Introducing Project Based Learning for Teaching and Learning Electrical Drives: A case of UPV

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***Abstract*— This contribution describes the change in learning methodology introduced in the subject Dynamic Analysis and Control of Electrical Drives within the Industrial Engineering (Electricity branch) Master Degree at Escuela Técnica Superior de Ingeniería Industrial, Universitat Politècnica de Valencia. The main purpose of the methodology change was to improve the student outcomes attainment by applying Project Based Learning. This methodology change was meant to improve also the student's ability to solve problems and their responsibility on their own learning through a project aimed at the development of an electric drive. Evidence has been collected in three main aspects to attest the achievements: first, the student outcomes attainment level is improved (along with other positive aspects), second, the student perception of their attainment is very positive, and, third, the instructor opinion on the methodology change is extremely positive.**

Keywords*— *project based learning, electrical drives, student outcomes

I. INTRODUCTION

Electrical machines are basic elements of almost all industrial processes nowadays in their role of driving force of all kind industrial drives. Thus, it is of the outmost importance that modern engineers be trained on the basic aspects of electrical drives. Some of the most relevant aspects in their learning include understanding the machine's working principles, recognize basic elements of their design and how they influence the machine performance or how to operate the electrical machines more efficiently [1–3]. All these abilities ask for a combination of theoretical and practical knowledge, beyond what can be generally achieved with traditional laboratories based on the commercially available machine test benches and controllers that populate many subject related labs.

Problem and/or Project Based Learning (PBL) has been reported as quite effective to train engineering students at tacking problems like the ones they will face in their industrial practice [4–6]. One of the kay aspects defining PBL is learning by action, integrating knowledge with action combining activities integrated in the curriculum and student input into a single framework in an applied setting, in which the instructor plays a facilitator role [7], [8]. The PBL methodology is thus described as an active learning pedagogy facilitated by the instructors that has the potential to transform the student body acting as a catalytic agent. PBL lies quite in opposition to traditional lectures, as students are set to face specific problems and, to solve them, they must use an objective plan, giving them the possibility to create a fresh cognitive force that works as a stimulus for learning while it gathers momentum and drives the knowledge innovation [9]. PBL is being increasingly introduced in the curriculum in many countries and institutions as a way to face the traditional approach's failure provide the student abilities and attitudes required in the frame of a vastly globalized economy [10], [11].

PBL has been reported (widely, but also in the field of electrical-electronic engineering), to have many advantages, as well as some risks that must be taken into account when introducing such methodology change. Reference [12] remarks a high degree of autonomous learning, a development of deep thinking abilities or of a deeper responsibility on the students own learning based on an study on three UK universities. However, a negative impact on the student confidence, some reluctance on part of the students or a negative perception on the student work-load can also be expected as a result of the introduction of the methodology, as reported in that study. Some references can be cited also reporting more concrete experiences of this kind of methodology change: [13] reports an improvement both in student outcomes attainment and grades, [14] remarks the positive boost on student outcomes attainment and in the employer's perception of the students involved, beyond the improvement on subject proficiency or in critical thinking abilities, or [15] the improvement of student motivation towards the subject as well as in the subject grades and on critical thinking abilities. It is also convenient to consider the student viewpoint, as in [16], which analyzes the introduction of this kind of active methodologies from with this perspective and remarks that, in spite of the expected drawbacks like the work-load increase, the risk of a more superficial learning or the difficulties associated to the evaluation, it results in a high student satisfaction with the change or its ability to improve the students abilities and attitude towards learning. References [17–21] reach similar conclusions to the ones just described.

This contribution is organized as follows: Section II deals with the context of the case study, considering mainly the learning activities organization, the students and the instructors, Section III introduces the main and the secondary objectives of the learning methodology change, Section IV delineates the main aspects of its implementation in terms of schedule, tasks, partial objectives and required equipment, Section V analyzes the results achieved through the evidence collected in terms of student grades and of student and

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instructors opinion and, finally, Section VI describes the conclusions of this case study.

