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Active Learning Strategy Applied to Control Theory Teaching

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***Abstract*— This work presents an active learning strategy applied to the Control Theory course for engineering students. It shows the importance of new approaches to classic teaching in this area. Background: Active learning strategies seek to make the student the center of the learning process, enabling them to develop skills to learn, to question reality, have a critical reflection on the subject, learn how to work in a team, and promote the dissemination of innovative ideas. The strategy proposed aims to promote an alternative to traditional classes of control theory, leaving the teacher as the center of learning and placing greater relevance on the active participation and responsibility of the student during their learning. This strategy consists of dynamic classes based on small challenges and a final project challenge. In the latter, each group must identify the system involved, simulate it, design a controller based on some control techniques studied, and implement it through operational amplifiers or microcontrollers. In addition, students must prepare a report and answer some theoretical questions. Results obtained and the students' evaluation regarding their learning show the importance of using an active learning methodology in engineering courses.*

I. INTRODUCTION

TODAY'S Society is increasingly globalized, connected, and dynamic. However, when observing teaching, especially at the higher level, there is a large gap between what is taught or the way it is taught and what is required by this society. Thus, it is not uncommon to find situations in which the student does not have the ability to put into practice a certain concept or solve a practical problem.

To solve such a problem, more effective teaching tools are needed. According to Camargo & Daros (2018), if we understand that be being qualified can act, then we need teaching tools that provide the opportunity for the student to act from the knowledge acquired in their studies. Corroborating this teaching need, the Cognitive Sciences present the mental model concept, which are cognitive structures applied to characterize the ways in which people understand and interact with the world. According to Moreira (2016), from the point of view of these mental models, it is possible to say that learning consists of to build mental models of what is being taught while teaching is to facilitate the building and reviewing of mental models. Thus, it is important the production of tools and methodological actions that allows the development of the mental models or the review of those that the students already have.

A methodology or tool that put the student in the center of the learning process, that is, in which the student participate actively, is called Active Learning Methodology. Clearly, the student always takes part of the learning process, but, often, their role is simply watch, listen, take notes, or memorize a subject, which does not contribute to the evolution of their mental model.

Some works in engineering point out that the use of active methodologies provide several benefits to the students with the development of demanded competencies, such as: more motivation, deeper knowledge of the concepts, ability to apply the concepts, ability to project, critical thinking, team- work, problem-solving, analysis, communication and collab- oration (Jayaram, 2014; Hosseinzadeh & Hesamzadeh, 2012; Hernández-de Menéndez et al., 2019).

These benefits can be also perceived in the comparative study of the satisfaction on learning process in active learning and traditional classrooms presented by Hyun et al. (2017). Authors surveyed sixteen classes of courses in business and education, and they note that active learning influences positively. In (Freitas & Fortes, 2020), the authors also present a study of on satisfaction learning, involving 115 engineering students, that confirm the increase in their motivation and learning on active learning classrooms. Furthermore, it’s observed that there is an expectation from these students that the classes should not remain only at the theoretical level but should make it possible to apply the knowledge acquired in real problems (about 83% students informed that it is a privileged way to facilitate his learning).

A case study in a Vehicle Dynamics course presented by Hernández-de Menéndez et al. (2019) also observed as a result that, through an active methodology, learners had the opportunity to acquire and practice different technical skills in a controlled/supervised manner, analyze how a system works in practice, test and observe different responses and have a deeper understanding of the elements’ interactions. The students can also make mistakes without assuming the economical responsibility for fixing the equipment.

In (Elmôr Filho et al., 2019), the authors describe the main idea for twelve active learning strategies and methods: peer instruction, just-in-time teaching, think-pair-share, in- class exercises, thinking-aloud pair problem-solving, groups with different tasks, constructive controversy, jigsaw, groups challenges, teaching cases and problem-based learning. But, how to effectively adapt such methods to engineering courses? Some works address this issue.

