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An Active Approach for Teaching and Learning Electrical Technology

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Abstract: This contribution describes the change in methodology introduced in the subject of electrical technology within the industrial technologies engineering degree at Escuela Técnica Superior de Ingeniería Industrial, Universitat Politècnica de València. The main purpose of the methodology change was to improve the attainment of student outcomes by the introduction of project-based learning supported by flipped teaching. Moreover, a software tool was developed that generates standard exercise statements for the design of electrical installations. Using this tool, students can practice with different problem exercises, enter their solution, and receive immediate feedback on their results, improving the teaching–learning experience. The level of student outcomes attained was improved, and other positive aspects arose from the experience, such as boosting students' responsibility in their own learning (learn to learn), their ability to solve problems, and students' motivation. Furthermore, the instructors' opinions on the methodology change were highly positive.

Keywords: flipped teaching; project-based learning; practice-based theory development; electrical technology

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1. Introduction

Electrical installations in general, and low-voltage installations in particular, are essential in any productive activity in any of the three sectors (primary, secondary, and tertiary) and also in the residential field. Graduates in industrial technologies, regardless of their field of specialization, will come into contact with these types of installation throughout their professional activities, either in their design and maintenance or simply as mere users of them. Therefore, these students must be able to deal with the problems related to these types of installation that will be presented to them. To do this, they should know and understand the physical principles behind the design and operation of electrical installations to make them efficient and safe [1,2]. This paper will focus on the study of low-voltage electrical installations in industrial installations with low- and high-voltage supplies. This study is approached from a double perspective: on the one hand, it deals with those aspects necessary to be able to work with real industrial installations, but special emphasis is also placed on the concepts on which these installations are based. This way, everything studied can be easily extrapolated and adapted to other types of electrical installations (residential, service sector. . .) and to other voltage levels (high voltage) so that students will be able to adapt quickly to the future technological and regulatory changes that may arise [3].

New teaching methodologies, unlike traditional teaching, focus on the students, who develop autonomous and collaborative learning via work while instructors act as guides for them. This has given rise to applied methodologies such as project/problem-based learning (PBL) and flipped teaching (FT), which have been reported as quite effective to train engineering students to face problems such as those that may come up in their industrial practice [4–7].

The effects of introducing active methodologies such as PBL are amply available in the literature [8,9]. One of the most relevant aspects defining PBL is its integration of knowledge with action by combining the activities integrated in the curriculum and student input in an applied setting, with the instructor acting as a guide and facilitator [10]. PBL is being increasingly introduced in curricula in many countries and institutions as a way to face the failure of traditional approaches to provide students with the abilities and attitudes required in the frame of a vastly globalized economy [11].

Nevertheless, despite the change in focus in teaching methodologies, part of the teaching system still relies on the development of problem-solving activities as an important learning tool [12].

Specifically in the teaching of electrical technology, teachers can lean on a multitude of books that include already-solved problems to support their teaching [13,14], as well as exercise templates to be solved on the web.

However, none of these exercises are adjusted to the actual teaching of the subject, which means that the level of effort required to solve a problem may not be correct or the regulations applied may be different because they are outdated or come from a foreign legal standard. Consequently,the use of these exercises by students for their learning does not always provide them with the desired knowledge. The alternative to using external exercises is to develop one's own exercises for a subject. However, there is a low degree of variability in solved exercises available the students [13,15]. Thus, when it comes to designing good short problems or exercises in this kind of course, several requirements must be met, such as the following [16,17]:

- A learning curve adjusted to the needs of the students so that the material is neither too easy nor too difficult.
- The exercise must be conceptually clear without falling into ambiguities that could lead the student to wrong solutions.
- The data provided must be highly accurate. Any wrong data in the exercise will most likely lead to a poor exercise.
- In the case of engineering exercises, which are based on mandatory and changing regulations, each exercise must be updated to the regulations in force at the time the exercise is shown to the student.

Furthermore, students are expected to learn to work with the uncertainties that can occur in real environments, where not all parameters are strictly defined, and, in such cases, they must be estimated in an appropriate and reasoned manner.

Flipped teaching can introduce a more active approach to learning since, by transmitting the information to be learned online, class time is no longer spent explaining concepts to students. To illustrate this, Figure 1 shows a comparison between traditional and flipped approaches. In this way, introducing flipped teaching approach, it is possible to incorporate active learning and problem-solving activities during a class session [18].

Thus, the advantages of introducing flipped teaching in higher education can easily be found in the literature, as well as some risks to be considered when introducing such a change in methodology [6]. Regarding the field of learning in the area of electrical engineering, the literature highlights the positive momentum in the outcomes obtained by students, as well as their increased commitment to the subject [7]. However, it also points out how a fully flipped teaching approach could be too demanding for students in advanced engineering courses due to the complexity of the units, which require a large shift in their workload [19]. On another note, the authors of [20,21] analyzed the introduction of this type of methodology from the students' point of view, pointing out that despite the expected drawbacks, such as an increased workload or the risk of more superficial learning, the results showed high student satisfaction with the change and the ability to improve both students' skills and attitude towards learning. As a more complete experience in the application of this methodological change, Refs. [22,23] identified the possibility of some resistance from students to this new approach according to the interviews conducted, which may translate into less participation in class activities and/or increased feelings of stress when completing work. However, it did represent a significant improvement in student outcomes.

Therefore, with the aim of increasing productivity for both teachers and students in the PBL framework, FT could provide the support needed [24]. Integrating the two methodologies can promote Bloom's higher-order learning. Together, they harness each other's strength to promote the rationalization of valuable time. In this way, greater productivity is expected lo lead to better learning [25].

PBL supported by and blended with FT are two of several pedagogy components, such as the integration of technology, digital curricula, and literacy. This learning can lead to authentic learning experiences, mimicking real-life working experiences, as seen in engineering in general and in this course in particular.

This contribution reflects the results of a change of approach in the subject of electrical technology with the introduction of FT and PBL, including a new software tool for problem practice. The paper is organized as follows. Section 2 deals with the context of the case study, mainly considering the organization of the learning activities, the students, and the instructors, and introduces the main and the secondary objectives of the new learning methodology. Section 3 delineates the main aspects of its implementation. Section 4 details the development of the FT sessions in terms of schedule, tasks, partial objectives, and required equipment. Section 5 develops the low-voltage installation and design project. Section 6 elaborates on the exercise generator tool. Section 7 analyzes the results achieved through the evidence collected in terms of student grades and students' and instructors' opinions, and, finally, Section 8 describes the conclusions of this case study.

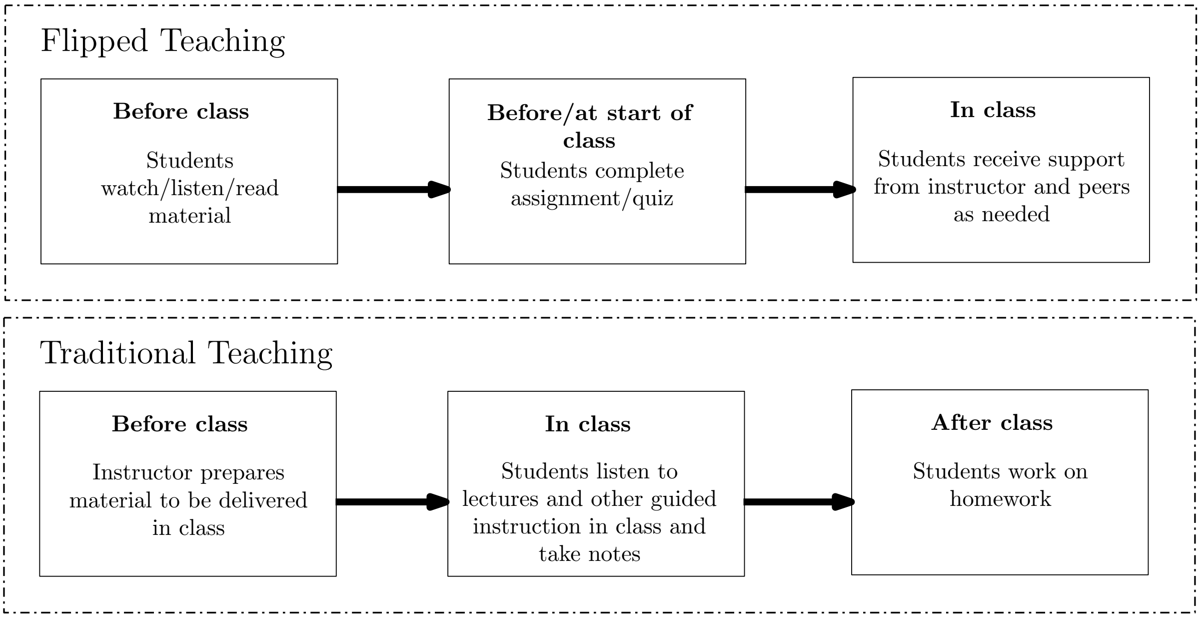


Figure 1. Comparison between traditional and flipped teaching approaches.