II. Context

This contribution describes the change in methodology introduced in the subject Dynamic Analysis and Control of Electrical Drives (DACED) within the Industrial Engineering (Electricity branch) Master Degree (IEM) at Escuela Técnica Superior de Ingeniería Industrial, Universitat Politècnica de Valencia (UPV). The subject is followed by about 10 new students each year during semester B (spring) within the second year of the two-year program. The students are organized in a single theory and practice classroom and laboratory group. The original subject design comprises 24 theory/practice sessions with a total duration of 36 hours in 1,5 hour sessions and 3 laboratory sessions of 3 hours for a total of 45 hours of on-site activities corresponding to 4,5 ECTS (European Credit Transfer System). Although the IEM has a large yearly student income of roughly 300 students/year, the DACED subject has a relatively low enrollment due to the following main facts: first, the electricity branch is one of eleven possible choices among others like mechanical, energy production or electronics, second, the IEM has a large group of outgoing students on the second year but the similar amount of incoming students tend to choose subjects delivered in English, and third, the IEM has about one third of incoming students from specialized engineering degrees who follow an broader curriculum that precludes specialization subjects. This relatively small yearly enrollment makes the subject quite suitable for a full implementation of the PBL methodology. With regard to the instructors, although actually, being a small group, only 3 teachers were involved, the fact is that these teachers are part of a larger Education Innovation and Quality Team within UPV integrated by 7 full-time instructors in different academic categories. This team has been concurrently working in the introduction of PBL methodology in the degree subject Electrical Machines and received support from the rest of the team members.

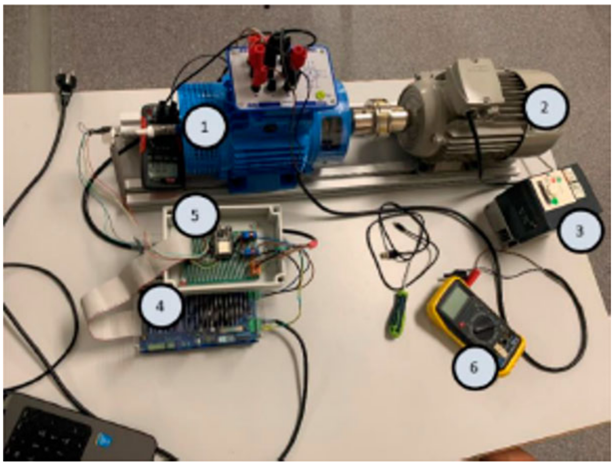


Fig. 1 Prototype test bench. 1. Main machine (Slip-ring induction motor, 0,6kW, 230V, 50 Hz, 1430 rpm) 2. Auxiliary machine (indcution motor, 1,1kW, 1440 rpm). 3. Auxiliary inverter (VF control). 4. Motor control evaluation board (2 kW 3-phase STEVAL-IHM028V2 inverter). 5. MC development board with ESP-32, Hall-effect current sensors and inverter control connections) and 6. Standard electric lab instrumentation.

III. Purpose

The main purpose of the methodology change was to improve the student outcomes attainment by applying PBL. This methodology change was meant to improve also the student's ability to solve problems and their responsibility on their own learning through a project aimed at the development of an electric drive. During the project development, the students were meant to apply typical engineering activities.

Besides, the methodology change was accompanied by an adaptation of the subject curriculum from a quite formal and standard one mainly based on traditional lectures aimed at the progressive development and analysis by the instructor of the Simulink models of different controlled electric drives to a more open model aimed at developing a working drive in three main stages: analyzing the electrical machine transient performance and the effect of the feeding conditions, developing adequate electronic converter operation procedures able to provide the required feeding conditions and, finally, developing, selecting, implementing and testing of at least one control strategy for the selected drive.

IV. Approach

The main purpose has been divided into three specific goals (or actuation steps) that can be summarized in the coming items. Although these activities are here described as independent items, one has to understand that there was a strong interrelation in their initial definition and progressive development due to the strong influence any of them has on each of the rest.