Freitas et al. (2013) present a methodology based on the “Motivation through Challenge”, where, along the classes, the students perform the speed control of a conveyor belt prototype triggered by a direct current motor, using scrap material. In the work of (de Araújo et al., 2016) the authors present a hybrid Problem Based Learning model applied to the undergraduate course of Agricultural and Environmental Engineering, in which the students should perform research about the problems in their field of study and present their own solutions. Using a project-based learning methodology where the students of the Master of Aerospace Engineering degree of the Universidad Politécnica de Madrid are required to perform a preliminary design of a Space Mission, the work of (López-Fernández et al., 2019) demonstrated that the motivation of students was enhanced compared to a teaching centered approach.

In turn, Wiggins et al. (2017) propose a method to assess student perspective of engagement in an active learning class- room. And Tharayil et al. (2018) list strategies to mitigate student resistance to active learning, e.g., explain course and activities expectations, assume an encouraging demeanor, design activities for participation, and use incremental steps. Authors also emphasize the importance of course planning to obtain an effective learning strategy.

The main contribution of this work is to present the planning and application of an active learning methodology to promote an alternative to traditional classes of control systems in higher education. Here, the teacher is not at the center of learning anymore and greater importance is placed on the active participation and responsibility of the student during their learning process.

Specifically, the methodology applied aims to develop in the students a critical and problem-analytic capacity, to increase students’ motivation and commitment, to make the students able to develop and analyze control systems (from the identification of these systems until the design of a controller, using the tools presented in control theory), and to integrate content already learned in other subjects such as, electronics and electrical circuits, with subject-specific content.

We present an experience with the application of an active learning methodology in the subject Controle Analógico (Analog Control) of the undergraduate course of Electrical Engineering of the Instituto Federal de Minas Gerais, Campus Avançado Itabirito, in Brazil.

II. METHODS

The first step for the application of the learning methodology of this work is the planning and surveying of a concept map of the subject chosen, Controle Analógico, as can be seen in Fig. 1.

This subject belongs to the set of mandatory subjects of the Electrical Engineering course, being offered in the 8º term of the course. Thus, in general, the students already have a sound knowledge of math, physics, and electronics. However, the motivation for the application of an active methodology was, in this case, the union between the perception of the need the students had to apply their knowledge and the desire to make the content of the subject more concrete.

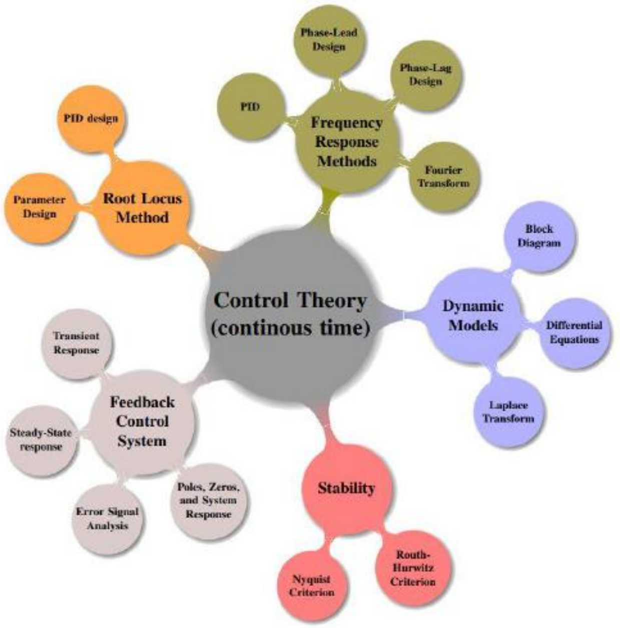

Fig. 1: Summary of the conceptual map of the Control Theory course.

A. Overview of the methodology

The methodology proposed can be summarized in Fig. 2. As the subject present new concepts for the students, it was adopted, in the beginning, short lectures of each topic of the subject. Those lectures had the duration of one hour, interspersed with one of the activities proposed: quizzes or challenges.

In general, the quizzes focus on the fast and interactive verification of the concepts taught using straight questions and answers, besides to promote an engagement of the students (Plump & LaRosa, 2017). Some quizzes were performed in a practical way, where the student should simulate and verify the result of the question.

