Improving Student Outcomes Attainment by Project Based Learning in Electrical Machines

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***Abstract*— This contribution describes the change in methodology introduced in the subject Electrical Machines within the Industrial Technologies Engineering 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 active methodologies, specifically Project Based Learning supported with Flipped-Teaching. This methodology change was expected to improve the integration of knowledge by the students through the development of a project aimed at the analysis of induction machines. Evidence has been collected in three main aspects to attest the achievements: the student outcomes attainment level is improved, along with other positive aspects like boosting the student responsibility in its own learning (learn to learn), the ability to solve problems or also the student motivation.**

Keywords*— *project based learning, electrical machines, 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].

The advantages of the introduction of active methodologies like Flipped Teaching (FT) and PBL are readily available in the literature, as well as some of the risks that must be taken into account when introducing such methodology change. For example, in the field of electrical engineering learning, [12], on an study on three UK universities, remarks a high degree of autonomous learning, a development of deep thinking abilities and of a deeper responsibility on the students own learning. However, this study also describes a negative impact on the student confidence, some reluctance on part of the students or a negative perception on the student work-load change. As 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, and [15] the improvement of student motivation towards the subject as well as in the subject grades and on critical thinking abilities. On the other hand, [16] analyzes the introduction of this kind of active methodologies from the students viewpoint 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. Similar conclusions to the ones just described can be found in [17–21].

II. Context

This contribution describes the change in methodology introduced in the subject Electrical Machines within the Industrial Technologies Engineering Degree (GITI) at Escuela

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Técnica Superior de Ingeniería Industrial (ETSII), Universitat Politècnica de Valencia (UPV). The subject is followed by about 300 new students each year during semester B (spring) within the third year of the four-year program. The students are organized in 5 theory and practice classroom groups and in 15 laboratory groups, but the actuation described is mainly related to the activities developed during the classroom sessions. The subject 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). To alleviate the difficulties in the methodology change and also due to the fact that the rotating electrical machines had been previously perceived as more difficult, the scope of the actuation was limited to the second part of the subject related with rotating electrical machines. A similar actuation for the first part of the subject, related to transformers, has been scheduled for the coming year to provide a more uniform learning experience along the whole subject.

III. PURPOSE

The main purpose of the methodology change was to improve the student outcomes attainment by applying active methodologies, specifically PBL supported with FT. This methodology change was expected to improve the integration of knowledge by the students through the development of a project devoted to the analysis of induction machines. 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 a traditional lectures aimed at the progressive development by the instructor of the equivalent circuit of the induction machine) to a more open model aimed at discussing the main facts behind the equivalent circuit of the induction machine and then to its application to develop the ability to determine the mechanical (torque vs. speed) electrical (current vs. speed) and energy (efficiency vs. speed) characteristics, to understand the importance of constructive parameters on performance figures, to recognize the start-up difficulties and how the design can alleviate them or the operation of induction machines within converter-fed drives.

IV. APPROACH

The main purpose has been divided into several 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. Work-grup creation and management

The creation and management of a work group, formed not only by the subject teachers but reinforced by fellows with previous experience in the introduction of modern learning methodologies as well as junior teaching staff, was taken as one initial, fundamental step for the success of the actuation. This was perceived to be so due to the fact that a high degree of coordination was required to offer a quite uniform learning experience along the 5 classroom groups and also because the complexity and intensity on the planned activities. This work group has been working on a scheduled basis to check the progress and attainments in the remaining specific goals. This goal has turned out to be very effective as the members are now applying the methodology to other subjects and disseminating the positive experience. It has clearly turned out to be important to have, from the beginning, the support of a group as the work to be developed in the remaining goals and the expected difficulties in the methodology change implementation were intense. Thus, the group support has meant a boost in confidence and motivation for all its members. The work-group is enrolled in the UPV's Education Innovation and Quality Teams (EICE) and, as such, the members' activity is recognized in the UPV productivity program and the team is entitled to receive institutional support for the development of their activities in preferred conditions.

