labor and skills.

Having a workforce with the right skills contributes to sustainable growth, leads to innovation, and improves companies' competitiveness. The European Year of Skills 2023 Report helps companies, particularly SMEs, address skills shortages. It promotes a reskilling and upskilling mindset and helps people acquire the right skills for quality jobs (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-year-skills-2023_en). In the Eurobarometer 2023 study where 19350 companies from the 27 EU countries plus Iceland, Norway, Switzerland, the United Kingdom, North Macedonia, Turkey, the United States, Canada, and Japan (non-EU countries) were interviewed, shocking results were published.

As shown in **Fig. 1**, in the European community, on average, 54% of the companies interviewed stated that their main problem in recent years has been finding specialized human resources with the right skills to meet their needs (Blue bars, EU). When this question is analyzed about company size, there is an evident growth directly proportional to size, i.e., 54% of micro companies (<10 employees), 62% of small companies (between 10-49 employees), 68% of medium-sized companies (up to 249 employees) and 72% of large companies (250 or more employees). Similarly, the countries that participated in the study demonstrated the same difficulty, with 51% of the companies interviewed answering that their main difficulty is finding Human Resources with the right skills (Non-EU countries). For comparison, the second most popular answer was regulatory obstacles, which, as can be seen, oscillates between 30% of the answers.

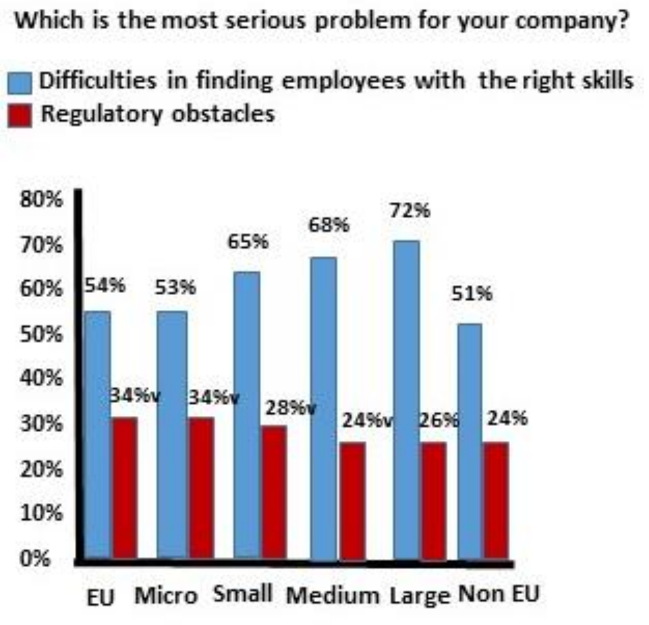

Fig. 1. Eurobarometer 2023 report to the question “What is the most serious problem in your company?” The bars represent 19,350 participating companies from the European Union (EU) and non-EU countries (Non-EU countries). The EU responses were divided by company size. (Data taken from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-year-skills-2023_en).

The problem of finding professionals with the necessary skills requires higher education institutions to establish experiences in the comprehensive development of competencies for an entire group.

strategies for developing skills that are useful for students' futures and productive for employers.

C. Goal of this study

To develop the skills of the future, this study presents a proposal for a teaching model using experiential learning, specifically Challenge-Based Learning, but not in a typical way but in an innovative model using several challenges per class and evaluating the development of skills under a specific monitoring scheme; we have called this development ***Multichallenge-Based Learning.***

Several reports indicate that experiential learning has dominated the competency-based teaching strategy in recent years [1]; education has gone from just an information instrument to involving the student in learning by actively resolving problems. A problem, a project, a practice, and, recently, a challenge. It has recently been described that a challenge is a more complex structure and requires more interaction between the teacher and students than projects, practices, or problems. [5]. The big difference is that challenge-based learning (CBL) involves a much more significant amount of uncertainty than other teaching models [6] [7].