The challenges along the classes had great importance in the adopted methodology. They are part of the building/assimilation of the content by the student. In the same way of an approach based in problems, the first challenge proposed to the student is, usually, poorly structured, that is, lack elements to be solved in class. Thus, based on the student's questions, the challenge is structured and then, a solution related to the topic studied is implemented. In this methodology there were partial challenges with simpler activities and a more complex final challenge, proposed by the end of the term, to evaluate the general knowledge of the students about all the topics studied in the subject.

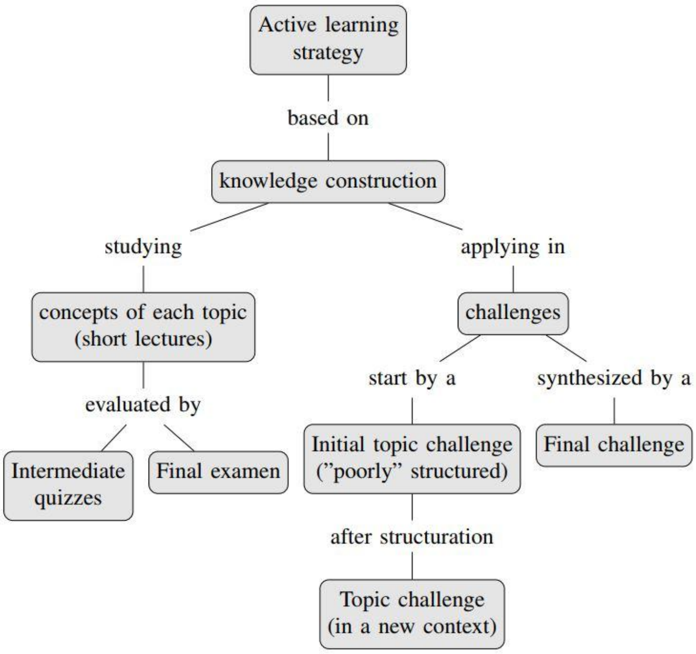

Fig. 2: Summary of the active learning strategy proposed.

B. Challenges

An example of a partial challenge proposed was the identification of a physical second order system built using amplifier circuits (see example available in our GitHub repository) in the free application Circuit simulator available in (Falstad & Sharp, 2021). First, the students performed measurements of this system output by applying a unit step input. After, they understood that it was a system similar to a second order one, as they saw in the lecture and then, they found its mathematical model through the measurement of the damped oscillations, the overshoot, etc. Finally, the students made a report using their conclusions and analysis performed during the challenge.

Following the methodology, by the end of the subject, the student has a final challenge, where they should apply the knowledge acquired along the term and be prepared for the second individual test. It is expected that the student be capable of analyze and identify a system as well as perform the project of a controller so that the output of the system follows some desired requirements.

The Fig. 3 illustrates the scheme of a plant proposed using operational amplifiers used in one final challenge. In the beginning, the students were encouraged to seek a controller that satisfied the requirements using only a closed-loop gain and to verify if this gain was capable to obtain the results by analyzing its root locus. After this analysis, the students were asked to perform the controller design using, for example, the frequency response of the plant, and then, perform a PID controller design using the Ziegler-Nichols method. The requirements for the system output given a step input were: (i) null steady state error, (iii) settling time less than 4ms (considering a 2% error) and (iii) overshoot less than 10%.

In another semester a different final challenge was proposed, where students had to develop a controller for a ball and beam system illustrated in Fig. 4. This system is composed of a sensor, responsible for measuring the distance of the ball to the center; a servomotor, responsible for the actuation (change of the base position); and a microcontroller board in which the controller obtained by Root-Locus and a PID design is discretized and implemented by the students.

It was also built a guide to help the students to analyze the system containing analysis of internal and external stability, analysis by Nyquist criterion, how to find the plant model, discretization, etc.

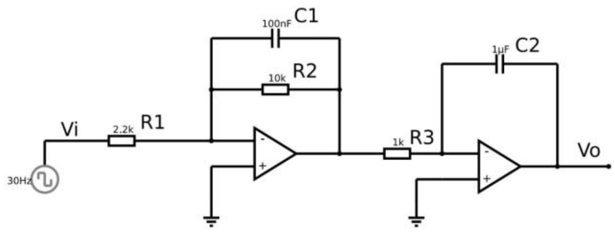

Fig. 3: Scheme of the circuit built as the plant of one of final challenges.