TABLE I. UPDATED STUDENT OUTCOMES

N	Student outcome
1	Understand the basic facts and operation modes of the asynchronous electric machines. Understand the influence on the operation modes of external variables like the axle torque or the feeding frequency.
2	Know the main constructive variants of the asynchronous machines and justify their main advantages and drawbacks.
3	Understand the main rules about the creation of the Airgap magnetic field by one or more phases of one or more windings of the asynchronous machine, and also the main relationships between the airgap magnetic field and the properties and the parameters defining windings and winding currents.
4	Understand the basic principles that drive the induction of emf in the asynchronous machines phases by a rotating magnetic field depending on the winding constitution and understanding also the main relationships between the induced emf properties, the airgap magnetic field characteristics and the winding parameters.
5	Recognize the two main reference systems in asynchronous machines and their influence on the calculation of the induced emfs in stator and rotor.
6	Acknowledge the equivalent circuit of the asynchronous machine and the meaning of each one of its parameters.
7	Apply the equivalent circuit of asynchronous machines to obtain the main speed characteristics of the asynchronous machines: mechanic (torque), electric (current) and energetic (efficiency).
8	Apply parameter estimation methods using test or catalog data in order to identify the main parameters of the asynchronous machine equivalent circuit.
9	Understand and apply the basic rules for high efficient speed control of asynchronous machines.

B. Definition of a detailed, adapted set of learning outcomes

The second specific actuation planned and executed was the adaptation of the subject curriculum in terms of specific and detailed learning outcomes adequate to the new learning methodology to be used, Table I. On the one hand, these detailed learning outcomes had to be derived from the degree's learning outcomes explicitly assigned to the subject and within the methodology change actuation frame. On the other hand, the newly defined set of detailed learning outcomes should be adapted to the FT and PBL methodologies to be applied as a way to facilitate the definition of specific activities for the pre-session student work, the in-session work on more advanced topics and application, and the after-session student work to further apply the developed knowledge in their project. The resulting set of detailed and specific learning outcomes was made available to the subject students in the on-line 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 increased responsibility on their own learning sometimes associated to the use of active methodologies.

C. Definition of the subject activities schedule

The development of the subject activities schedule had to be oriented at the attainment of the defined specific learning outcomes and also adapted to the new methodologies, including the development of the sessions preparatory material (FT) and of the session and after session activities expanding this preparatory material and applying it on the successive steps of the PBL student project. The result is a detailed schedule comprising, for each of the 12 programmed sessions, the related specific learning outcomes, and a description of the student activities for the pre-, in-, and post-session periods including, for example (but not limiting to), video watching, work with special simulators, self-assessing questionnaires, introduction and in-session discussion of advanced concepts, implementation of specific stages of the student group project, discussion of the results achieved by the different groups and two special session devoted to the public group tutoring of the project development.

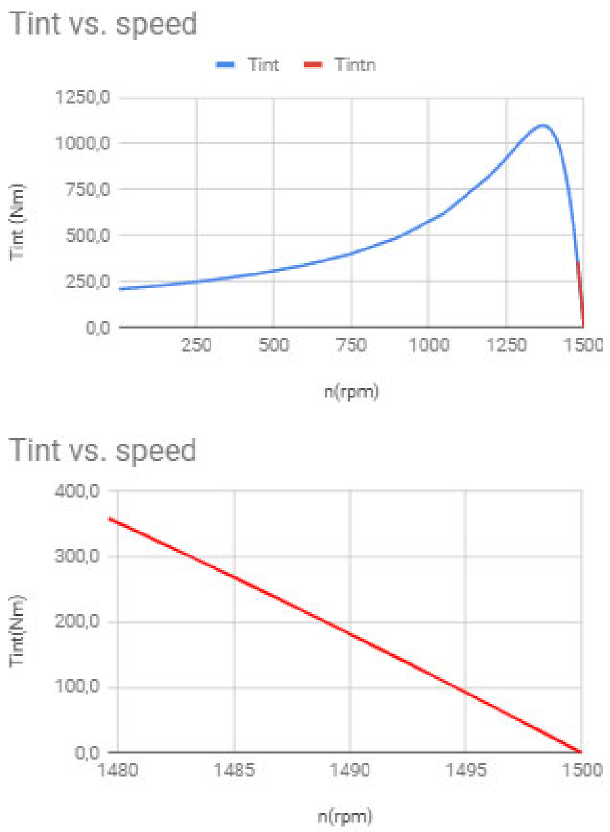


Fig. 1. Example of the Google Sheets calculated torque-speed curve of a 55kW, 4 pole asynchronous machine, and detail of the no-load to rated load interval.