A. Definition and construction of a set of prototype development benches

This step is mandatory as the typical schedule of a one semester subject does not allow for a completely open project definition. Thus, some key components must be made available to the student's groups as boundary conditions to facilitate the instructor role during the student's project development while keeping a high degree of variability between student's groups to accommodate different electrical machine typologies, electronic converter operation procedures and control system strategies.

To this end, the main component of the prototype development benches had to be a microcontroller (MC) easily programmable and powerful enough to compute the control tasks, including communications elements to implement de drive user interface, and with enough analog and digital inputs/outputs. The MC selected was the ESP32, for which there exists a large and active developer's community, can be programmed in a fairly standard environment (Arduino), and is powerful enough in terms of speed, memory and I/O. This MC was then complemented by an array of typical drive sensors (motor currents, different encoder models), a 2 kW 3-phase motor control evaluation board (STEVAL-IHM028V2, basically a three phase inverter with inverter legs control signals available) and a set of AC machines (several squirrel cage induction motors and a couple of wound rotor induction motor which were meant to be excited with DC in the rotor to reproduce either Brushless DC or AC machines depending on the rotor winding configuration), Fig. 1. The development benches kept a deep flexibility thanks to the programmed software and to the different options with regard to motor types, converter operation possibilities and different sensors included.

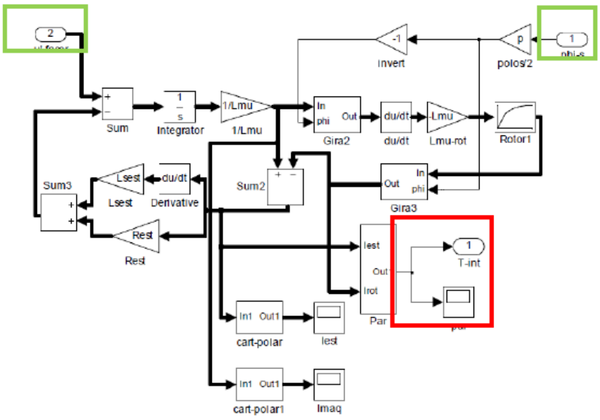


Fig. 2 Simulink model produce by students for the transient analysis of the induction machine.

B. *Development of a set of standard projects*

The aim at developing this projects prior to the methodology change introduction was twofold: first, to give the instructor experience and the peace of mind that the actual projects could be fulfilled by the enrolled students, and, second, to provide the instructor (and then the students) some kind of guide as to the rough steps to be taken in the development of the projects. Up to know we have three projects available to cover the three main drive technologies nowadays: induction, Brushless DC (BLDC) and Brushless AC (BLAC). These three projects have been developed (mentored by the expected subject teachers) as Degree or Master Thesis for several students and covering all or some of the aspects of the projects, depending on their complexity. Each of these standard projects includes three main parts or steps to guide the development of each kind of drive project: electrical machine dynamic analysis, inverter operation including different PWM modulation techniques, and drive control, including torque/flux and speed control loop.

1) *Electrical machine dynamic analysis*

The first step in the project development is always the analysis of the transient performance of the machine selected

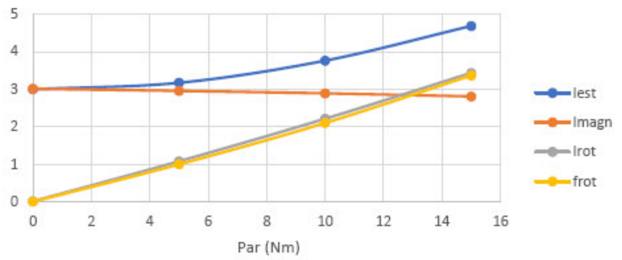


Fig. 3 Effect on the operating parameters of a squirren cage induction machine of a load torque step at rated voltage and frequency.

