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RESEARCH ARTICLE

Learning Enhancement of Control Engineering: A Competition-Based Case

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ABSTRACT The transition from academic training to professional life is not an easy task. In recent years, various learning enhancement methodologies have emerged to reduce this gap, which focuses on both soft and technical skills. Specifically, Competition-Based Learning (CBL) seeks to improve learning and motivation through the competitive component, which has detractors and defenders. In this framework, the present work proposes a national competition, CIC2022, within the field of control engineering that uses a testbed with an Unmanned Aerial Vehicle (UAV) for helping to link theory and practice. The main objective is to analyze the results of CBL on learning. In addition to explaining the characteristics of the competition and the academic results obtained, a survey answered by participants provides conclusions on the effectiveness of the methodology and other issues related to the contest. Greater motivation and teamwork promoted the active learning of students and improved the autonomous acquisition of technical skills.

INDEX TERMS Competition-based learning, contest, higher education, automatic control systems, testbed, UAV.

I. INTRODUCTION

In today's higher education, there are several challenges for students, most of them related to a lack of motivation [1], [2], [3] and lack of preparation for the labor market [4]. For these reasons, teachers and researchers are working to implement active methodologies that put students at the center of the teaching-learning process [5], [6]. Nowadays, the labor market demands people who not only have technical knowledge but also demonstrate teamwork skills, innovation, logical and critical thinking and time management; in short, resolute and autonomous people are in demand. These concepts are framed as learning outcomes by the Bologna process [7], which places them as fundamental pillars of education. In this sense, multiple methodologies have been developed, such as: Game-Based Learning (GBL) [8], [9], Flipped Classroom [10], [11], [12], Project-Based Learning (PBL) [13], [14], Problem-Based Learning [15] or Competition-Based Learning (CBL) [16], [17], [18], [19], [20].

Like it or not, the real world is competitive, and, more or less clearly, competition has been and continues to be present in education [21]. According to the Institute of Competition Sciences [22], more than 450 educational competitions at all student levels are currently open. Some examples in the field of engineering are entitled: Aerial Drone Competition, American Solar Challenge, ASME Student Design Competition, Best Robotic Challenge, Simulation Hub Valve Design Challenge, and Water Environment Federation Student Design Competition. These are contests [23], [24], [25] in which several teams of students participate to solve a problem or present a project with characteristics like what can be found in real life [26], [27]. The big difference with professional life is that the work done is compared with the rest of the teams [28]. This is intended to motivate students to get the best marks,

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leaving in the background the conformism of working "the minimum to pass," a common situation in university courses.

In this framework, the research carried out in this paper aims to analyze whether the CBL methodology favors the acquisition of skills in subjects related to automatic control [29]. These subjects present a teaching challenge mainly due to the mathematical complexity [30] involved in a context where students' background and skills in basic sciences vary greatly and tend to decrease. In addition, students perceive a gap between theory and practice [31], which makes it difficult to understand and assimilate concepts [32], [33], [34]. To overcome these drawbacks, the trend has been to use testbed platforms representing real laboratory-scale processes on which to develop practices to improve the acquisition of knowledge and skills [35], [36], [37], [38], [39], [40], [41]. The current proposal extends this philosophy by adding a competitive component, giving rise to a national competition under the umbrella of the Spanish Committee of Automatics (CEA) [42], [43], to asses whether this new approach improves the learning process.

The document is structured as follows. The second section outlines the main characteristics of the CBL methodology and makes a literature review of supporters and detractors. Then, the third section describes the contest and the technical performance of the participants. In the fourth section, a survey answered by the participants makes it possible to analyze soft and hard competencies and several aspects of CBL methodology. Finally, the conclusions drawn are discussed in the fifth section.

II. CBL METHODOLOGY

Competition-Based Learning (CBL) is defined as a student-centered learning methodology, which combines Project-Based Learning (PBL) and competitions [44], taking as a pedagogical reference the constructivist theory of knowledge [45], [46]. This methodology seeks to increase student motivation [47], improve academic performance, develop creative thinking, and enhance teamwork skills. Some of its main characteristics are listed below:

- It should be done in groups, to mitigate the impact of negative aspects of competition such as selfishness, stress, or hyper-competitiveness.
- All team members should be active in their learning process.
- The problems or objectives raised should be linked to the academic curriculum and syllabus.
- The proposed problems should be multidisciplinary, challenging and as close as possible to a real-life situation.