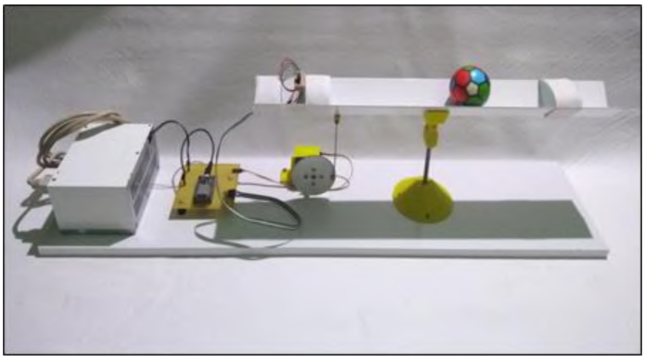

Fig. 4: Ball and Beam as the plant of one final challenge.

C. Evaluation

An important active methodology aspect is the student evaluation, which should be part of their learning process (Pironel & Vallilo, 2017), that is, the evaluation should be thought as a manner to favor and stimulate the students to think. Thus, it was proposed evaluation activities and their scores, during the term, were distributed according to the Table I. It is possible to observe in the table the scores for the individual exercises (in the form of quizzes) that, together with the challenges performed in groups, compose a total of 50% of the subject's grade.

Table I: Evaluation activities and their corresponding scores.

Score percentage	Assessment activity
25%	1^{st} test
25%	2^{nd} test
6%	Quizzes
24%	Practical challenges
20%	Final challenge

Finally, aiming to improve and speed up the communication between the teacher and the students, it was researched between several tools, the one that could meet this expectation. Then, it was chosen the Google Classroom platform. In this platform, all the students have access to the subject content, the activities and they also can send their results, receive their grades, and post their doubts and questions related to the subject.

III. RESULTS

In this section it will be presented some results obtained by the students during the execution of the quizzes, partial challenges, and final challenge as well as their evaluation of their experience with the methodology proposed.

A. Methodology results

It was performed a practical quiz using the software Octave in order to make more solid the knowledge and to encourage the students to find the answers by themselves. The quiz was about the step response of a second order system with variations of its damping coefficient (ζ) and natural frequency (ω_n). Thus, the students obtained a classic figure, common in many control systems books, illustrated in Fig. 5.

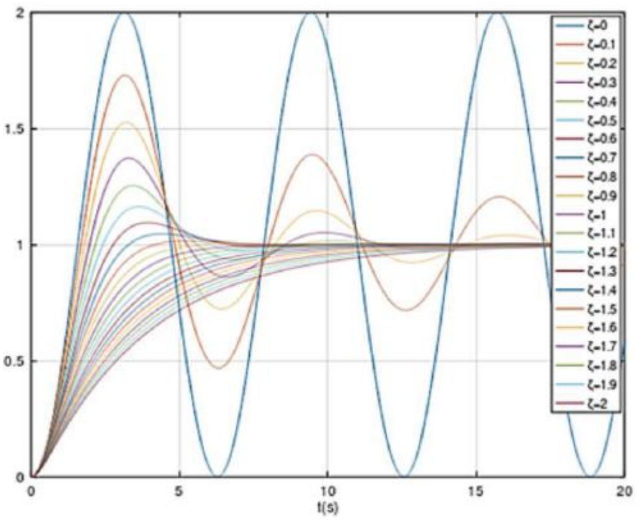

Fig. 5: Result of a practical quiz: step response of a second order system by varying the damping coefficient.