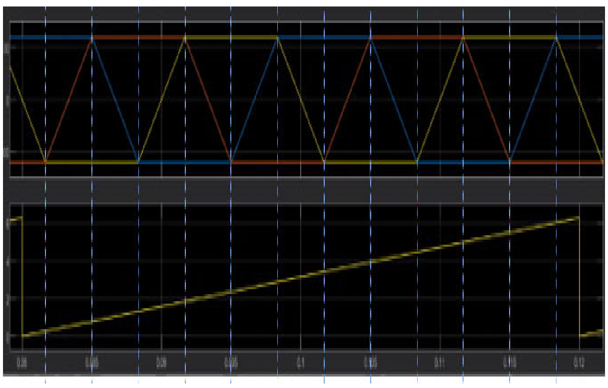


Fig. 4 Analysis with Simscape of the induced emf in a 4-pole BLDC machine.

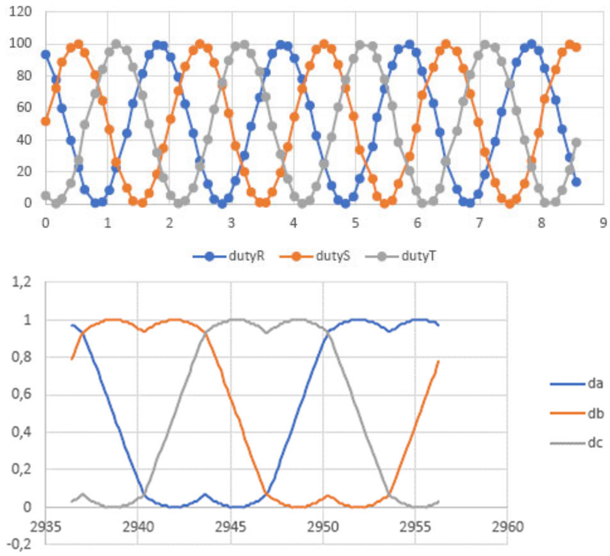


Fig. 5 Results of the duty cicle calculation for three-phase PWM and SVPWM. Calculated on-line at constant modulation index and frquency with the ESP32.

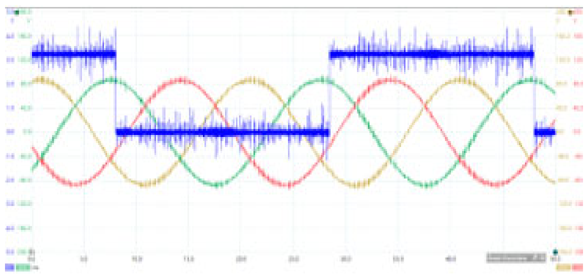


Fig. 6 Osciloscope measurement of the phase emfs of a BLAC machine vs the postion signal generated by the ESP32 (50% duty cicle on position).

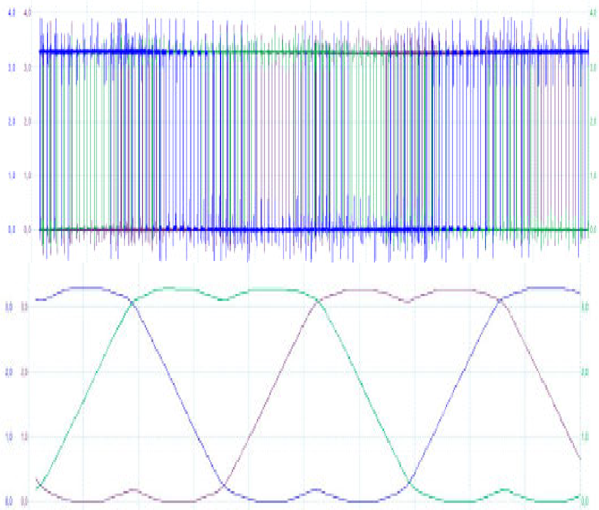


Fig. 7 Actual inverter control signals at constant modulation factor and frequency generated by de ESP32. Above: direct measurement. Below: signals filtered at 1kHz low pass filter.

as drive kernel with the aim set at setting the foundations of the machine control.