2. Context

This contribution describes a change in methodology introduced in the subject of electrical technology within the industrial technologies engineering degree (GITI) at Escuela Técnica Superior de Ingeniería Industrial (ETSII), Universitat Politècnica de València (UPV). The subject is followed by about 275 students every year during their first term (semester A) within the fourth year of the four-year program. A total of 486 undergraduate students enrolled in the electrical technology course participated in this study, more specifically 258 students in the year 2022 and 228 in 2023. The required course provided an introduction to switchgear and the design and sizing of low-voltage electrical installations. The students are organized in 5 theory and 15 laboratory groups, but the actuation described is related to the activities developed during the classroom sessions. All groups work in coordination at the same pace. The subject comprises 24 theory/practice sessions with a total duration of 48 h in 2 h sessions and 4 laboratory sessions of 3 h for a total of 60 h of on-site activities, corresponding to 6 ECTS (European Credit Transfer System).

The scope of our intervention focused on improving students' competence in the design of electrical installations through the application of PBL. Likewise, to facilitate the learning process with this methodology, a series of FT sessions were designed. This way, students could work on basic concepts prior to the session, and the time spent in sessions could be used for advanced topics and applications to continue applying the knowledge developed in their project. Furthermore, a software tool was developed that generates standard exercise statements for the design of electrical installations.

The intended purpose of the change in our approach to the subject was to improve students' outcomes and their skills in the design of low-voltage electrical installations. To this end, FT and an information communication technology (ICT) tool were implemented to enhance the project-based learning of the subject.

In order to achieve this overall objective, a subdivision into the following specific objectives was proposed:

- To improve the teaching–learning process for students regarding the typical elements and equipment that involves low-voltage installations. To this end, flipped teaching was applied, and the constructive, functional, operational, and economic aspects of these kinds of elements were studied in depth.
- To achieve effective development of the students' capacity for analysis of the operation of low-voltage installations in terms of safety for both users and the installation itself.
- To improve the capacity for the analysis and design of low-voltage installations. To this end, project-based learning was introduced, aimed specifically at:
  - Creating suitable designs of electrical distribution lines and lighting systems. The safety criteria established in the regulations must be considered.
  - Selecting protection elements and systems for the safety of users and the installation itself.

The methodology change was accompanied by an adaptation of the subject curriculum from a quite formal and standard model, mainly based on traditional lectures, to a more open model, in which the study of low-voltage electrical installations is approached from a dual perspective: on the one hand, practical aspects are addressed, which are necessary for working with industrial installations, but emphasis is also placed on the concepts on which these types of installations are based, so everything studied can be extrapolated to other types of electrical installations and voltage levels, providing the student with the tools to adapt quickly to any technological and regulatory changes that may arise.

In order to introduce the proposed methodological changes, new materials should be developed. Initially, four complete FT sessions were planned and carried out. At the beginning of each session, the learning outcomes that students were expected to achieve in each session were identified. All sessions had a short theoretical introduction, reinforced with audio-visual material, and finally included self-assessment questions. Subsequently, a computer tool was developed for students to solve defined problems and to obtain feedback to improve their learning process. At the same time as a statement is generated, the program developed generates a template for the user to enter the answers. Finally, the student, after solving the exercise, enters the template into the program. The program analyzes the results and gives feedback to the user. Finally, a project was prepared with the aim of improving and strengthening students' competences in the calculation and design of electrical installations and their protection. This work was carried out in parallel with the previous software tool to develop another program that would be able to generate variants of the project of similar difficulty for all groups of students. For the management of the projects, a task is generated on the student platform, from which the students have access to their statements and answer templates. Additionally, to facilitate corrections by the teacher, the application generates a spreadsheet with the solutions to all the projects generated.

Regarding the effect of the change in methodology, to asses and compare the outcomes, a comprehensive plan was developed. Applied skills grades were used to directly assess and compare student attainment between the previous methodology and the innovative methodology. This compared the combination of a multiple-choice test and an open-response test up to the introduction of the methodological change against the grades obtained after the introduction of the methodological change. Interviews and discussions were conducted with the instructors of the course to uncover gains that may not have been evident in the test data. In addition, brief surveys were administered with the objective of gathering information on the perceptions of both students and professors. Finally, focus groups of students were conducted to assess the benefits and drawbacks of the introduced methodology.

3. Approach

In order to achieve both the main objective and the specific objectives outlined above, a series of previous activities or action steps were proposed, which can be summarized as the creation and management of a work group, the definition of the subject's activities schedule, and the definition of a detailed, adapted set of learning outcomes.

The creation and management of a work group was considered a key initial step for the success of the actuation. This work group consisted not only of subject professors but was also reinforced with fellows with previous experience in the introduction of modern learning methodologies. It should be noted that the work group was enrolled in UPV's Educational Innovation and Quality Teams (EICE), and, as such, the members' activity is recognized in the UPV productivity program. The work group was asked to check on the progress toward and achievement of our specific objectives, overcoming any challenges that may arise with the continuous support of the group members. The experience was motivating and resulted in the application of the methodology to other subjects, as well as the members of the group disseminating their positive experiences. The development of the subject activities schedule was oriented at the attainment of the defined specific learning outcomes and adapted to the new methodologies, expanding the preparatory material and applying it to the successive steps of the PBL student project. The result was a detailed schedule for each programmed session, the related specific learning outcomes, and a description of the students' activities for the pre-, in-, and post-session periods. These included video watching, working with special simulators, completing self-assessment questionnaires, the introduction of and and in-session discussion of advanced concepts, the implementation of specific stages of the student groups' projects, and discussions of the results achieved by the different groups, among others. The subject curriculum was adapted in terms of specific and detailed learning outcomes appropriate for the new learning methodology to be used, which have been summarized in Table 1. These detailed learning outcomes had to be derived from the degree's learning outcomes, which are explicitly assigned to the subject, and within the methodology change's actuation frame.

On the other hand, the newly defined set of detailed learning outcomes needed to be adapted to the PBL methodology supported by FT. This was applied to facilitate the definition of specific activities for student work conducted pre-session, work conducted in-session, which focused on more advanced topics and application, and student work conducted after the session to further apply their developed knowledge in their project. The resulting set of detailed and specific learning outcomes was made available to the subject students in the online learning support platform of UPV, PoliformaT, along with additional learning plan activities. This was one of the actions taken to help alleviate student worries about the increase in responsibility for learning on their own sometimes associated with the use of these methodologies.

Table 1. Updated outcomes.