For the partial challenge exemplified in the Section Methods (the second order system with amplifiers), it is expected that the student plot in Octave the step response of the second order system that they modeled and compare with the data collected from the physical system. The same is expected from the first stage of the final challenge, where the students need to obtain the transfer function that model the plant mathematically according to Equation 1.

$$\frac{V_o}{V_i} = \frac{R_2}{R_1 R_2 R_3 C_1 C_2 s^2 + R_1 R_3 C_2 s} \quad (1)$$

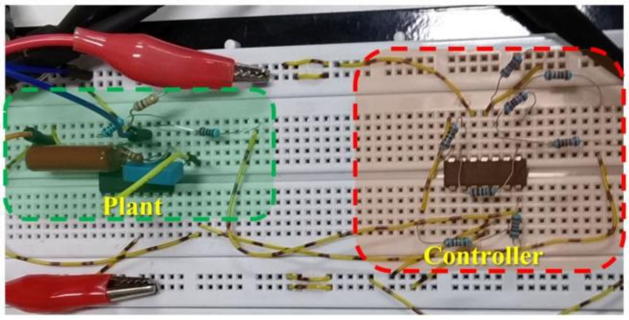

Fig. 6: Complete circuit with the plant and controller designed using operational amplifiers in a final challenge.

The student perceives that the model response follows the practical one as designed. This allows the student to feel that they did a good job and that what was learned can be applied in the real world, motivating the study of the theoretical content. Following with the challenge, the student observed, through the root locus analysis, that only a proportional controller is not enough to ensure that the system behaves as required. Now, the challenge is to design a controller using some technique learned as, for example, the frequency response of the plant. With the model of the controller, the students did the design of its circuit, using operational amplifiers and then, built the complete circuit, in the simulator, with the plant and the controller together.

A PID controller design using the Ziegler-Nichols technique (for a PI controller) was also implemented. The students observed that this method did not ensure the settling time required, and a fine-tuning of the gains was necessary. With this they learned that a PID controller design can be simple and also how to make an empirical tuning, often used in the industrial controllers. An issue pointed out by a student was the practical aspect of the PID controller assembly using operational amplifiers, as shown in Fig. 6. It was noted that the integration time can cause a lot of noise in the signal leading to the decision to perform an implementation of the PID, in parallel (see simulation and scheme in the material provided in our GitHub repository). Thus, in the physical circuit, the gains could be easily adjusted using potentiometers.

In the challenge, using a ball and beam system, the approximated model is described by the Equation 2:

$$H(s) = \frac{H_0}{s^2(\tau s + 1)}, \quad (2)$$

where H0 is obtained by geometric parameters and τ is the time constant of the servomotor. The discretized controller becomes a difference equation given in Equation 3 and implemented in the microcontroller by the students:

$$u[k] = A \cdot e[k-1] + B \cdot e[k] - C \cdot u[k-1], \quad (3)$$

where u is the discrete controller action, e is the error measured between the desired position and the actual ball's position, k is the discrete time, and A, B and C are positive constants obtained by the discretization process from the analog controller design using, e.g., poles placement method.

The Fig. 7 illustrates the measurement of the ball's position and the control action signal during the experiment. The Fig. 8 shows a screenshot of the video of the experiment, provided in https://youtu.be/XzO4Rm7Hi-4 (also available in our GitHub repository).

In both challenges the students verified if the project requirements were satisfied and built the physical systems. Comparing the results of the simulated and the physical systems, they validated the controller designed and verified the stability of the system.

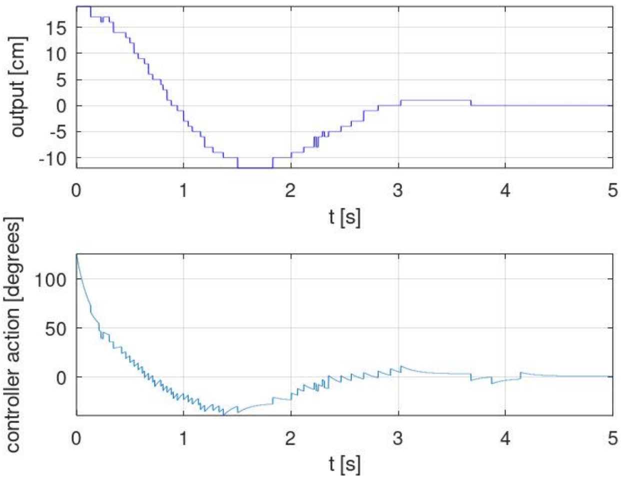

Fig. 7: Step response from 16 cm to zero (center position) and the controller action calculated by the microcontroller.