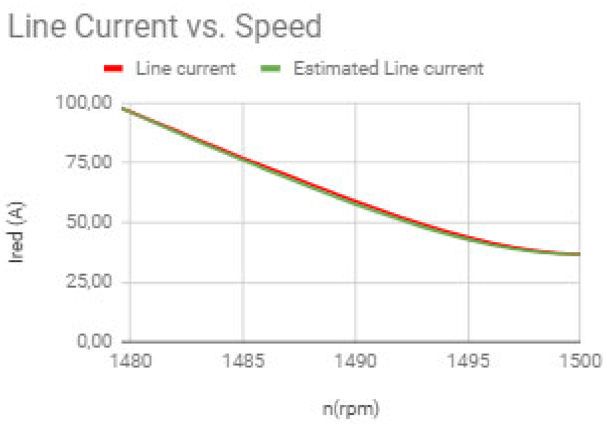


Fig. 2. Example of the Google Sheets comparison between the equivalent circuit calculation of the line-current and the estimation from no load and full load data of a 55kW, 4 pole asynchronous machine. Detail over the no-load to rated speed range

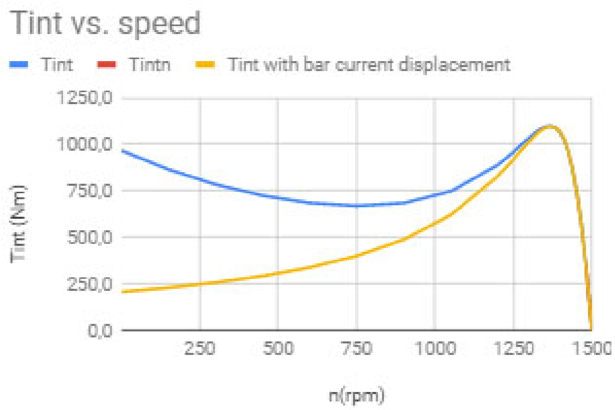


Fig. 3. Example of the Google sheets Comparison between the machine torque calculated with constant rotor parameters and accounting for rotor bar current displacement of a 55kW, 4 pole asynchronous machine.

D. Definition of an electrical machines performance analysis project

The main aim behind the definition of the subject project was to provide the instructors with a tool that should help the students in their development of the specific learning outcomes. This tool had to be adapted to the activities schedule to provide the students with a learning development frame that could be as uniform as possible for the roughly 70 project groups tutored within 5 different classroom groups. Thus, having in mind the learning outcomes and subject schedule frame, the project was defined as an electrical machines performance analysis project comprising several main stages, all of them planned to be solved using a spreadsheet (the students have a campus license for MS Excel, but all examples have been developed with the free Google Sheets):

a) Calculation and discussion of the main performance characteristics using the machine equivalent circuit over the motor range (current consumption, torque and efficiency vs. speed) from equivalent circuit constant parameters data (Fig. 1). Comparison of the most relevant results provided by this analysis with catalog data (rated current, torque, efficiency and power factor, as well as starting current and torque).

b) Evaluation of the accuracy of simplified estimations of torque, current consumption and efficiency between no-load and full-load. The group has to evaluate approximate estimations of torque, current consumption and efficiency on the no-load to rated load range by comparison with the values yielded by the full equivalent circuit (Fig. 2). These estimations only require very limited data like the rated torque, current, and efficiency or the non-load current and machine losses.

c) Analysis of the influence of rotor resistance, leakage reactance and magnetizing inductance, on torque at rated speed, maximum torque and rated power factor. The group must analyze the required change on any of this equivalent circuit parameters to achieve a desired change in the operation parameter most related to it and discuss the effect on the remaining operating parameters.