N	Student Outcomes
1	To understand the structure of users' electrical installations and the elements of which they are composed; to understand the function of the different elements (switchgear, wires, switchboards, grounding systems, and transformer substations).
2	To identify the electrical switchgear used in low-voltage electrical installations, the function of the different devices, the constructive aspects, the parameters and characteristic curves that determine their operation, and the basic regulatory aspects that they must comply with.
3	To know and understand the structure of the different grounding systems that may be in electrical installations of industrial plants, the function and structure of each of these systems, the parameters that characterize them, the basic aspects of their design, and the basic regulatory aspects that they must comply with.
4	To understand the dangers to which users of electrical installations are exposed. To know and understand the safety measures that electrical installations must comply with in order to guarantee the safety of users, as well as the regulations they must comply with.
5	To differentiate the different trunking systems used in electrical installations and the design process in accordance with current regulations.
6	To interpret and know how to apply methods to protect installations from overloads, short circuits, and overvoltages.
7	To know the basic aspects of lighting installations and how to apply basic methods of sizing indoor and outdoor lighting.
8	To identify the different types of transformer substations and the basic aspects of their design and regulations.

4. Development of the FT Sessions

To facilitate the students' learning process, 4 FT sessions were designed with didactic materials that the students had to work on before attending the classroom sessions. The result was a timetable detailing, for each session, the related learning outcomes, a summary of the material to be worked on prior to the session, and, finally, the on-site sessions in which these concepts were to be worked on. To provide better legibility, the timetable was organized into two tables. Table 2 details the student outcomes expected for each lesson, and Table 3 summarizes the resources available and the development of the sessions.

Table 2. Student outcomes for each FT session developed.

Lesson	Student Outcomes
1	To know the processes, effects, and difficulties involved in interrupting an electrical current. To be aware of the importance of limiting or mitigating the adverse effects that occur during power outages. To comprehend the need to have different specialized devices in electrical installations to interrupt the current in different conditions, as well as their main characteristics.
2	To analyze the function of circuit breakers in electrical installations, know the parts that they are composed of, and understand the function of each component. To differentiate between the different types of triggers used in circuit breakers (CBs). To identify the parameters and characteristic curves used in the selection of CBs. To relate the characteristic curves of the CBs with the triggers used. To discern between CBs and miniature circuit breakers (MCBs), as well as their fields of application.
3	To know the role of fuses and contactors in electrical installations and the physical basis of their operation. To know the parts that they are composed of and understand the function of each component. To know the parameters and characteristic curves used in the selection of fuses and contactors. To know the different electrical circuits to consider in the practical application of contactors.
4	To understand the concept and operating principle of the residual current circuit breaker. To know the characteristic parameters necessary for their selection. To differentiate between the different existing types. To understand their usefulness within the electrical installation.

Table 3. Design of the FT sessions.

Lesson	Resources	Class	After	The Student Must Study
1	Video: electric arcs Video: interrupting alternative current vs. direct current Reading session: Effects of interruption of electrical current Questionnaire	Review questionnaire Deepen interrupting electrical current Introduction to switchgear	To review concepts	Prior to the second class session
2	Video: mechanical parts of CBs Reading session: Selection of CBs Questionnaire	Review questionnaire Group discussion on advantages/disadvantages of the triggers	Review of functioning principle of CBs, triggers, constructive elements of CBs, and their curves	Prior to the third class session
3	Text reading and video viewing: fuses in electrical installations Questionnaire	Review quiz Review and expand concepts Discussion of concepts in class	Review of operating principle and fuse construction elements	Prior to the fourth class session
	Text reading and study of characteristic curves Questionnaire	Review and expand concepts Delve into the use of characteristic curves	Review of parameters for the selection of fuses and exercises on the application of the characteristic curves of fuses	
	Text reading: Types of fuses Questionnaire	Review quiz Review and expand concepts	Review of types of fuses Discussion of concepts in class	
	Video: operation and contactor construction elements Questionnaire	Review quiz Review and expand concepts Practical examples of the use of contactors	Review of contactors	
4	Review the resources uploaded to the platform	Review the operating principle and resolve doubts		Prior to the eighth class session
	Video: display of residual current circuit breaker operation Questionnaire	Review quiz		

5. Definition of the Low-Voltage Installation Analysis and Design Project

The main aim was to try to help the students improve and strengthen their skills in the calculation and design of electrical installations and their protection. It was decided that the project would be carried out in groups of a maximum of 3 people. Therefore, more than 90 variants were to be generated with a learning development frame that could be as uniform as possible. To this end, the work involved was carried out in parallel with the previously detailed software application. We developed another application that was able to generate variants of a project of similar difficulty for all groups of students. Furthermore, this application allowed us to generate as many different variants of a standard project as requested. Bearing in mind the learning outcomes and subject's schedule, the project was defined as a low-voltage installation analysis and design project to be solved using a spreadsheet, referring specifically to:

- The suitable sizing of electrical distribution lines and lighting systems. Therefore, the safety criteria established in the regulations needed to be considered.
- Calculating short-circuit currents to select protection elements and systems for the safety of users and the installation itself.

Figure 2 shows a partial screenshot of the statement of a project to be carried out by a group of students that was generated by the application we developed.

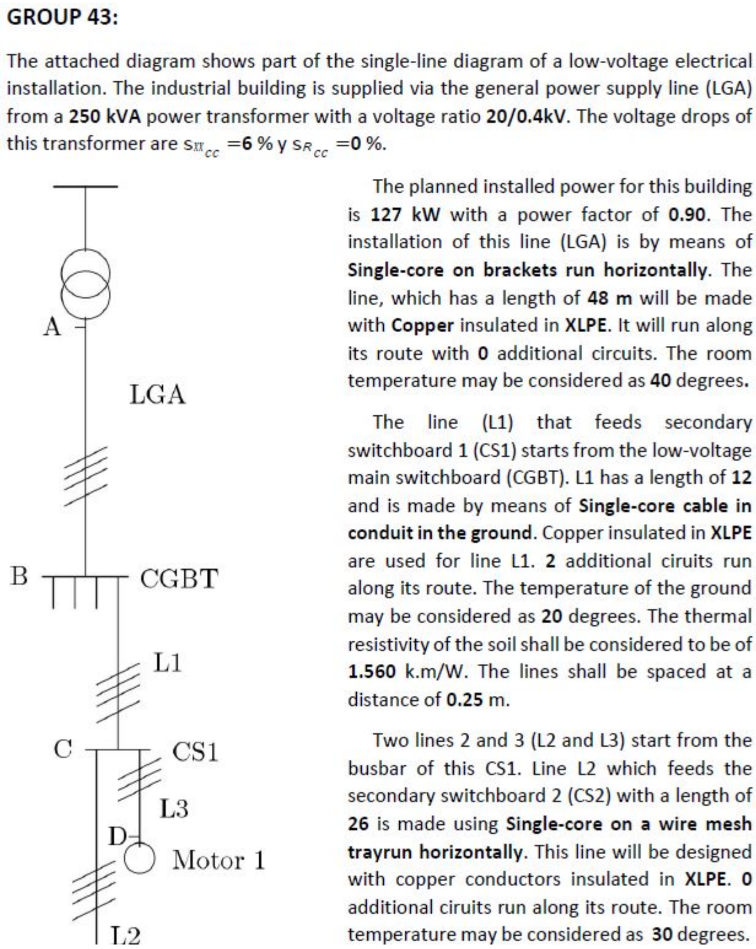


Figure 2. Part of the project instructions proposed to a group of students.

To manage the projects, a task was created on the PoliformaT student platform, from which students had access to their statement and an answer template. At the end of the activity, they had to upload the completed template as a response to the task. As mentioned above, the paper that was due was completed as a group. However, students were encouraged to carry out the different tasks of the project individually with the purpose of sharing their results among the group members once completed. In this way, they could identify differences between their results and discuss solutions and/or explain concepts to each other, so that the experience could serve as a further tool to reinforce their learning and encourage self-learning.