For example, on the induction machine, the group has to implement the machine model in Simulink (Fig. 2) and analyze the effect, under constant voltage and frequency, of changes in the load torque over the rotor current, rotor frequency, stator current and magnetizing current. To start at the lower stages of development with the ESP programming,

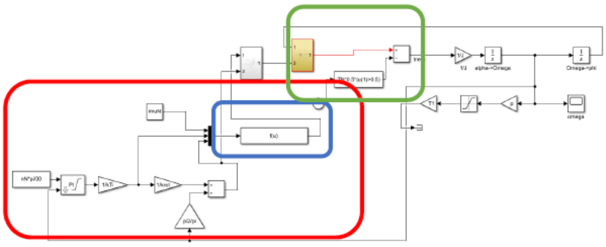


Fig. 8. Simulink model of the induction machine vector control.

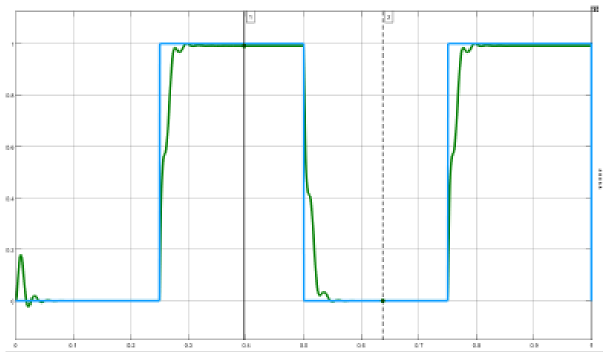


Fig. 9. Simulink calculated torque response of the induction machine vector control.

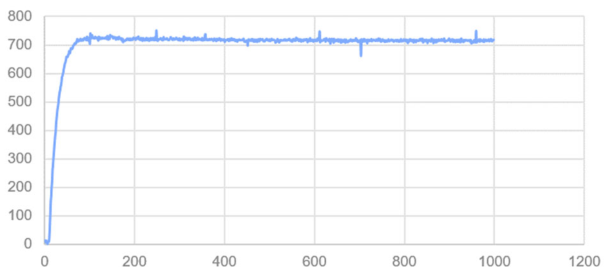


Fig. 10. Tuned current controller on a BLDC machine recorded with the ESP32.

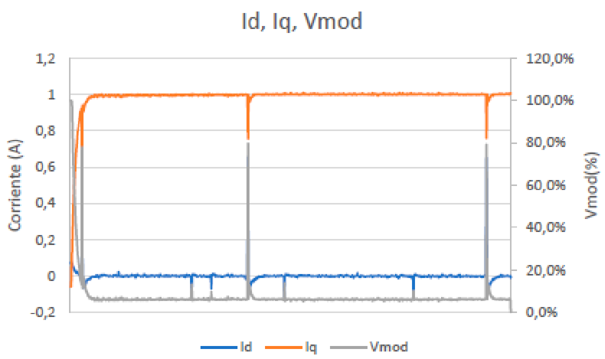


Fig. 11. Decoupled current control in direct and quadrature axis of a BLAC machine recorded by de ESP32.

the group also prepares code to capture stator voltages and currents during a load torque step to compare with the Simulink results.

For the BLDC machine, the group uses the Simscape Brushless DC machine model to simulate different tests in order to obtain the main machine parameters (emf and torque constant, stator resistance and inductance) which are then compared with the actual tests performed on the test bench (Fig. 4).

2) Inverter operation

Once the key aspects of the transient operation of the machine have been stablished, it is time to start working with the PWM routines of the ESP32 to prepare the inverter modulation as a way to control machine voltage and current.

In the induction and the BLAC machine this means preparing first triangular three-phase PWM modulation as a preliminary step to develop the industry-standard Space Vector PWM (SVPWM), Fig 5.