D. One Challenge, one course?

The CBL has been designed from the beginning as a situation where teachers agree and decide the challenge closest to the competencies that will be developed in an entire work group. Suppose the challenge is the product of a collegiate discussion exercise by teachers. In that case, this guarantees that the process of developing and assigning student tasks is established. If this challenge is done through the presence of training partners, a training partner is usually chosen who determines most of the challenge or its entirety. In this case, teachers need support in establishing evaluation rubrics, establishing the role of the training partner in the evaluation process, and developing the resolution of the challenge.

Higher education institutions are challenged to keep up with the demands of the labor market and prepare students with the skills necessary to face an increasingly changing world [6]. For this reason, educational techniques, technological resources, and global knowledge certification approaches change simultaneously and respond to the evolution of employer demands. For this reason, teaching practices in higher education must bring students together and expose them to challenges, often created by employers, that allow them to develop in a quasi-work environment. Until today, teaching practice establishes that a challenge is chosen for the entire group, and specific strategies or tasks are divided to obtain the solution by using this process to evaluate the students' competencies.

In this communication, we present evidence of a new and innovative challenge-based teaching scheme that uses several challenges with several training partners and encompasses all experiences in the comprehensive development of competencies for an entire group.

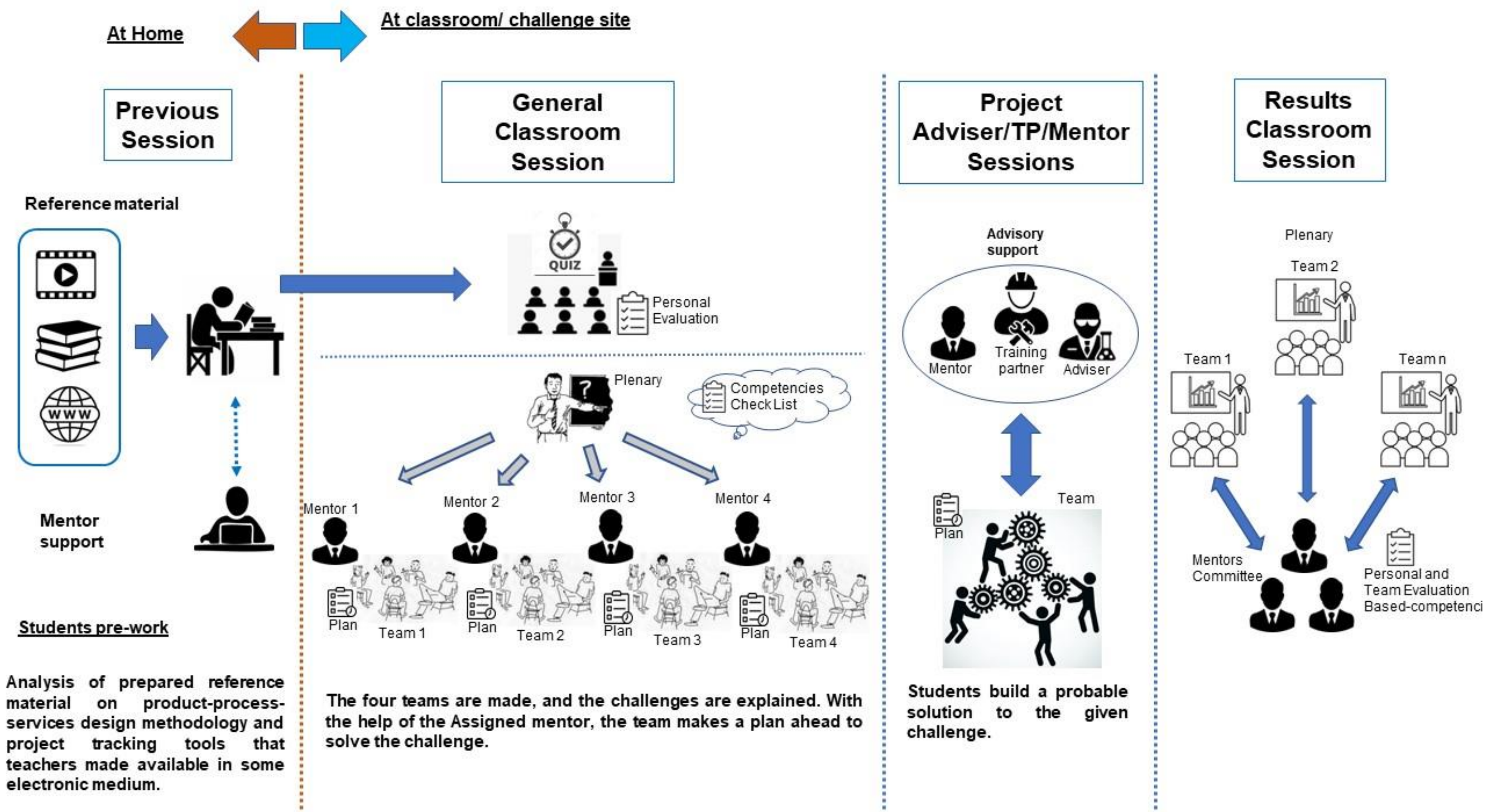

Figure 2. Activities developed by the academic committee and the students during a multi-challenge experience (see text for details).

II. METHODOLOGY

A. *Multi-Challenge-based learning experience*

To deliver a challenge-based active learning experience, we designed a roadmap with two fundamental moments: **BEFORE** and **DURING** the course. In a previous report, we stated the steps that must be followed for a multi-channel-based learning experience [8], briefly:

Before the course:

1. **Establish a relationship with one or more training partners (TP)**. This is fundamental; before any subject design or CBL academic experience, there must be a group of training partners [9]. That can be a company, a non-governmental organization, an academic institution, a team of researchers, or an entrepreneur who wants to share current and relevant academic development challenges according to the student's level.

For the multi-challenge experience, we look for at least four types of challenges:

A) Technological Engineering Challenge,
B) Research Challenge,
C) Entrepreneurship Challenge and
D) Business Entrepreneurship Challenge.

For this, the teachers in charge of the subject must visit the training partners' facilities to detect opportunities to develop the students' skills.

2. **The commitment of Teachers** (the faculty responsible for the experience; here, it is recommended that several responsible teachers be able to carry out the multi-challenge experience) meets to analyze the challenges proposed by the training partners. It must first be determined which challenges meet the expectations for developing competencies declared by the subject. Additionally, an agreement must be reached to establish the evaluation technique and instruments [10] [11].

The critical points are designing teaching strategies, scheduling sessions at the academic institution and the training partner's facilities and establishing teams for developing the resolution of the challenge.

It is important to note that some challenges may not be appropriate for the course's objectives, or their complexity may not be what is sought within the course's scope. These challenges are archived for later use and analysis. Only those challenges that have the approval of the academic committee of teachers are used for implementation. In our case, the elected training partners are those described in **Table 1**, which describes the type of challenge involved in the multi-challenge experience.

3. Signing of the commitment letter to resolve the challenge. Once the challenges and training partners have been chosen, an analysis of the relevance of the objectives and academic and ethical standards is carried out. With this data, a written document called a "commitment letter" is drawn up that establishes the guidelines for intellectual property regulations, the protection of personal data, and the confidentiality that must be maintained when confidential data is used. This letter, as well as the development protocol, has been approved by the institutional ethics committee.

During the course:

4**. Document the initial proposal of the challenge**. The course begins once the faculty committee determines the challenges with all the characteristics above. In the first session of the semester, students are divided into teams depending on the challenge to be solved (in this research, following **Table 1**, there were four challenges: technological, research, entrepreneurship, and business). This document includes the ideas, activities, and sessions that will be carried out to solve the challenge (**Fig. 2** shows each of the phases of the course in detail).

TABLE **1.** TRAINING PARTNERS WHOSE CHALLENGES WERE APPROVED BY THE ACADEMIC COMMITTEE TO BE DEVELOPED IN THIS MULTI-CHALLENGE EXPERIENCE.