Definition of the Project Evaluation Rubric

A project rubric was developed in order to give feedback to students and improve their learning process. The rubric with the teacher's comments was available to students when their grades were published. Additionally, students had access to the automatically calculated solution so that they could compare their results with the correct answers. Therefore, our method facilitated teachers' grading process by providing a clear, uniform frame known both by students and by evaluators. Figure 3 shows a partial screenshot of the rubric used in the review of the project. In this last process, it was decided that the teaching staff should be present so that they could give the pupils indications not only about their mistakes but also about the part of the calculation process where they made a mistake. This way, teachers were able to identify if there were concepts that had not been completely assimilated by the students, allowing teachers to offer the necessary explanations to improve student comprehension.

Additionally, in order to support students in their learning of this part of the subject, an automatic exercise generator was developed. Each exercise was unique; we aimed to improve students' skills by having them solve these type of exercises.

Título de la rúbrica exportada: Electrical technology Project Exportada desde el sitio: T.Elec Fecha de la exportació: 17 de octubre de 2022					
Thermal Sizing					
LGA : 0.0 puntos	**E : 2 puntos** Incomplete results.	**D : 4 puntos** Numerous errors. Inadmissible/inconsistent results.	**C : 6 puntos** Some calculation errors and/or selection of incorrect table values.	**B : 8 puntos** Virtually no calculation errors and correct selection of parameters for dimensioning.	**A : 10 puntos** No calculation errors, correct selection of parameters, correct design.
L1 : 0.0 puntos	**E : 2 puntos** Incomplete results.	**D : 4 puntos** Numerous errors. Inadmissible/inconsistent results.	**C : 6 puntos** Some calculation errors and/or selection of incorrect table values.	**B : 8 puntos** Virtually no calculation errors and correct selection of parameters for dimensioning.	**A : 10 puntos** No calculation errors, correct selection of parameters, correct design.
L2 : 0.0 puntos	**E : 2 puntos** Incomplete results.	**D : 4 puntos** Numerous errors. Inadmissible/inconsistent results.	**C : 6 puntos** Some calculation errors and/or selection of incorrect table values.	**B : 8 puntos** Virtually no calculation errors and correct selection of parameters for dimensioning.	**A : 10 puntos** No calculation errors, correct selection of parameters, correct design.
L3 : 0.0 puntos	**E : 2 puntos** Incomplete results.	**D : 4 puntos** Numerous errors. Inadmissible/inconsistent results.	**C : 6 puntos** Some calculation errors and/or selection of incorrect table values.	**B : 8 puntos** Virtually no calculation errors and correct selection of parameters for dimensioning.	**A : 10 puntos** No calculation errors, correct selection of parameters, correct design.
Voltage Drop Sizing					
LGA : 0.0 puntos	**E : 2 puntos** Incomplete results.	**D : 4 puntos** Numerous errors. Inadmissible/inconsistent results.	**C : 6 puntos** Some calculation errors	**B : 8 puntos** Virtually no calculation errors or no calculation errors but no selection of optimum cross-section (phase and neutral).	**A : 10 puntos** No calculation errors and optimal selection of cross-sections (phase and neutral).
L1 : 0.0 puntos	**E : 2 puntos** Incomplete results.	**D : 4 puntos** Numerous errors. Inadmissible/inconsistent results.	**C : 6 puntos** Some calculation errors	**B : 8 puntos** Virtually no calculation errors or no calculation errors but no selection of optimum cross-section (phase and neutral).	**A : 10 puntos** No calculation errors and optimal selection of cross-sections (phase and neutral).

Figure 3. Partial screenshot of the rubric used in the correction of the projects, which was also given to the students as feedback on their papers.

6. Development of the Automatic Exercise Generator

This section presents the development of the exercise generator designed for the didactic unit on the basic sizing of low-voltage electrical installations, where the calculation of short circuits in different parts of the installation was carried out in order to be able to subsequently choose the appropriate protections. Using this program, the students themselves could generate any exercise from this syllabus. Each exercise was unique and was aimed at improving students' skills when solving these types of exercises. The interface of the exercise generator was designed to be used by any user, be it an instructor or a student. Therefore, it had a minimalist structure and consisted of only two buttons and a terminal box where various messages were displayed, as shown in Figure 4. Students could not modify the configuration of the generator through the interface. The only way to configure the parameters of this program was to access the configuration files inside the installation folder, where only authorized users had access.

When the 'Create exercise statement' button was pressed, a new exercise was generated on the spot as randomly as possible within the limits set in the software's configuration. Each exercise generated was assigned a unique identifier, which was used to let the software know which exercise was being checked. The format of the generated exercises is detailed in Section 6.1. The program's terminal showed the details of the exercise generation process from the start of the exercise to when the exercise files were saved, as illustrated in Figure 4. By clicking on the 'Review the answers' button, the program prompted the user to select the file containing the answer sheet of the solved exercise. When the exercise sheet was entered, the generator program compared the results entered with the actual results of the exercise. In this case, the exercise parameters were embedded within the spreadsheet and were not visible to the learner. The program's terminal showed the development of the revision of the results. If there was a mistake, a message was displayed indicating the incorrect result and the correspondent cell of the spreadsheet.

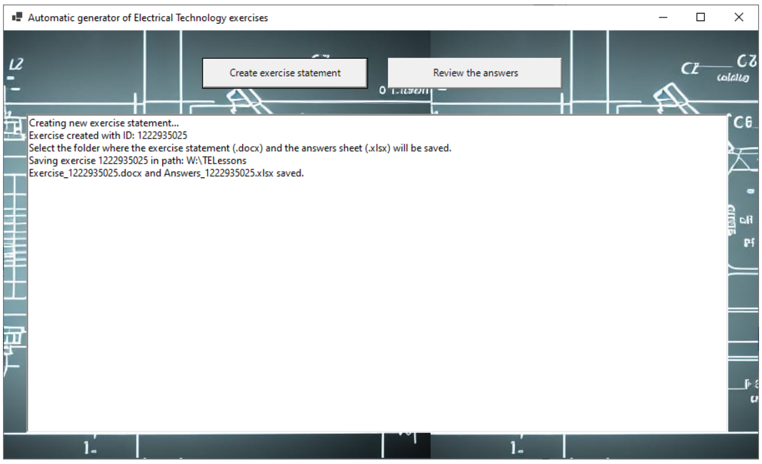
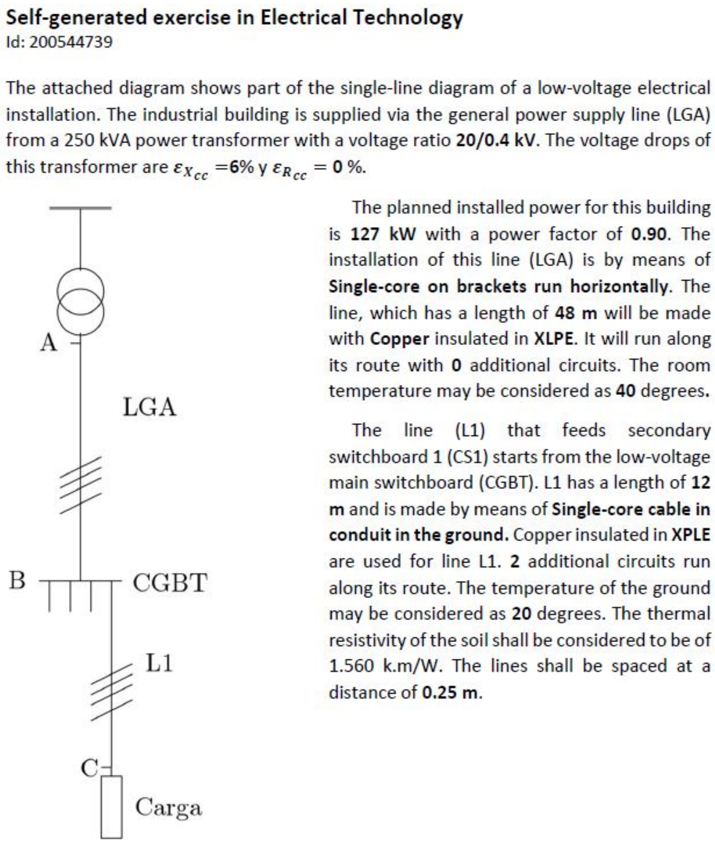


Figure 4. Interface of the electrical technology exercise generator software tool we developed.