For the BLDC, the inverter operation at this stage, for open loop current or voltage control, is very straightforward, and the effort must be driven to the inverter branch operation depending on the rotor position and, thus, to the position sensor reading. The rotor position sensor is mandatory also for the BLAC machine project as well, Fig. 6.

Under any project, and before the group is allowed to apply the actual inverter control signals with the inverter DC bus energyzed and a connected electrical machine, the group must be able to demonstrate that their modulation code on the ESP32 can produce a suitable set of modulation signals with direct oscilloscope measurement, Fig. 7.

3) Implementation of speed/torque control

The groups must face at this stage a two-fold objective: to develop a suitable control structure in Simulink/Simscape and to implement it on the ESP32. During the simulation stage the groups can more easily and more safely introduce changes in the control structure, adjust controller parameters, anticipate hazardous conditions, etc…It is thus mandatory to provide an acceptable simulated solution before being allowed to proceed to the ESP32 implementation, Fig. 8 and 9. Beyond that, and to stress on the drive security, as the first step in the ESP32 implementation, each group must demonstrate an operating overcurrent inverter shut-down protection, so that the implementation of possibly erroneous ESP32 control code will not result in damage to the inverter or to the electric machine. The security aspects are strongly reinforced during the development, for example on the tuning sequence of PI

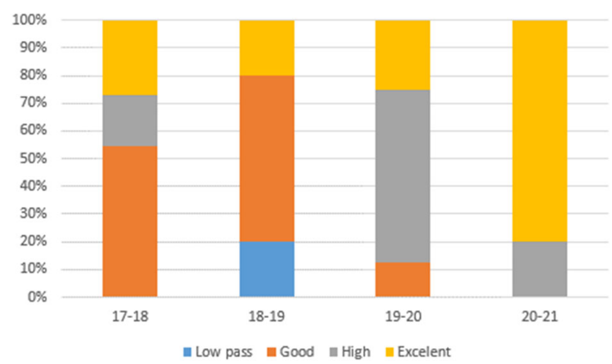


Fig. 12. Evolution of the final grades distribution by grade group before (up to 2019) and after (from 2020) the methodology change.

controllers, always starting at small gains and large integral times followed by a step-by-step safe parameter change, Fig. 10 and 11. The groups can explore different control techniques like VF and vector control of induction machines, vector control and DTC of BLAC machines and current-position control of BLDC machines.

C. Implementation of the ABP methodology.

This step has been introduced gradually as the prototype development benches and the standard learning projects were available. Unfortunately, the Covid-19 pandemic influenced deeply the implementation which took place in the spring semesters of the 19-20 and 20-21 academic years. This meant that some degree of confinement was present during both semesters (1/2 semester in 19-20 and ¼ semester in 20-21) limiting the effective introduction of the PBL methodology. However, during the 1st year, the part of dynamic analysis could be introduced on the induction motor project, and, during the 2nd year, the parts related to inverter operation and control implementation could be developed by a couple of student groups working on the induction motor and on the brushless DC motor projects.

V. Results

These specific goals were meant to help achieve the main purpose of the methodology change of this case study, and evidence has been collected in three main aspects to attest the achievements: first, an analysis of the evolution of part of the student grades, second, the results of a very concise survey sent to the students focusing on their perception of the effectivity of the methodology change on the student outcome attainment and of some expected side-effects, and, last, the results of a survey sent to instructors involved on the methodology change.

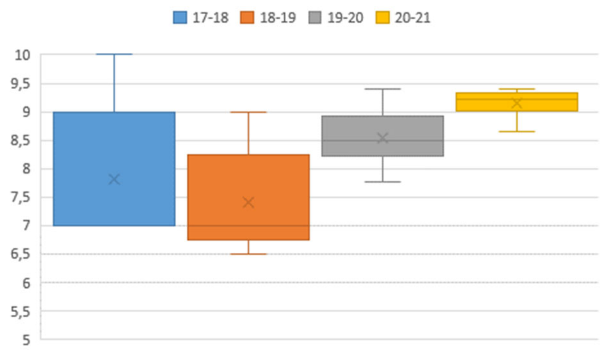


Fig. 13. Evolution of the final grades distribution before (up to 2019) and after (from 2020) the methodology change.