Additionally, it should always be kept in mind that the main objective of the competition is for the student to learn and acquire new knowledge relevant to their present, and future, academic careers. Thus, not only the result but also the process should be scored. The final victory takes a backseat compared to learning while competing. For these reasons, the prize for the winners should be symbolic as well as motivating, in a way that ensures the intrinsic involvement of the students and a quality effort on their part. It means effort should not only be focused on the reward and the desire to win.

Much literature has been written about the advantages and disadvantages of the competition-based methodology for learners. Some researchers favor CBL, while others are against it. Several cases are presented below.

Dragomir et al. [48] advocate its benefits and show an example of competition in which participants give their best, enhancing their motivation and improving learning. Gadola and Chindamo [49] claim that this methodology favors active learning and involves interpersonal skills. Chang and Du [50] present a mechanical engineering competition that stimulates students' enthusiasm for learning. The study by Mat et al. [51] observes a positive attitude towards technical knowledge, as well as working on the so-called "soft skills" such as teamwork and communication. Ediger [52] argues that cooperative goals make students better assume their responsibilities for the benefit of the team. The work of Lam et al. [53] confirms that a competitive element is an incentive to increase the motivation and effort of the participants. From a more psychological point of view, Johnson et al. [54], as early as 1985, analyzed the effects of cooperation, competitiveness, and individualism on learning, concluding that better results are obtained through cooperation.

On the other hand, there are researchers who claim that the competitive nature worsens the learning process by focusing on the end rather than the means. In this sense, Clavijo and Oh [55] highlight the negative aspects that competitions can entail, such as the definition of problems focused on results, an inconsistent scope due to their complexity, problems of compatibility between the competition and the regular course or not obtaining credits, the motivation being the economic prize. Vockell [56] also argues that when a student is under stress, a situation that can often occur in a competition, there are more negative effects than benefits.

In order to research and look into these statements, a contest is developed to analyze the impact of CBL on students and on the teaching-learning process.

III. STUDY OF A CASE

Taking advantage of the popularity of multi-rotor Unmanned Aerial Vehicles (UAVs), the proposed contest aims to motivate and improve the learning of automatic control while approaching a real problem, as well as gives visibility to the discipline of Control Engineering in the academic environment as in society. Hereinafter the competition is referred to as Control Engineering Contest (CIC2022). It was organized by the Control Engineering Research Group (ICON) of the University of La Rioja in collaboration with the Control Engineering Group of CEA. The competition was open to the participation of teams from all universities in Spain and abroad during the 2021-22 academic year.

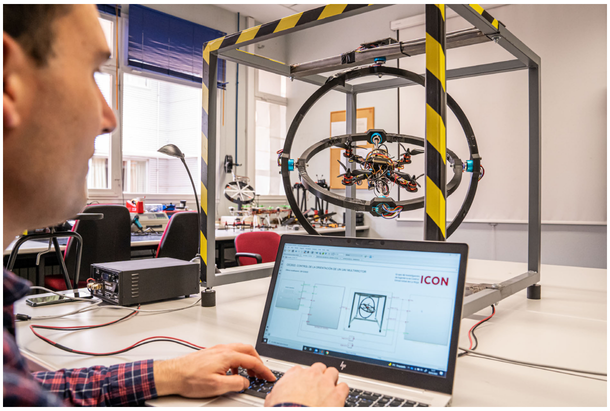

FIGURE 1. Benchmark for orientation control of a multirotor.

A. TESTBED

At the base of the UAV flight government is the control of its orientation (roll, pitch and yaw angles), this being the proposal for the CIC2022 [42]. It uses the testbed of Figure 1, which consists of a fully equipped quadrotor attached to a structure that allows free rotation in 3D without translation [43]. A flight controller is on board and the design of the control algorithms that will be implemented in it is the problem to be solved by the contestants. A simulation model, representative of the test bench, is also provided to perform low-order model identifications, control tests, and evaluations prior to real life operation. A MATLAB-Simulink® toolset enables simulations, flight controller programming, and real-time supervision and control. The control benchmark consists of tracking the UAV' s desired orientation angles and the performance is evaluated by measuring the tracking error and the control action in the three axes. The main control challenges are the non-linear and multivariable nature of the motion, how to obtain simple models for control design, a limited range of actuation, and a hard-constrained computational capacity. Different control strategies, structures, and implementation algorithms are possible. In summary, the platform can be oriented to undergraduate and graduate courses in control engineering and allows the instruction of theoretical and practical topics. The whole approach, common in the professional environment, can be difficult to tackle in classic classroom or laboratory sessions. Thus, the competition can improve the technical skills of the participants, beyond others such as creativity, autonomy, problem-solving, or teamwork.