6.1. Format of the Generated Exercises

Generally, professors deliver digital exercises statements in document formats such as PDF or Word, but for the delivery of their solutions, a spreadsheet is commonly used to enter the values to be checked. Accordingly, the exercise generator was programmed to return two files to the student for each exercise generated: a text document with the exercise statement (Figure 5) and a spreadsheet where students entered the results of their calculations (Figure 6).



Self-generated exercise in Electrical Technology
Id: 200544739

The attached diagram shows part of the single-line diagram of a low-voltage electrical installation. The industrial building is supplied via the general power supply line (LGA) from a 250 kVA power transformer with a voltage ratio **20/0.4 kV**. The voltage drops of this transformer are $\varepsilon_{X_{cc}}$ =**6%** y $\varepsilon_{R_{cc}}$ = **0** %.

The planned installed power for this building is **127 kW** with a power factor of **0.90**. The installation of this line (LGA) is by means of **Single-core on brackets run horizontally**. The line, which has a length of **48 m** will be made with **Copper** insulated in **XLPE**. It will run along its route with **0** additional circuits. The room temperature may be considered as **40** degrees**.**

The line (L1) that feeds secondary switchboard 1 (CS1) starts from the low-voltage main switchboard (CGBT). L1 has a length of **12 m** and is made by means of **Single-core cable in conduit in the ground.** Copper insulated in **XPLE** are used for line L1. **2** additional circuits run along its route. The temperature of the ground may be considered as **20** degrees. The thermal resistivity of the soil shall be considered to be of 1.560 k.m/W. The lines shall be spaced at a distance of **0.25 m**.

Figure 5. Example of a statement automatically generated by the software tool we developed.

As Figure 5 shows, the statement of the exercise presented a low-voltage installation, setting its single-line diagram and the parameters of this installation from the power transformer to the main connection, its internal branches, and the loads coupled to this installation. It was requested to solve the sizing of the conductors of this installation while calculating the short-circuit currents to subsequently select the appropriate protections. The variability of the exercise lies in the variation of the proposed installation and its parameters, while the resolution of the exercise requested did not vary (sizing and protections).

The answer spreadsheet included two tabs. The first tab corresponded to the solutions for the calculation of the sizing of the installation regarding all its wires (the general supply line, line 1, etc.), while the second tab corresponded to the solutions for the calculation of overcurrents. Both the text document and the spreadsheet displayed the identifier of the exercise they belonged to so that students could identify which exercise statement corresponds to each solution entered in the spreadsheet.

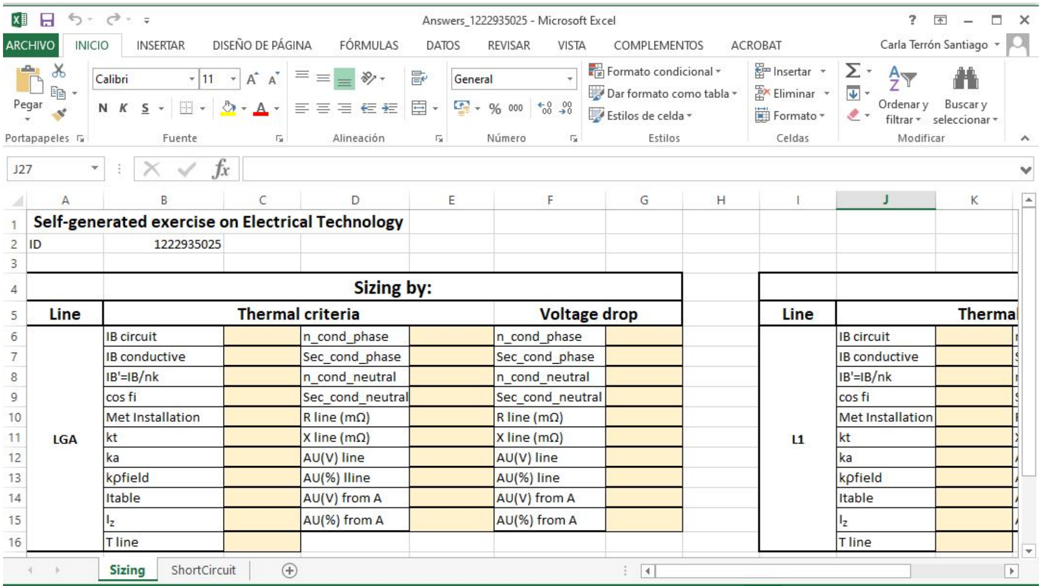


Figure 6. Example of the answer sheet for the exercise generator.

6.2. Internal Programming of the Exercise Generator

Considering the kind of exercises we self-generated, e.g., an installation with several boards, lines and loads, which can be divided into sub-exercises, an object-oriented programming philosophy was proposed. The program was implemented in the Visual Studio 2019 development environment. This development environment has libraries that allowed us to fully manage the generation and editing of text and spreadsheet files. Both file types were fully familiar to our engineering students. The main objectives of the program were the following, which have been summarized in Figure 7:

- The main objective of the **self-generator** interface.
- The **generated** object links to the **exercise** object and sends it to the **creating statement** and the **created answer sheet**, always in accordance with the limits set by the **regulation** object.
- The **solving** object links to the **exercise** object and computes it according to the **regulation** object.
- The **exercise** object involves the main parameters and functions of the exercise and links to the **HV line**, transformer, and **LV board** objects.
- The **HV line** object involves the main parameters and functions of the high-voltage part of the installation near the primary part of the power transformer.
- The **transformer** object contains the parameters and functions related to the substation transformer, which converts high voltages to low voltages. This transformer is

connected via its primary line to the **HV line** and via its secondary line to the main **LV line**.

- The **LV board** object involves the parameters and functions corresponding to a low-voltage board that is connected to an upstream LV line and a downstream LV line. The number of LV boards depends on the installation. Moreover, there must be a least one main LV board connecting the supply and one board on a secondary line. The **LV line** object involves the parameters and functions related to the LV distribution line, which is connected to the LV board upstream. Depending on the variant, it may also be connected downstream to another LV board that connects to other distribution lines. The number of LV lines depends on the installation.
- The **load** object involves the parameters and functions related to every load connected to the installation, e.g., lighting, machines, etc. There may be loads connected to different LV lines in the installation.

Figure 7 shows a diagram with the most significant objects for the program as detailed above.