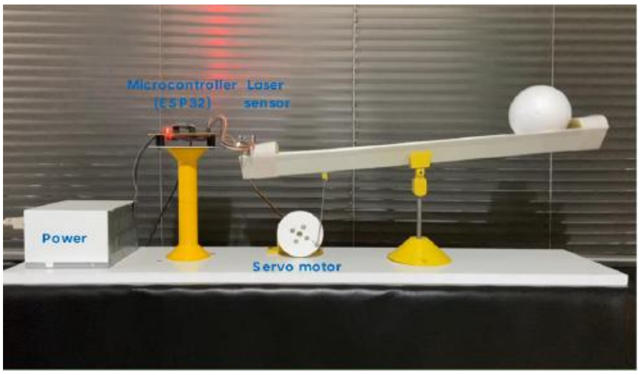

Fig. 8: Screenshot of experimental results video available in https://youtu.be/XzO4Rm7Hi-4.

B. Student's evaluation of the methodology

As it was initially proposed, we aimed to verify with this methodology the motivation, the student's analysis and learning abilities and provide an interface with other subjects of the course. Thus, as made by (Jayaram, 2014), we provided an online quiz for the students to fill in an anonymous and voluntary way.

In Fig. 9 it is possible to see the students' evaluation of the methodology through three principal questions:

• Q1: Has the methodology improved your ability to analyze a (control system related) problem?

• Q2: Did the methodology provide integration with other subjects in the course?

• Q3: Did the dynamics of the classes (theory interspersed with quizzes, challenges, simulations, and practical se- tups) improved the learning?

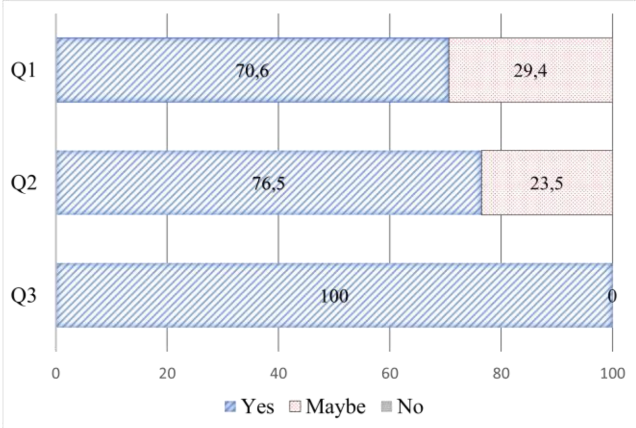

Fig. 9: Students' evaluation regarding three questions: Q1: Has the methodology improved your ability to analyze a prob- lem? Q2: Did the methodology provide integration with other subjects in the course? Q3: Did the dynamics of the classes (theory interspersed with quizzes, challenges, simulations, and practical setups) improved the learning?

Analyzing the collected data, in two reduced classes (seventeen students in total), it can be seen that the result related to the learning was relevant for the students. Most of them believe that the adopted methodology contributed to improve their learning and evaluate their learning at the end of the subject as good (63.2%) and very good (36.8%). This is also reflected by the commitment to study reported by students as being very good (21%), good (52.7%) and satisfying (26.3%). Following, it is the report of four students (translation from Brazilian Portuguese):

• Student 1: The learning was very good, because the development of the practical works generated a motivation and fondness by the subject and in solving the proposed problems. Thereby, there was also a greater participation of the students and of the teacher in the learning.

• Student 2: The use of different challenges allows a better hold of the content studied. Works performed in teams create experiences similar to those that the students will find in the job market and the problems involving real control situations bring a different motivation from that you normally have with the traditional methods.

• Student 3: Effective methodology, once the professor always requires the active attention and participation of the students. I believe that the laboratory class made the difference to this subject.

• Student 4: The association of the good organization of the content with the teacher's concern for the students' learning provided us with a good performance throughout the course, absorbing as much as possible what was passed on to us.

It was possible to note a different perception of the teacher's participation in the classroom, considered by 73.7% of students as a facilitator, requiring the student to develop and raise doubts to contribute to the discipline. Instead, 26.4% considered the teacher a content provider.