B. COMPETITION

The contest required the active participation of a tutor, who was the interlocutor with the organization, as well as the trainer and advisor of the team whose participants carried out the work autonomously. As mentioned above, the technical problem was controlling the orientation of the quadrotor in Figure 1. CIC2022 was conducted by the rules and technical notes published on 13th December 2021 [42]. The main characteristics of the competition are summarized below.

FIGURE 2. Development of the final phase.

- Two categories were proposed with different degrees of difficulty of the control problem to be solved:
  - Category 1. The UAV rotation is physically blocked in the Z axis (yaw). Thus, the objective is to control the roll and pitch angles according to the established references.
  - Category 2. The three angles of orientation (roll, pitch and yaw) are control targets.
- Undergraduate, master and Ph.D. students could participate and the teams had to be composed of a maximum of two students; this required both members to be active. The mailing list of the CEA Control Engineering group was used to publicize the competition among its members. Finally, a total of fourteen teams from universities all over Spain registered, eight teams in Category 1 (undergraduate) and six teams in Category 2 (master and Ph.D.).
- The competition was held in two phases:
  - Qualifying Phase (Phase 1) took place during a semester and was carried out using a simulator that faithfully represented the real system. Based on the technical information and the simulator provided by the organization, the participants proposed a control system together with a justification report. Once fixed a control experiment, an evaluation function quantified the control performance, and then, the quality of their controllers. After the deadline for submitting the results, five teams in Category 1 and four teams in Category 2 entered the competition. The top three teams in each category advanced to Phase 2.
  - Final Phase (Phase 2) took place in person during the "XLIII Jornadas de Automática" (Figure 2), a national congress that was held in Logroño from 7th to 9th September 2022 [57]. During the event, the qualified teams could experiment with the test bench, adjusting their control systems. In the final round, the organization proposed a certain experiment (angle profiles combined with different battery charge levels) and the contestants' controllers were tested. An evaluation function quantified the

control performance (tracking errors and control actions) of the proposals, ultimately determining the final ranking and the winner.

C. SCORING SYSTEM

Two different types of evaluations were used. On the one hand, a cost function evaluated the empirical performance of the participants' control system. On the other hand, a technical report where the participants justified their control strategy was evaluated. This avoids learning focused solely on results that would impede the acquisition of relevant hard and soft skills and it can reduce a possible negative impact on competitiveness, as more than the result is valued. In addition, technical documents are very common issues in any professional career.

In the Qualifying Phase, the final mark (SCORE) is weighted so that 70 % corresponds to the quantitative assessment of the control system performance (INDEX) and the remaining 30 % to the report justifying the strategy followed (DOC). The evaluation of the report considers the design methodology, the characteristics of the control system, the coherence and clarity of the drafting, and the quality of the documentation. The evaluation committee's score out of 10 points for the report quality is obtained as the weighted average of the scores provided by three experts.

In summary, the score for this phase is obtained by applying the following formula: SCORE $=$ INDEX $\times$ 0.7 $+$ (1-DOC/10) $\times$ 0.3. This scoring system also avoids the classification of teams that present control laws which, despite obtaining good empirical results, could have been obtained by trial-and-error without applying theoretical concepts studied in subjects related to the competition. On the other hand, the Final Phase only considers the quantitative evaluation (SCORE $=$ INDEX) upon the fact that the use of the real plant adds complexity and trains practical skills. A lower SCORE means a better position in both phases of the competition.

With the particularities of being an experiment in simulation or on a real platform, we proceed similarly in both phases to obtain INDEX fusing a cost function. An experiment is configured by the organization to evaluate the participants' control systems: under different levels of battery charges, a time profile of desired roll, pitch, and yaw angles is proposed. Once the simulation or real tests have been completed, an evaluation function quantifies the differences in tracking error and control action between the participants' control and a reference control for each degree of freedom (roll, pitch and yaw). The said cost function computes behavioral indices that are well-known in control engineering: IAE (Integral of Absolute Error), ITAE (Integral of Absolute Error weighted over Time), and IAVU (Integral of Absolute Control Action Variation). Finally, an overall cost function combines the above indices into a weighted sum INDEX. An index greater than one quantifies how much the performance deteriorates from the standard, while an index less than one measures the degree of improvement. The comparison of the contestants' overall indices ranks the teams: the lower the index, the better the position.

TABLE 1. Category 1. results of the qualifying phase (Phase 1).