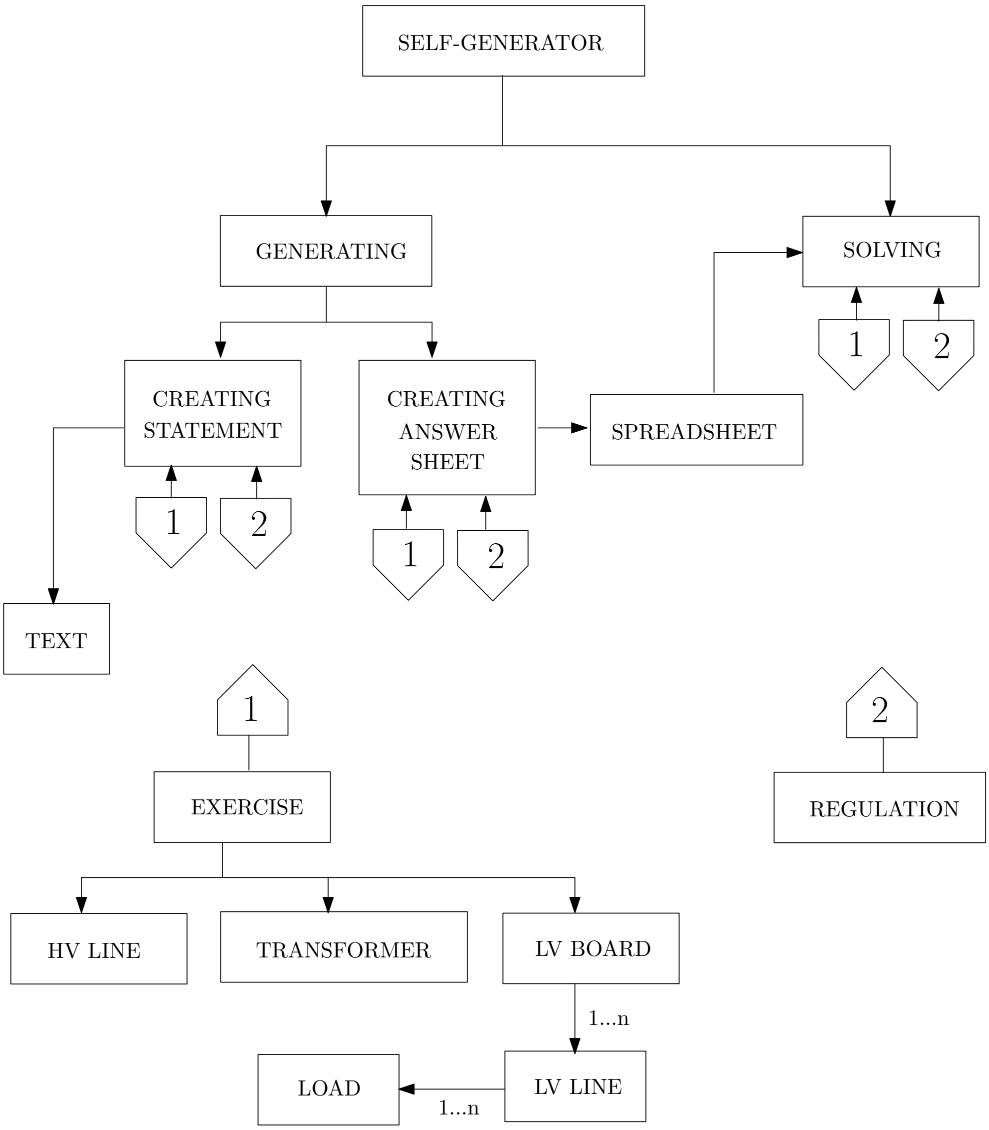
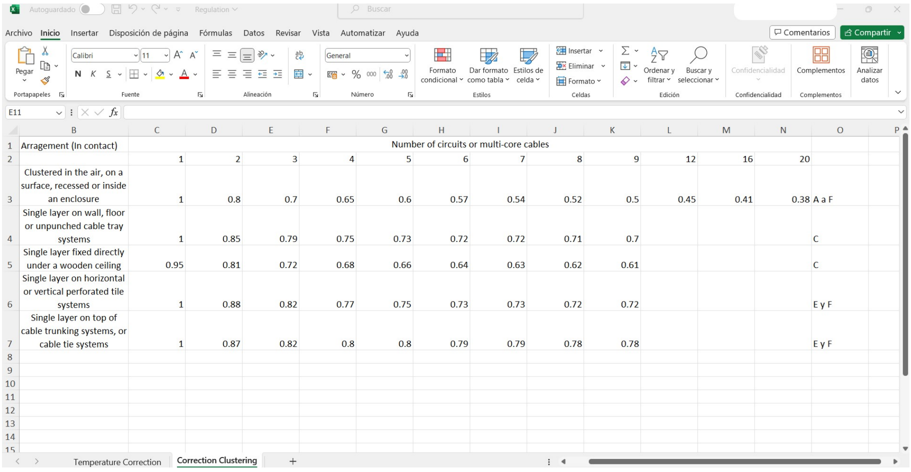


Figure 7. Interoperability scheme of the most relevant objects of the self-generating program.

This type of exercise, where a low-voltage installation is developed, are regulated by the Low-Voltage Technical Regulation, among other standards. Both for the generation of exercises and for their resolution, it is necessary to consider this and other standards. For this reason, all the relevant parameters of the regulations were codified in a spreadsheet to be used by the self-generator program both for generating and solving exercises, as in Figure 8. In the case of changes to the values indicated in the regulation, it would only be necessary to update this spreadsheet file, and the self-generator program would consider the new regulations.



Arragement (In contact)	Number of circuits or multi-core cables												
	1	2	3	4	5	6	7	8	9	12	16	20	
Clustered in the air, on a surface, recessed or inside an enclosure	1	0.8	0.7	0.65	0.6	0.57	0.54	0.52	0.5	0.45	0.41	0.38	A a F
Single layer on wall, floor or unpunched cable tray systems	1	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.7				C
Single layer fixed directly under a wooden ceiling	0.95	0.81	0.72	0.68	0.66	0.64	0.63	0.62	0.61				C
Single layer on horizontal or vertical perforated tile systems	1	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72				E y F
Single layer on top of cable trunking systems, or cable tie systems	1	0.87	0.82	0.8	0.8	0.79	0.79	0.78	0.78				E y F

Figure 8. Spreadsheet with the regulation parameters.

7. Results

For the assessment of the results obtained, we present our evidence in relation to students' achievement of competence (grades), assessments by the students, assessments by the professors in charge of implementing the innovative methodology, and feedback received by instructors' colleagues on the innovative methodology that was implemented.

7.1. Analysis of Student Attainment

Regarding student attainment, the most appropriate data to establish a valid comparison between an old methodology and a new one are the results of applied skills assessment systems used every year. This was the combination of a multiple-choice test and an open response test up to the introduction of the methodological change, which was compared with the grades obtained after the introduction of the methodological change. The authors have found these grades to be the most reliable in representing the attainment degree of the student outcomes.

Before proceeding to show the comparison of results, it should be borne in mind that the methodology was applied twice, in the academic years 2022/2023 and 2023/2024. Nevertheless, a history of grades for the last few years was also available. The analysis was carried out on the grades of the part of the subject that best reflected the scope of competencies associated with the methodology implemented until 2021 and project grades from 2022 onwards. The results of the above comparison are summarized in Table 4 and in Figures 9 and 10. The grades were set in a 0–10, scale where less than 3 was a weak no-pass, under 5 is a no-pass, under 7 is just passing, under 9 is a high pass, and 9–10 is excellent. Figure 9 shows the distribution of grades, with a clear decrease in passing and below passing grades and a large general increase in the highest attainment levels, which improved from 37.9% to 93.1%, as well as a strong increase in the total of passing grades, which improved from 57.2% to 99.3%. This could be taken as a clear indication that the change from a more traditional learning methodology to active methodologies, such as PBL supported with FT, helps those students who find the subject especially difficult or less interesting to achieve an acceptable outcome level, thus contributing to an increase in the degree's effective rate. Furthermore, Figure 10 also shows a clear increase in the average grade after the introduction of the new methodology, and the distribution of grades is more concentrated in the upper part of the full range, confirming the ability of the new methodology to better attract less engaged students.

Table 4. Evolution of grades for applied skills.

Year	2019 [1]	2020 [1]	2021 [1]	2022 [2]	2023 [2]
Enrolled	287	300	270	261	241
Weak no-pass	21.3%	10.3%	17.0%	0.0%	0.0%
No-pass	30.0%	14.6%	33.6%	0.0%	1.3%
Pass	15.0%	14.6%	28.2%	5.0%	7.5%
High pass	11.3%	27.6%	12.4%	60.5%	46.9%
Excellent	22.5%	33.0%	7.1%	34.5%	44.3%

[1] Before methodology change. [2] After methodology change.