Some level of additional uncertainty must be assigned to the results of this study due to the concurrent Covid-19 pandemic and its possible side effects on the three mains aspects considered: the student outcome and the student and instructor perception of the methodology change. In this respect it is worth mentioning that the methodology change was first introduced just after the onset of the strict confinement stablished in Spain starting on 2020/03/15 and that meant that it was finished under a full on-line scenario as the return of the students to the University was not possible until September 2020. And then, during the second academic year of the methodology change, roughly a 25% of the planned sessions in the spring semester were conducted on-line due local confinements of shorter duration associated to further pandemic waves.

A. Analysis of the student attainment

In relation to the student attainment, the data best suited to establish a valid comparison is the final subject grade: open answer exam and laboratory deliverables up to the introduction of the methodology change vs. the grades obtained for the drive project after it (made up of the group deliverable and a specific evaluation of the oral project presentation during the three sessions accommodated: machine analysis, converter operation and drive control implementation). The authors deem this grades as the most reliable to attest the attainment degree of the student outcomes due to the fact that they are the global result of the student effort.

TABLE I. SUBJECT FINAL GRADES EVOLUTION

Year	2018[a]	2019[a]	2020[b]	2021[b]
Enrolled	11	5	8	10
No-pass	0%	0%	0%	0%
Pass (< 7/10)	0%	20%	0%	0%
Good (7~8/10)	54,5%	60%	12,5%	0%
High (8~9/10)	18,2%	0%	62,5%	20%
Excellent (9~10/10)	27,3%	20%	25%	80%

a. Before methodology change

b. After methodology change

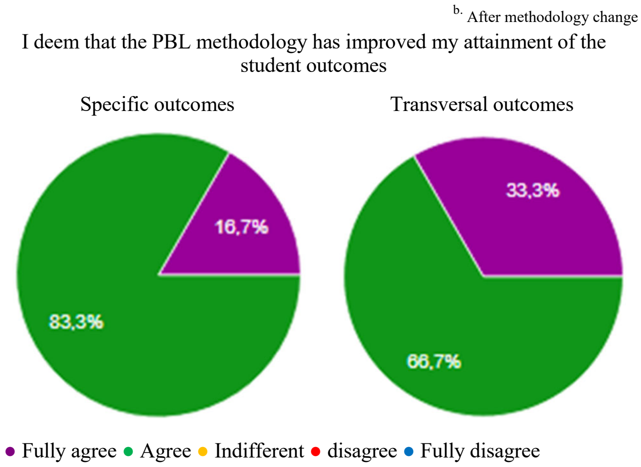
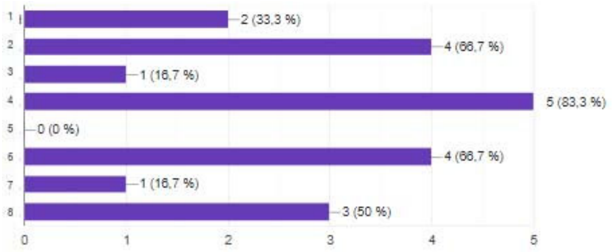


Fig. 14. Student perception of the effect of the methodolgy change in the student outcome attainment.

The results of the stated comparison are summarized in Table I and in figures 12 and 13. Being a last year subject in the specialization branch, the instructors generally enjoy very focused, well-motivated students which results on a 100% pass rate in the subject in recent years. The grades are stated in a 0-10 scale where under 7 is a weak pass, under 8 is a good pass, under 9 is high pass and up to 10 is excellent. A direct comparison of the subject grades comprising the learning outcomes stated achievement before (up to 2019) and after the introduction of the methodology change (from 2020) show the clear positive effect of the methodology change. As a way of example Fig. 12 shows the grades distribution with a clear decrease of good and below grades showing a large general increase in the high attainment levels from 32.8% to 93.8%% or a strong increase in the excellent grades from 23% to 53%.