ID	ROLL	PITCH	INDEX	DOC	SCORE	POS
101	0.665	0.463	0.564	8.50	0.4399	**3**
102	0.657	0.701	0.682	9.00	0.5073	**5**
103	0.678	0.460	0.569	9.00	0.4283	**2**
104	0.698	0.551	0.625	8.00	0.4972	**4**
105	0.504	0.503	0.503	8.50	0.3974	**1**

TABLE 2. Category 2. results of the qualifying phase (Phase 1).

ID	ROLL	PITCH	YAW	INDEX	DOC	SCORE	POS
201	0.779	0.627	0.614	0.673	6.00	0.5914	**4**
202	0.582	0.589	0.497	0.556	9.00	0.4191	**1**
203	0.625	0.692	0.683	0.667	8.50	0.5119	**3**
204	0.791	0.555	0.401	0.582	8.50	0.4526	**2**

D. RESULTS

This section discusses the quantitative results of the competition. The tables and scores that contain this information have been published on the CIC2022 website [42]. Once the control systems and the documentation provided by each team had been evaluated, Tables 1 and 2 were generated, which summarize the results of the Qualifying Phase.

The interpretation of the columns is as follows:

- INDEX: the value of the cost function that evaluates the control system performance. It is computed as the average of the performance values for each angle of rotation. The score for each angle contains the weighted sum of three components (IAE, ITAE, IAVU).
- DOC: score, out of 10, given by the evaluation committee to the documentation submitted.
- SCORE: the final mark of each team. Since the INDEX is based on a cost function, the best SCORE is the lowest value.

Based on the results in Tables 1 and 2, teams 105, 103, and 101 in Category 1 and teams 202, 204, and 203 in Category 2 qualified for the Final Phase. All participating teams, both in Category 1 and 2, managed to beat the reference control system (see column INDEX). This achievement is not a trivial task and denotes a high involvement of the participants.

Within the framework of the congress activities, the Final Phase of the contest was developed as follows. On the first day, the participants were informed about the schedule and rules of the contest, as well as they were instructed on the implementation of control systems on the real platform. Two test sessions of two hours each were enabled in which the participants were able to test and adapt their control designs. Finally, on the last day, the final test was evaluated. The experiment involved different changes in the reference angles of roll, pitch, and yaw to be tracked. To make the competition more realistic, the experiment set up for each category was carried out by applying 10 V, 11 V, and 12 V supply voltages,

TABLE 3. Category 1. Results of the final phase (Phase 2).

ID	V bat	ROLL	PITCH	SCORE	AVG	POS
101	10 V 11 V 12 V	1.076 1.076 1.935	0.900 0.749 0.833	0.988 0.912 1.384	1.095	**2**
103	10 V 11 V 12 V	0.924 1.043 1.271	0.599 0.600 0.769	0.761 0.821 1.020	0.867	**1**
105	10 V 11 V 12 V	0.810 1.101 4.221	0.616 0.712 2.186	0.713 0.907 3.200	1.606	**3**

TABLE 4. Category 2. Results of the final phase (Phase 2).

ID	V bat	ROLL	PITCH	YAW	SCORE	AVG	POS
202	10 V 11 V 12 V	1.017 1.218 1.373	0.769 0.658 0.812	0.895 0.900 0.905	0.894 0.925 1.030	0.950	**2**
203	10 V 11 V 12 V	1.412 1.223 2.167	0.868 0.996 0.819	1.037 1.323 1.165	1.106 1.181 1.384	1.223	**3**
204	10 V 11 V 1 2V	0.806 0.970 1.120	0.879 0.810 1.048	0.921 0.913 1.003	0.869 0.898 1.057	0.941	**1**

which correspond to several operating ranges of the UAV battery. In this way, the behavior of the system can be evaluated when the batteries are discharged like what happens in free flight.

Figures 3 and 4 show the results achieved by the control laws for the 11 V experiment at the Final Phase. Quantitative results are in Tables 3 and 4: SCORE collects in one index the behavior of the two/three axis; AVG is the mean of scores for the three operating voltages and, eventually, ranks the teams in such a way that a lower average value indicates a better result. The performance obtained by all the proposals was satisfactory despite the new challenges introduced by the real platform. Based on these results obtained, it can be stated that the acquisition of technical competencies by the students has been suitable: control theory has been put into practice to solve a complex real problem.