Training Partner	**Challenge**	**Type of Challenge**
Electromobility Lab	Electrostatic Drive	**Research**
Universal Robot	Training platform interactive	**Entrepreneur**
Intelligent Automatization Lab	Cybersecurity Device	**Entrepreneur**
IAMSM	Autonomous vehicle	**Technological**
}ICE	Emergency Aereal Recognition	**Business**
Mexico Ministry of Defense	Dron kits	**Technological**
Tech Borregos	Electric Mobile platforms	**Research**
Petrol Industries SIIP	Automatization of water plant	**Technological**
Xico	Automatization kit tools	**Business**
GENERAC	Alternative energy sources	**Research**
Electromobility Lab	Pothole tracking	**Research**

5. Final evaluation session. Depending on the length of the multi-challenge learning experience (it can last up to 10 weeks), teams develop the probable solution using experts from both the educational institution and the training partner. Once the team's mentors have endorsed the solution proposal, a presentation is made to the faculty and experts of the training partners. In this session, the observations collected by the evaluators are established to improve the final document. This forum enriches the discussion. If the result of solving the challenge is a prototype, the progress of the prototype is presented at this stage. It is important to note that if the challenge resolution proposal does not meet the quality standards of the information and the use of technology and data, the students will not be approved for not achieving the competencies. In this case, students will have one last opportunity to present in a later space, making the pertinent modifications suggested by the evaluation committee. In this case, the student will not have access to the maximum grade, and the exam will be considered sufficient.

6. Presentation at an IEEE Poster session. A second evaluation of the resolution of the challenge is in an academic engineering fair where the results, already with the observations made in the review of the presentation, are presented in poster format to the academic community. The poster regulations available in the IEEE are strictly followed. The engineering fair is an event held collegially among all engineering careers that allows the exchange of ideas and academic discussion between academic peers. External evaluators, professors, and academics from the institution and other programs and external professors act as evaluators of the presented poster. In addition, the general public can also attend, such as parents, other students from different courses, friends, etc.

7. Presentation of the final comprehensive report. The final delivery of the extensive report of the entire multi-challenge experience is made. It reflects the observations of the challenge in question and those made to the challenges of the teams that simultaneously solved challenges other than their own (See **Fig. 2**). This deliverable includes all observations, corrections, and evaluation of each challenge. If it turns out to be a prototype, it is presented in its final version at this stage.

III. RESULTS

A. *Before the Challenge*

The multi-challenge-based learning (mCBL) experience was applied to the "Design and execution of mechatronic systems" subject at the School of Engineering and Sciences was carried out. The subject's objective is that after the course, the student will be able to:

-Propose feasible and cutting-edge technological solutions to solve industrial, social, and environmental problems.

-Apply methodologies and technological tools to design mechatronic systems.

-Validate automation proposals to guarantee quality, safety, and productivity.

-Implement automation proposals using cutting-edge technologies.

-Develop research on the state of the art based on reliable sources to generate a proposal for a mechatronic system.

- Generate innovative proposals for a mechatronic system according to standards.

-Evaluate the technical and economic feasibility of technological development based on constraints.

B. *Training partners*

The committee of teachers responsible for the subject visited various training partners developing challenges. Several challenges were unsuitable and discarded. After an analysis, the challenges and training partners chosen for our multi-challenge experience were those described in **Table 2.**

TABLE 2. COMPETENCIES TO DEVELOP IN "DESIGN AND IMPLEMENTATION OF MECHATRONIC SYSTEMS."

Graduation competence	Description
SMR0103C	Methodologically selects components according to technical specifications.
SMR0201C	Propose cutting-edge technological solutions to industrial, social, and environmental problems.
SMR0202C	Applies technological methodologies and tools for the design of mechatronic systems.
SMR0303C	Applies technological methodologies and tools for the design of mechatronic systems.
SMR0402C	Generates innovative proposals for a mechatronic system by standards.
SMR0403C	Evaluates the technical and economic feasibility of technological development based on constraints.
SMR0401C	Prepares research on the state of the art based on reliable sources to generate a proposal for a mechatronic system.
SEG0202A	Evaluate the impact of entrepreneurial initiatives on a personal level, on the environment, and on different interest groups from an ethical and sustainability framework.
SIIT0302C	Generates proposals for solutions to problems under conditions of uncertainty and different levels of complexity based on engineering and science methodologies.