Regarding the critical analysis of the problems, five students reported that the subject made it possible to improve the control systems analysis while two students reported that, maybe, it helped a little. Concerning the interface with other subjects, only four of the students believe that the subject contributed only a little with the multidisciplinary and reported that the total amount of hours of the subject should be greater giving more time for this kind of interaction.

In general, the Google Classroom platform was also evaluated as good (26.4%) or very good (73.7%) by the students

C. Grades

Final grades are ranked on a scale of 0–100, where 0-39 is unsatisfactory, 40-59 is weak, 60-69 satisfactory, 70-79 good, 80-89 excellent, and 90-100 outstanding. Figures 10a and 10b show the histograms and boxplots from final grades of the available classes while Table II summarizes the main information from the data. The mean (and the median) of the final grades in Class 1 is considered good while in the Class 2 it falls in the satisfactory range.

We use these grades to evaluate the following hypothesis: the strategy proposed it's not sensible to the change of the final project. Thus, the grades of students (Class 1 and Class 2) are statistically compared using a two-sided Student's t-test to check this hypothesis. Statistical significance was defined as a p-value below a critical α-value of 5%. The premises of normality and homoscedasticity of the data were verified by Shapiro-Wilk (Shapiro & Wilk, 1965) test and Fligner-Killeen (Fligner & Killeen, 1976) test, respectively. The t-test returned a p-value equal to 0.609 (t[15] = 0.523), thus we can conclude that there is not statistical evidence to reject our hypothesis. Moreover, the effect size obtained by Cohen- test (Cohen, 1988) is equal to 0.258, which it is considered a small effect here.

Table II: Summary of the final grades.

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max
Class1	38.30	66.03	78.00	70.20	78.85	84.80
Class2	50.00	60.02	66.35	66.93	74.70	82.60

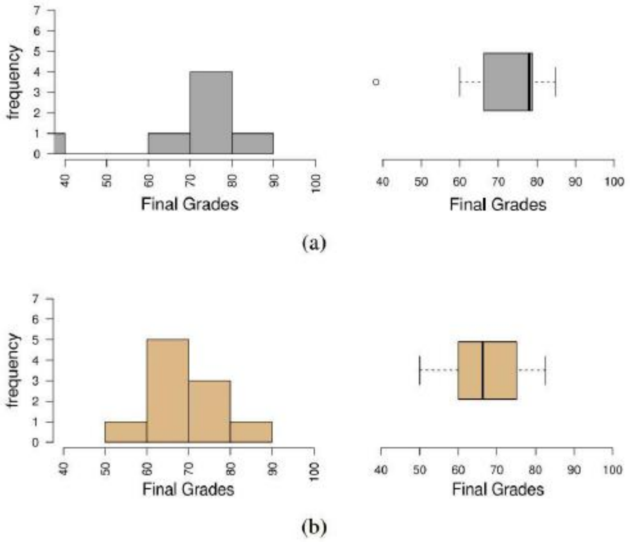

Fig. 10: Histograms (left) and boxplots (right) of final grades. (a) Class 1. (b) Class 2.

IV. CONCLUSION

This work presented an experience applying an active learning methodology in the control systems field. The methodology proposed was well evaluated by the students and the results obtained in the challenges were fruitful. Thus, the methodology presented is an option to the usual control systems expository classes evidencing the importance in using an active learning methodology in engineering undergraduate courses.

An important point raised by the students was the need for an increase in the total amount of hours of the Controle Analógico subject because the time to accomplish the final challenge was short, which made most of the students to work only on the circuits simulations. A solution for this issue could be to focus on the physical implementation of the control systems previously projected, in the final months.

As next steps we intend to begin a teaching project, involving the students, in the development of control systems learning kits which can be used to help the students in the execution of the challenges, allowing them more interaction with a real implementation and practical challenges related to control systems projects. Furthermore, we aim to build the structure to implement the ball and beam system as part of a remote lab so that the challenges can be applied in remote teaching and by professors of other institutions.

V. AVAILABILITY OF DATA AND MATERIALS

The data that support this study are available in https://github.com/Adrielle-Santana/Active-leraning-in-control-theory.

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