Regarding Category 1, a closer look at Figure 3 shows that the reference tracking for the roll angle is very similar for all three teams. However, team 103 presents the best reference tracking for the pitch angle. Table 3 reaffirms all this. Regarding Category 2, Figure 4 shows a better performance of teams 202 and 204, especially for the roll angle compared to team 203. Table 4 indicates how teams 202 and 204 finally obtain a very similar average index, and the winner is decided by one hundredth in favor of team 204. A close look at Table 4 reveals how the main differences between the two teams produce in roll and pitch angles: team 202 is better in pitch angle and team 204 is better in roll angle.

The winners of the competition in Category 1 and Category 2 were team 103, from the University of AlmerÃB-a, and team 204, from the Polytechnic University of Valencia, respectively.

IV. DISCUSSION

Once the competition was over, a survey [58] was passed to the participants[1] to obtain feedback on different aspects related to the contest, and particularly to perceive the impact of CBL methodology. The wide range of questions can be grouped as follows:

- General: duration, difficulty, documentation, support and assistance, scoring system, and links to the academic curriculum and syllabus.
- Acquisition of technical competencies and soft skills.
- Application of CBL methodology.

For the participants of the Final Phase, some questions were added about the face-to-face event, the experimentation with the physical system, as well as different aspects related to the organization of this phase.

Those questions that are most relevant to the objective of the current paper are following analyzed in two blocks. On the one hand, the questions related to the acquisition of skills, both hard and soft, are discussed. These results are shown in Figures 5 and 6. On the other hand, the most relevant questions referring to the methodology and the organization of the contest are analyzed. These questions are presented in Table 5.

A. SKILL ACQUISITION

In the context of CBL, two questions were asked about the acquired competencies: one about control engineering skills and another about transversal competencies. Regarding the format, the questionnaire was multiple-choice among predefined competencies, although the participants could also add their own answers.

In terms of technical skills (Figure 5), although answers are even across all options, some of them stand out:

- Controller tuning using both classical and heuristic techniques. This makes sense since the control problem was based on the precise tuning of controllers to achieve the goal, therefore, much of the time was spent on the adjustment of controllers.
- Use of specific software. The key reason for this is that the simulation model and the implementation algorithms ran upon MATLAB-Simulink®, a widely used tool in engineering and education.

The entire set of selected competencies reveals the superiority of the contest over the mere academic context due to the possibilities offered by the testbed, the practical approach, and the time available to spend on problem-solving.

According to the soft skills (Figure 6), autonomous learning, planning and time management, the application of theoretical knowledge in practice, and teamwork stand out. The answers reaffirm the conclusions obtained by Mat et al. [51]. Taking the general characteristics of CBL as a reference, the most voted options are intrinsic properties of this methodology, which show their correct integration in the competition.

[1]The survey was conducted under an anonymous identity. Participants were informed about the use of their responses in research studies.

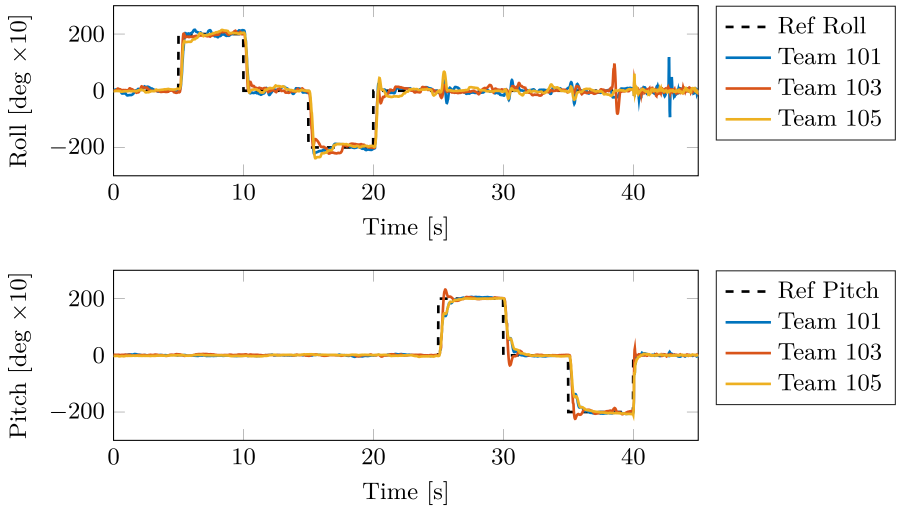

FIGURE 3. Category 1. Experimental results of the participating teams.