C. *Teams and Challenges*

Thirty-four students were separated into 11 groups, each with a particular challenge. The fitting tutors for each challenge were built up, comprising a part of the preparing accomplice, at least one educator of the subject, and specialists as outside advisors. At that point, the students were asked to sign the commitment letter. Sometime recently, at the beginning of the exercises, the individuals of the scholarly committee met to guarantee that each tutor had the fundamental reference fabric to begin the encounter. This fabric was accessible to the understudies through effectively available computerized stages (**Fig. 2**).

D. *Plenary sessions*

A quiz was carried out in the first plenary session in the classroom. In addition, an evaluation of the students was carried out to find out their interests so that they could choose an appropriate challenge (**Fig. 2**). Once this evaluation was carried out, the 11 teams were classified into four types of teams depending on the challenges (research, technological, business, and entrepreneur). The teams met their mentors and support team, with whom they analyzed the challenges and began developing strategies for possible solutions. The teams had sessions at the academic institution with mentors, additional professors from the institution, and external advisors, as well as at the training partner's site with engineers and collaborators from the same training partner. This interaction occurred every week during the duration of the course (**Fig. 2**). At the end of the course, several plenary sessions were held where each of the teams presented their solution proposal, explained the characteristics of the challenge and the required competencies were evaluated by the mentors of all the challenges, as well as by external professors who served as evaluators. The discussion of each of the solution proposals made the students exchange ideas, improve the solutions, implement new ideas and strategies, and, if they had any structural errors in the planning, correct them. These plenary sessions were of extensive discussion, and students could get involved in challenges they did not develop directly (**Fig. 2**).

E. End of the experience

At the end of the course, the students were ready for the final evaluation before the academic committee members, who would evaluate the graduation competencies in a final presentation. In this evaluation, observations of improvement were made and recorded in a minute. During the meeting, specifications were given for preparing a poster with the characteristics requested by the IEEE. The students then created a poster for the engineering academic day. They were evaluated by a committee of professors from the engineering faculty who participated and were external to the multi-challenge experience. The evaluations were under a presentation rubric in which all team members participated. With the observations collected, the teams finalized the final details to prepare the final report, which consisted of a structured report with a predetermined format. This document was the final evidence of the experience, and the teachers had elements to evaluate the development of the evidence objectively.

IV. DISCUSSION

The competencies required for a stakeholder must be developed daily in higher education institutions. One of the most advanced teaching strategies used in higher education in recent years has been challenge-based Learning (CBL). Within the CBL, it has been established that the plan of having a challenge for a group of students is adequate to monitor the development of both transversal and disciplinary competencies of each student, including the division into teams to have alternative solutions to the challenge is very useful for comparing progress in skill use among the same students. In this report, we describe a multi-challenge strategy in the same group that is used to develop the required competencies of students who do not have a single objective but several challenges and acquire the competencies not only through the resolution of their challenge but also through a deep discussion of the solution to the challenges of the students of the same group, but different challenge. The involvement of the students in various challenges, even if they were not responsible, was a good bank of ideas, strategies, and discussion; the constructive criticism towards the work of others invites the analysis of the proposals, the study of the challenge of the classmates, and an integral solution. A survey of the students who carried out this experience showed that more than 70% preferred the multi-challenge experience to the single-challenge classes for the entire group population (**Fig.3**). The essential question of this academic development is whether the students obtained the skills and knowledge from solving all the challenges or only the one developed with their team. This question was asked in the final survey. The response percentages are shown in Fig.4. It is exciting to observe that 100% of the students developed skills and obtained skills from resolving the challenges assigned to their teams; on the contrary, as seen in Fig. 4, when they were asked about the knowledge and skills acquired from the resolutions of the other teams' challenges. Notably, more than 50% had between 80 and 100% acquired an understanding of the different challenges not carried out by them, while only 9% established that they did not learn anything from the other challenges. As this is the first time this modality is carried out, monitoring the graduates and their work skills will significantly help understand and improve the areas of opportunity in this model, which can be perfected. Universities such as Eindhoven T/U have specific spaces for developing challenges and promoting skills development beyond a subject within an academic program. Additionally, new topics within the implementation of challenges are the ethical considerations of solving challenges, which is done in great detail at UCL in the United Kingdom. Another notable example is the graduate programs in Engineering Education at the University of Texas in San Antonio, where they study CBL as a helpful teaching technique for developing future competencies. In any case, these studies show that an educational model's flexibility can be essential in forming skills for the future to develop better specialized human resources that avoid the main problem of companies today: finding human resources with the skills required for specialized work. In any case, these studies show that an educational model's flexibility can be essential in forming skills for the future to develop better specialized human resources that avoid the main problem of companies today: finding human resources with the skills required for specialized work. The strategy still has some areas of opportunity that can be improved, both in planning and in the evaluation rubrics, perhaps adding a final session of a reflection exam where problems are established that challenge students to use the acquired competencies. The innovation presented here is a substantial advance to our conception of CBL; perhaps this new strategy should be added to the one already described by Van dem Bemt et al. [4] [12].