1 I have felt more insecure

2 I think I have achieved a more lasting learning

3 It has helped my subject profiency

4 It has contributed to develop my problem solving abilities

5 My learning was more superficial

6 I felt more responsible of my own learning

7 It has meant a higher work-load

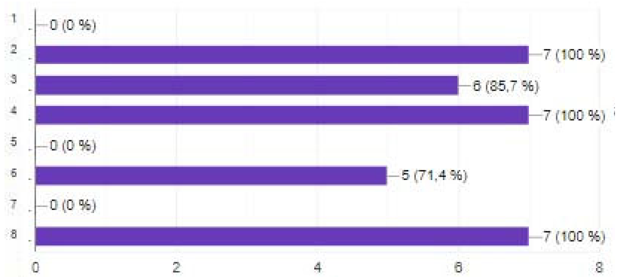
8 I was more motivated to learn in the subject frame

Fig. 15. Student perception of the methodology change side-effects (year 2021).

This, for example, can be taken as a clear indication that the change from a more traditional learning to active methodologies like PBL helps those students who find the subject less interesting to achieve a very good outcome level. Fig. 13 shows also a clear increase in the average grade after the introduction of the new methodology and a more compact distribution of the students grades in the upper part of the full range, which confirms the advantage of the new methodology to motivate students to yield their best.

B. Student perception of the methodology change

With the aim set at getting a high answer rate and, thus, reliable results, we designed a very concise form with the help of Google Forms which was distributed to the students of the last academic year that had been subject to the full methodology change. The survey included only three questions directly related with the intended results of the learning methodology change: how deeply had the new methodology affected the student outcome attainment of the subject's specific and transversal student outcomes and how they felt about the expected possible positive and negative effects of the methodology change.



1 The students have felt more insecure

2 I The students have achieved a more lasting learning

3 It has helped to improve students' subject profiency

4 It has contributed to develop students' problem solving abilities

5 Student learning was more superficial

6 Students felt more responsible of their own learning

7 It has meant a higher work-load for the students

8 Students were more motivated to learn in the subject frame

Fig. 16. Teacher perception of the methodology change side-effects (year 2021).

The results of this survey are summarized in figures 14 and 15, having an overall answer rate of 60% of the subject's enrolled students, conferring the results a high reliability and representability. All the students attest the positive impact of PBL on their attainment of the specific and transversal student outcomes.

Fig. 15 shows the results in terms of the side-effects of the methodology change beyond the impact on the student outcomes attainment. This part of the analysis of the results confirms some of the conclusions of previous studies like the perception of the improvement in the ability to solve problems (83,3%), of the self-responsibility of the learning process (66,7%), or the fact that it helps develop a more lasting learning (also 66,7%), although pointing out already known drawbacks like some degree of insecurity feeling (33%) or the perception of an increased work-load (16,7%).

C. Instructor perception of the methodology change

Finally, we collected and analysed also the teacher's perception on the effect, strengths and drawbacks of the methodology change showing a very uniform and positive response, as can be seen in Fig 16. The survey was sent to the teachers in the teaching unit responsible for the subject coordination, who are well acquainted with the methodology change. All teachers answered the survey and all of them agreed with the positive impact on the student outcome attainment (85,7 % fully agree) both in the specific and on the transversal student outcomes. Beyond that, the teachers show also a very uniform and positive opinion (100%) on the more lasting learning, the improvement on student problem solving abilities and on the student motivation.

VI. CONCLUSIONS

The main conclusion is that our experience in the introduction of PBL in the learning of electrical drives confirms the main conclusions in the literature regarding the introduction of active methodologies in other fields of engineering education: the student outcomes attainment level is improved, along with other positive aspects like boosting the student responsibility in its own learning (learn to learn), or the ability to solve problems. However, the instructors must be aware of the change possible drawbacks like the perception on an increased workload for both students and teachers.

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