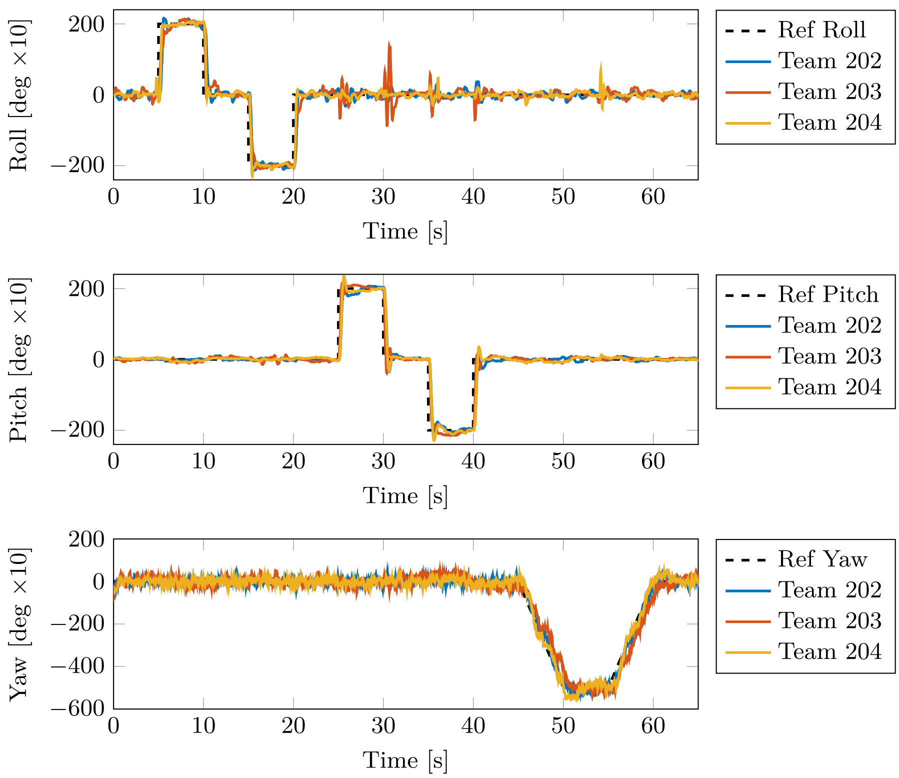

FIGURE 4. Category 2. Experimental results of the participating teams.

As further reflections let us consider limitations within the subjects that do not arise in the contest: learning concepts that can be extended because they are not part of a formal syllabus or self-developments that should not follow a traditional practice script. These reasons may mean that some soft skills have more impact on students.

B. METHODOLOGY AND ORGANIZATION

As mentioned above, Table 5 shows other relevant questions and the results of the contestants' survey.

Active learning is checked by the first question (Q1). 62 % of the contestants were very interested in expanding their own knowledge of control engineering and the remaining 38 % were quite interested.

Regarding the competitive nature of the contest, one of the most controversial aspects in terms of its effects on learning, several questions were asked (from Q2 to Q6). 85 % of the students considered that this feature stimulates learning much or very much, while for the other 15 % something. These results are in line with those presented by Gadola and