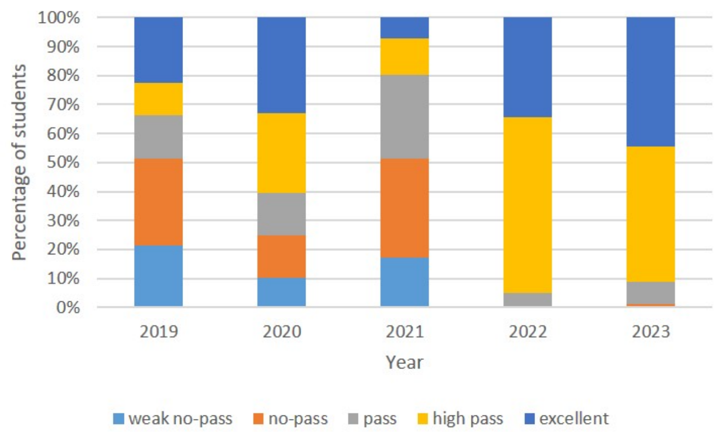


Figure 9. Evolution of grade distribution by grade group in the applied skills evaluation before (up to 2021) and after (from 2022) the actuation.

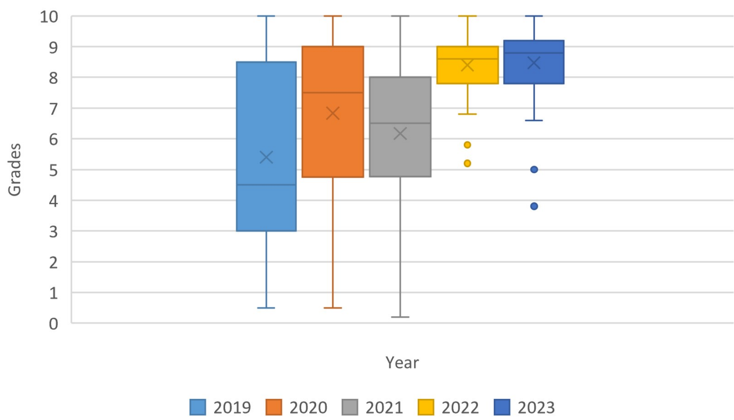


Figure 10. Evolution of the applied skills grades distribution before (up to 2021) and after (from 2022) the actuation.

7.2. Student Perception of the Methodology Change

The previous section has shown that the change in the methodology lead to an improvement in the evolution of the students outcomes. However, it is also important to know the opinion of the students in order to conduct a broader analysis and to be aware of whether they perceive this change in methodology in a positive way. It is also important to know how they perceive their learning process and the development of their own self-learning skills. For this purpose, a very concise form was distributed with the help of

Google Forms among the students of one class of the academic year 2022/2023 that had been subjects of the methodology change. The survey included only four questions: how deeply had the new methodology affected the students' attainment of the subject's specific and transverse student outcomes and how they felt about the FT sessions developed. This was carried out with the aim of obtaining the maximum number of participants in the survey. The length of a survey is inversely related to the likelihood that students will complete it; the longer the survey, the lower the willingness to participate. Since students responded to the survey after they had completed the course and received their final grades, this avoided possible bias or apprehension if the comments were not favorable. Moreover, considering students are usually busy with other activities, our concise survey aimed to maximize response rates.

The results can be seen in Figure 11, which shows that students perceived a slightly positive impact regarding FT, probably due to the already known drawbacks of this type of methodology, such as the perception of a higher work load or, sometimes, of more superficial learning or even feelings of insecurity [26]. Nevertheless, overall, students attested to the positive impact of PBL on their attainment of the specific and transverse student outcomes.

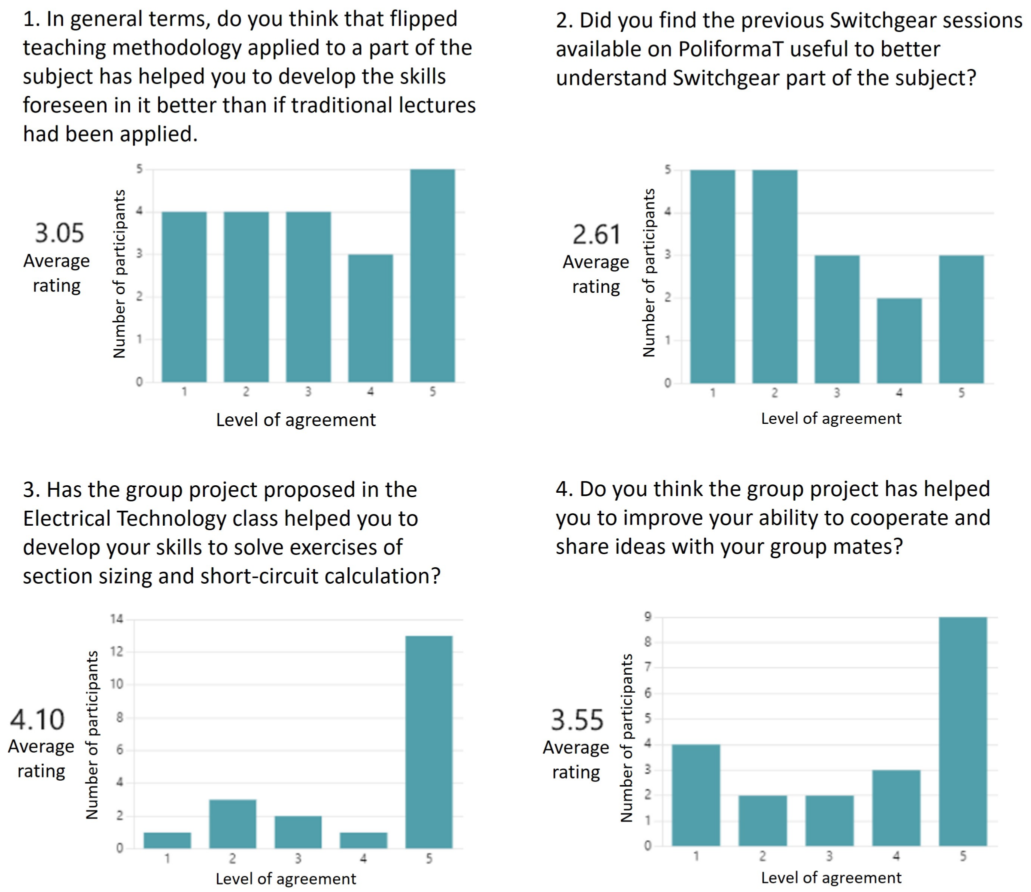


Figure 11. Student perception of the methodology change, 2022.

Additionally, to gain a deeper understanding of the students' perception of the applied methodology, several interviews were conducted with the students by the teachers of the subject. These were usually carried out with groups of 3 students at the end of the course, and with an estimated 15 students interviewed per course year.

The interviews were structured with two distinct parts. Firstly, the aim was to know what the students thought about the approach, which involved asking them open questions, e.g., what points they felt could be improved. This lead to an open dialogue in which the students told the teachers key points such as what their experience had been like, what they thought about the methodology, whether it had helped them, etc. Students talked to the teachers without any kind of pressure as they already knew their grades and the interviews took place after the course was over. The conclusions drawn from this part of the interview were in line with the results shown in the student survey. Subsequently, the interviews were more focused on the technical aspects of the course, and students were encouraged to talk about the concepts they worked on. It could be observed that, despite the time elapsed, they continued to have a clear idea of the concepts they had worked on using PBL supported with FT and the self-generating exercise program, and some students had even extrapolated what they had learned to situations in their daily lives or were successfully applying what they had learned in their jobs.

7.3. Instructor Perception of the Methodology Change

Along with the students' perception, it was also considered necessary to understand the perception and thoughts of the subject professors in order to make an overall assessment of the change in methodology. Several follow-up meetings were held with the staff who taught the subject. The most significant conclusions were that the students had shown a high degree of involvement in the development of their projects. It was observed that the change in the methodology favored the acquisition of competences by the students. However, it was found that students were not as involved with the FT sessions as they were with their projects. This second aspect was discussed with students, from which we concluded that these activities were only carried out by students who attended class regularly; in addition, they pointed out that, due to their high teaching load, it is challenging for them to combine all activities.