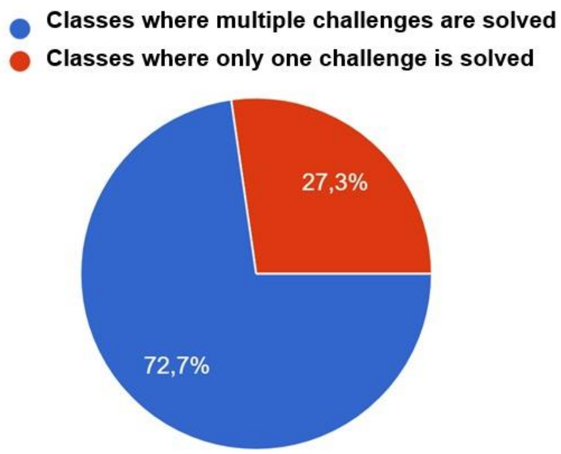

Fig. 3. Percentage of answers to the students about their preferences for one or several challenges in the class n=34.

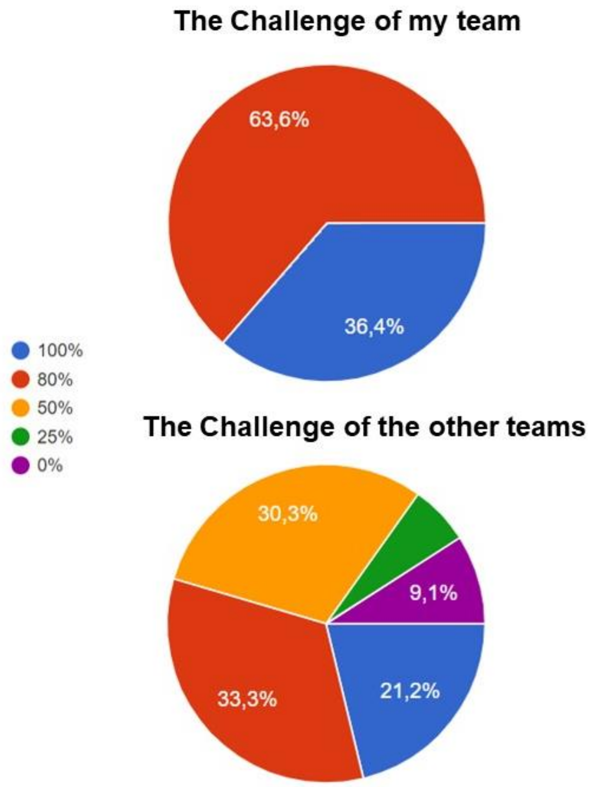

Fig. 4. Percentage of answers to the students about the acquired knowledge from the resolution of their team's challenge and other teams' challenge n=34.

V. ACKNOWLEDGMENTS

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