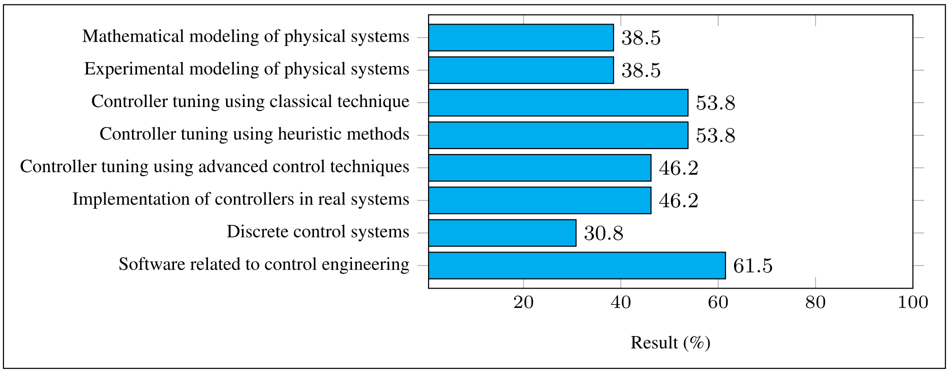

FIGURE 5. **Answers about the acquisition of technical skills.**

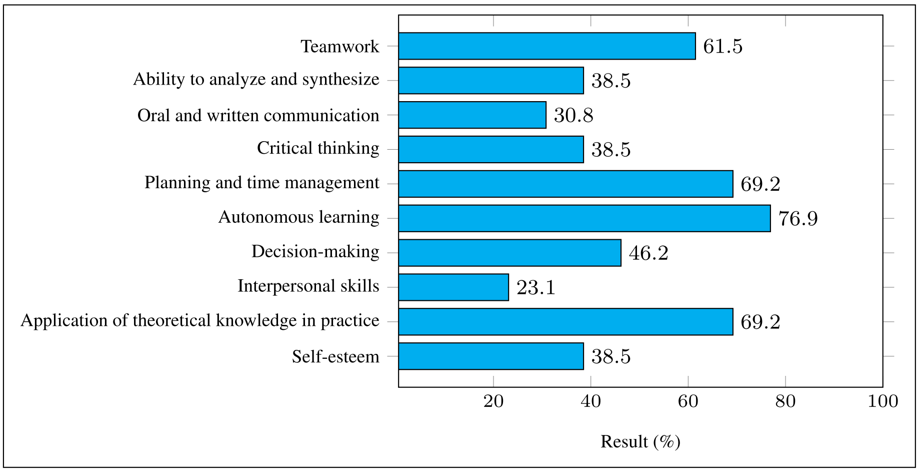

FIGURE 6. **Answers about the acquisition of soft skills.**

Chindamo [49] and Chang and Du [50]. Motivation follows a similar trend, with 23 % being something motivating, while the remaining 77 % much or very much, corroborating the findings of Lam et al. [53]. As for its similarity to professional life, the range of responses is wide: 15 % said it is not very similar, 31 % something similar, 46 % quite similar and the remaining 8 % believed that competitiveness is very similar to professional life. Another point of debate is competitiveness versus stress. While 54 % affirmed that they have never or hardly ever had this feeling, the remaining 46 % opted for sometimes or often. In this line, the percentages obtained can be aligned with Vockell's ideas [56]. Although the data are inconclusive due to the equality of the percentages, the negative impact is lower. To conclude this block of questions on competitiveness, 85 % of the students saw that, from a general perspective, it is a positive or very positive feature and 15 % neutral.

Related to the transversal competencies discussed above, a question (Q7) was asked about cooperation among teams in a contest of this kind, more specifically for the Final Phase, as it is a face-to-face competition. The results are mixed: 11 % of respondents thought it is impossible, prioritizing competitiveness, 22 % saw some possibility of help, 33 % were quite confident in cooperation and the remaining 34 % stated it is very possible to cooperate, prioritizing companionship as a means of learning.

A very interesting question is which they considered more relevant: winning the competition or the personal satisfaction of having learned (Q8) and, as expected, the results are mixed. 39 % preferred winning to learn, 23 % were indifferent and the remaining 38 % opted for learning to win. This equalization in the percentages differs from Clavijo and Oh [55], who state that the main motivation is the prize, especially if it is financial. However, it is interesting to note that no contestant just voted "winning the contest". At this point, the differentiation between the CBL methodology and an ordinary competition, without an educational component, is clear, since CBL focuses on learning as the main objective, making winning a stimulus to improve the learning process and results.

From an academic point of view, three questions were asked (Q9, Q10, and Q11). Concerning the academic curriculum, 85 % of the students believed that the contest was useful for a course they were taking. We can affirm that maintaining

TABLE 5. Survey: questionnaire and results.

Question	Answer	Result (%)
Q1. As a result of the competition, have you become interested in furthering your knowledge in the field of control engineering?	1 Not at all. 2 3 4 5 Very much.	0 0 0 38.46 61.54
Q2. Does the "competitive" nature of the contest stimulate learning?	1 Not at all. 2 3 4 5 Very much.	0 0 15.38 38.46 46.15
Q3. Does the "competitive" nature of the contest stimulate motivation?	1 Not at all. 2 3 4 5 Very much.	0 0 23.08 23.08 53.85
Q4. Is the "competitive" nature of the contest similar to what you might encounter in your professional life?	1 It is nothing like this. 2 3 4 5 It is very similar.	0 15.38 30.77 46.15 7.69
Q5. Has the "competitive" nature of the contest caused you stressful situations ?	1 Never. 2 3 4 5 Many times.	15.38 38.46 23.08 23.08 0
Q6. Rate the "competitive" nature of the contest.	1 Very negative. 2 3 4 5 Very positive.	0 0 15.38 38.46 46.15
Q7. Is it possible to cooperate among teams in a contest of this kind?	1 It is impossible. 2 3 4 5 It is very possible.	11.11 0 22.22 33.33 33.33
Q8. What do you consider more relevant: winning the contest or the personal satisfaction of learning?	1 Satisfaction of learning. 2 3 4 5 Winning the contest.	7.69 30.77 23.08 38.46 0
Q9. Has the contest improved your knowledge of related subjects in the curriculum?	Yes. No.	84.62 15.38
Q10. Rate the difficulty of the proposed control problem.	1 Very easy. 2 3 4 5 Very difficult.	0 0 30.77 61.54 7.69
Q11. Rate the time frame of the contest duration and compatibility with courses of your curriculum.	1 Difficult to adapt. 2 3 4 5 Easy to adapt.	0 0 0 46.15 53.85
Q12. How do you prefer to approach such a competition?	Individually. In pairs. In teams.	7.69 61.54 30.77
Q13. Assess the gap between working in simulation and with a real system.	1 Nothing interesting. 2 3 4 5 Very interesting.	0 0 0 0 100
Q14. The Final Phase took place during a congress with many other activities. How do you value this experience?	1 Very negative. 2 3 4 5 Very positive.	0 0 22.22 11.11 66.67
Q15. Do you feel that the competition has enhanced your education?	Yes. No.	92.31 7.69