Moreover, instructors' perceptions of the influence of the introduction of PBL and FT, including both the strengths and weaknesses of the change in methodology, were collected and analyzed through a Google form. The results of the survey are outlined in Figure 12 and show a very uniform and positive response. The new methodology has been found to favor the acquisition of skills by the students, as well as the students' responsibility in their own learning, their ability to solve problems, and also their motivation.

This change in motivation becomes apparent when examining the results over the years. It was noted that, with the traditional methodology, student performance gradually declined. Students' understanding and assimilation of concepts deteriorated and was particularly exacerbated by the impact of the COVID-19 pandemic, during which students may have adapted to alternative modes of learning. This trend was also reflected in the progression of grades, as shown in Table 4, where it is evident that in 2021, 50% of enrolled students did not pass the course. With the change of the methodology used to a more active approach, students became much more involved in their learning process.

Despite the fact that the results only cover the last two years and there are limited data available, the data clearly indicate the advantages of the change in the methodology for this part of the subject. Nevertheless, there exist some limitations to the present study. Certainly, a greater number of future studies of this nature would help to reaffirm the importance of incorporating FT and PBL in accomplishing positive outcomes. The success of the project-based and flipped learning environment presented here hinges on the students' compliance to the learning environment. In particular, students had to watch the video lectures and complete the online quizzes before coming to class with a basic understanding of the theory. Perhaps a more timely intervention would be to allow 30 min to those students who missed out on these activities to watch the video lectures and complete the quizzes before joining the others in the project.

Finally, there is, at present, no mechanism to measure deep learning among students who are able to critically learn new ideas and facts. However, it can be said that there was a positive change in trend since according to what was observed in the aforementioned interviews, the students have assimilated and better remembered the concepts worked on in the course. They were able to relate them to their daily life and jobs, which could be an indicator that they had a deeper learning experience. Deep learners can communicate between many ideas and are able to conduct existing knowledge migration to new situations, make decisions, and solve problems.

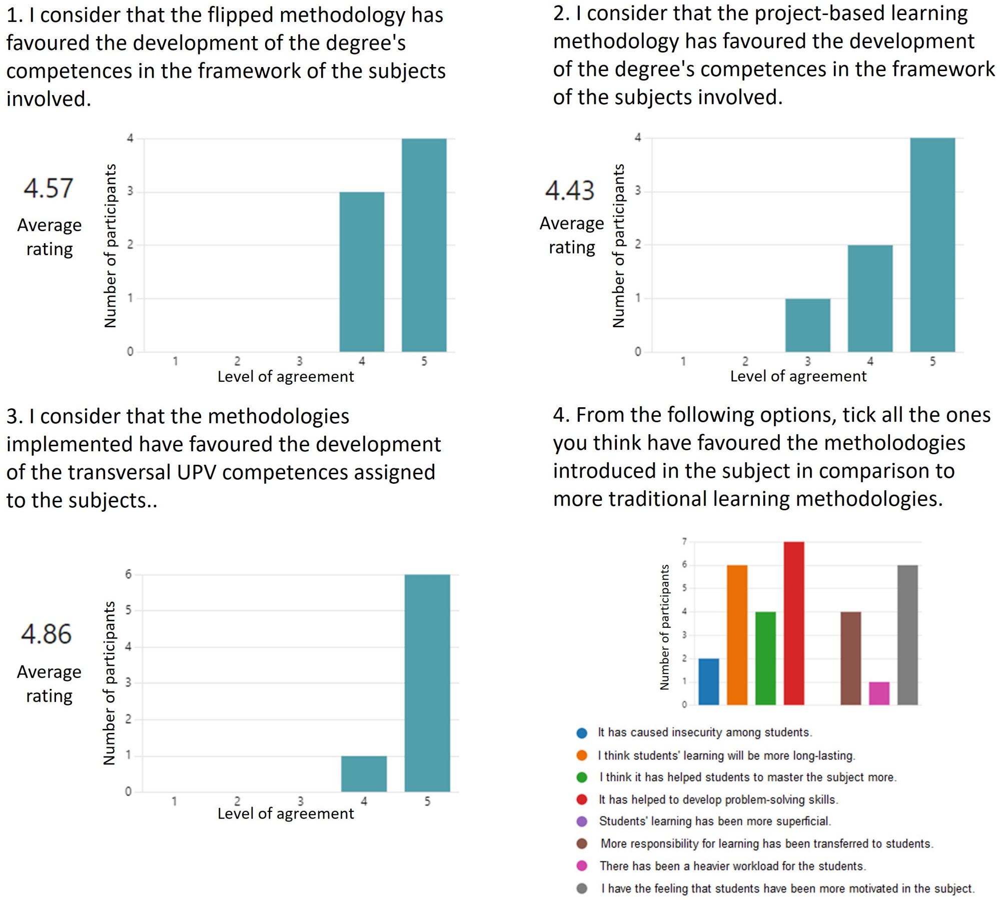


Figure 12. Instructor perception of the methodology change's side effects.

This article focused solely on examining grade variations over a five-year span. During the initial three years, conventional teaching methods were employed, followed by two subsequent years featuring a partially flipped approach and the introduction of a project-based component.

To evaluate the validity of the shift in course methodology, it is important to consider several confounding factors. These include factors such as class attendance [27], which has been observed to remain fairly consistent compared to previous years; class size [28], which has not notably changed; course difficulty [29], which has remained stable as the course has continued to cover the same concepts and maintained similar exam difficulty levels; and the distinction between effective and required courses [29], as in this case it is a required course for the degree. Although these factors could potentially influence outcomes, their stability suggests that changes in teaching methodology may indeed have had an impact.

Therefore, it is essential to view the findings of this study as indicative of a trend rather than definitive conclusions. Given the multitude of confounding factors, particularly when considering students' evaluations of the courses, drawing generalizations becomes challenging. However, it is noteworthy that some confounding factors, such as class attendance, class size, course difficulty, and the distinction between effective and required courses, have remained relatively stable compared to previous years. Despite these considerations, the general trend observed over the five years of this study suggests that students of electrical technology demonstrate improved learning outcomes when exposed to more active learning approaches, such as PBL supported by FT.

8. Conclusions

This work reflects the results obtained from the introduction of PBL supported by FT in electrical engineering education. This change in methodology was complemented by the development of an exercise generator program, which was adjusted according to the expected learning curve with no distinctions from manually developed exercises, and also with a self-assessment function so that students could practice and learn by correcting their own mistakes.

Based on the objectives set and the results obtained, it can be concluded that the experience improved the students' competence in the design of low-voltage installations.

The implementation of project-based learning was crucial for this improvement and managed to involve the students and make them more responsible for their own learning, as can be seen from the academic results obtained and from the student questionnaire. It was noted that the students assimilated the concepts more deeply since the tests were carried out once the course was completed. It was observed that the performance of students facing new "problems" was better on tests of the same difficulty as before the change of methodology. We could, therefore, conclude that the students had a better capacity for analysis and were capable of applying the concepts studied.

On the other hand, it could be observed that the FT sessions did not have the expected impact on students. After several interviews with different students, they alluded to the workload, and the fact that the sessions were not evaluated means that they decided not to be involved in them.

This serves as a point of reflection for the teaching staff, who will look for ways to make the students see the advantages of completing these sessions in their learning process. In addition, the possibility of redesigning the sessions to make them more "attractive" for the students will also be assessed.

The instructors' experience in the change of methodology confirms the main conclusion drawn in the literature: the level of attained student outcomes was improved, along with other positive aspects, such as self-learning and the ability to solve problems. However, the instructors must be aware of the possible drawbacks to this change in methodology, such as the perception of an increased workload for both students and teachers.

This current study could be the basis of ongoing work to collect more data and analyze the implementation of a more active approach in electrical engineering courses. In the future, we hope to develop and implement an assessment tool that can accurately evaluate engineering reasoning and critical thinking based on deep learning.

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