a link between the university environment and the contest is essential for adding value to the teaching-learning process. The difficulty of the proposed control problem was rated more highly: 31 % thought it was normal, 61 % considered it was difficult and the remaining 8 % thought it was very difficult. Regarding the appropriateness of the Qualifying Phase in terms of time, duration, and workload with university studies, all respondents considered it to be quite easy to adapt.

As for the contestant groups (Q12), 61 % of respondents preferred to participate in pairs, 8 % individually, and 31 % in teams. This values teamwork within small groups to encourage the real participation of all members.

The following questions are related to the CIC2022 competition itself. All the students considered it very interesting to work at the Final Phase with a real system as opposed to a simulated model (Q13). Thus, the similarity of the problem with real life, which is a key factor in CBL, was well assessed.

As mentioned above, one of the particularities of this contest is that its Final Phase took place during a congress (Q14). The results of the survey show that 67 % considered attendance at the congress to be very positive, 11 % found it positive and 22 % average.

To conclude this section, 92 % of the contestants stated that CIC2022 enhanced their education and improved their training (Q15). This is the objective sought, to improve the learning process with a complementary approach to traditional teaching methods. This is also the main conclusion drawn from research work in this field, as exemplified by Dragomir et al. [48].

V. CONCLUSION

This paper has presented a national competition on control engineering based on the principles of the CBL methodology. The main objective was to see first-hand the benefits of this proposal as a complement to traditional master classes in regular control engineering courses under the assumption that these subjects represent a challenge for professors and students due to their strong mathematical formalism that must be tested in practice. To this end, it is necessary to enhance the benefits of the methodology and at the same time to face the adversities that competitiveness can generate in the educational environment.

Based on the main features of CBL and our experience during this competition, the benefits are shown to be a reality, giving rise to more positive than negative arguments. This is justified through the technical results as well as, especially, the survey answers. Knowing the opinion of the students has provided a more global perspective than biasing the analysis exclusively on the numerical results or the feelings of the professors involved.

The competition brought greater motivation and active learning of students, which improved the autonomous acquisition of hard skills. In this sense, it should be noted that during the first phase many technical queries were answered. The final face-to-face phase exhibited hard work and effort from the students to achieve the best control performance. Consequently, evaluation results revealed great progress from the qualifying to the final phase. The enthusiasm and commitment of all the participants led to even a team participating remotely due to their inability to attend. Camaraderie entailed the exchange of information between teams. The best-valued soft skills were autonomous learning, bridging the gap between theory and practice, and teamwork.

On the other hand, the study also notes some drawbacks of the CBL methodology. For example, there was no individual assessment of students, no regular indicators of how they learn, and, as seen in the literature reviewed, some participants put competitiveness before learning. In addition, learning focused solely on results can be enhanced by considering assessments other than purely experimental performance. Thus, the Qualifying Phase of the contest also took into account technical reports that explained the control systems. Similarly, the participants suggested in the survey incorporating oral presentations during the evaluation of the Final Phase.

The impact of CIC2022 on academic performance was not assessed in the regular syllabus. In another context with a significant number of students from the same institution, it would be desirable to compare the academic results of the contestants with those of the rest of the students in the regular course, as well as to analyze the progress of the participants before and after the competition. In any case, the heterogeneous origin of the contestants and the training discrepancies favored collaboration between teams as a means of learning.

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