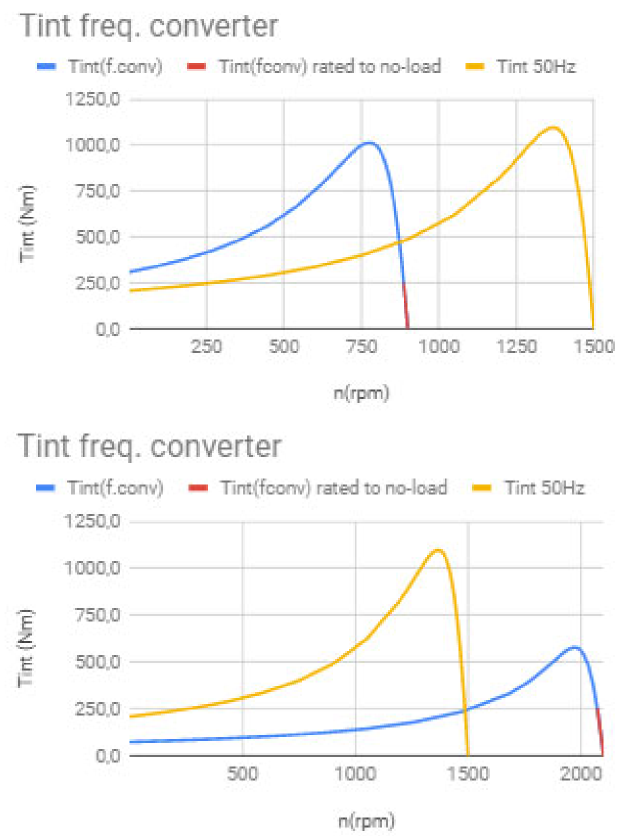


Fig. 4. Example of the Google sheets Comparison between the machine torque at rated frequency, and at 60% (above, constant flux) and 140% (below, flux weakening) of rated frequency of a 55kW, 4 pole asynchronous machine.

d) Determination of the current displacement effect on the start-up current and torque by adjusting the rotor resistance and leakage inductance variation with rotor frequency. The group must adjust the rotor resistance and leakage reactance change parameters at unity slip (rotor frequency equals stator frequency) so as to achieve agreement between the start-up torque and current stated in the manufacturer's data sheet with the values calculated with the bar-displacement equivalent circuit and, then, compare the torque and current consumption curves during start-up between the constant rotor parameter equivalent circuit prediction and that of the bar current displacement equivalent circuit (Fig. 3).

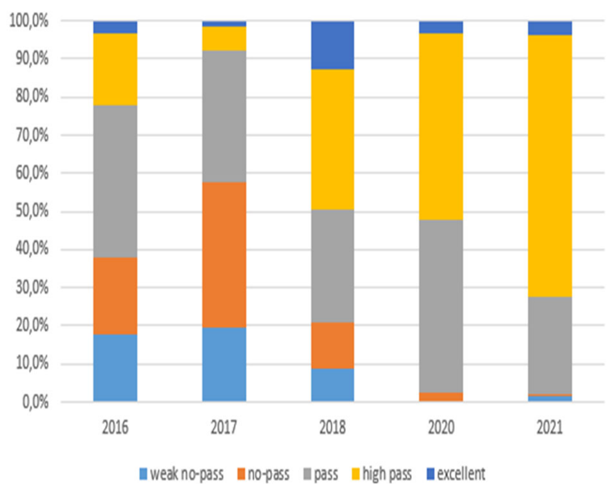


Fig. 5. Evolution of the grade distribution by grade group in the apllied skills evaluation before (up to 2018) and after (from 2020) the actuation.

e) Study of the converter fed operation and introduction to speed and flux control criteria through the analysis of the current, torque and efficiency characteristics at adjusted voltage and frequency under and above rated speed (Fig. 4). The group must calculate the torque, current consumption and efficiency curves at given frequencies bellow and above rated frequency and then analyze the effect of the control criteria (constant flux or flux weakening) at each frequency in comparison with the machine curves at rated frequency.

This project definition was completed with the assembly by the teaching staff of a large set of electric machines data to be used by a large number of groups each year to develop the group project. During the 2 years run since the change of methodology, more than 150 different induction machines data sets have been prepared from catalogue data of different manufacturers to be used by a similar number of student groups. This data sets have also been complemented with a numerical analysis tool (spreadsheet) that provides the subject teachers with almost all results of the electrical machines performance analysis project.

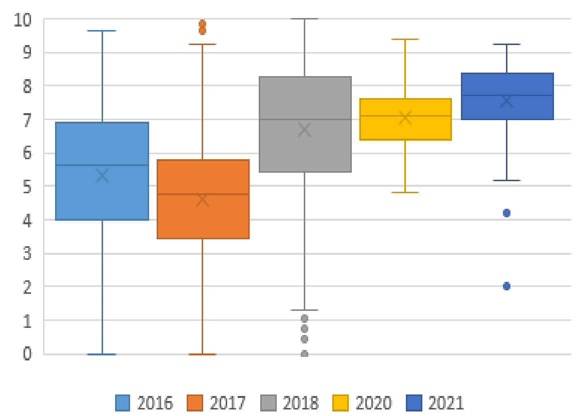


Fig. 6. Evolution of the applied skills grades distribution before (up to 2018) and after (from 2020) the actuation.

E. Defininition of a project evaluation rubric

The development of a project rubric was meant to fulfill two main objectives: first, guiding the project groups in the development of the learning outcomes and in the way they must be present in their deliverables, and then, facilitating the teachers grading by providing a clear, uniform frame known both by students and by evaluators.

V. Results

These specific goals were meant to help achieve the main purpose of the methodology change, 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

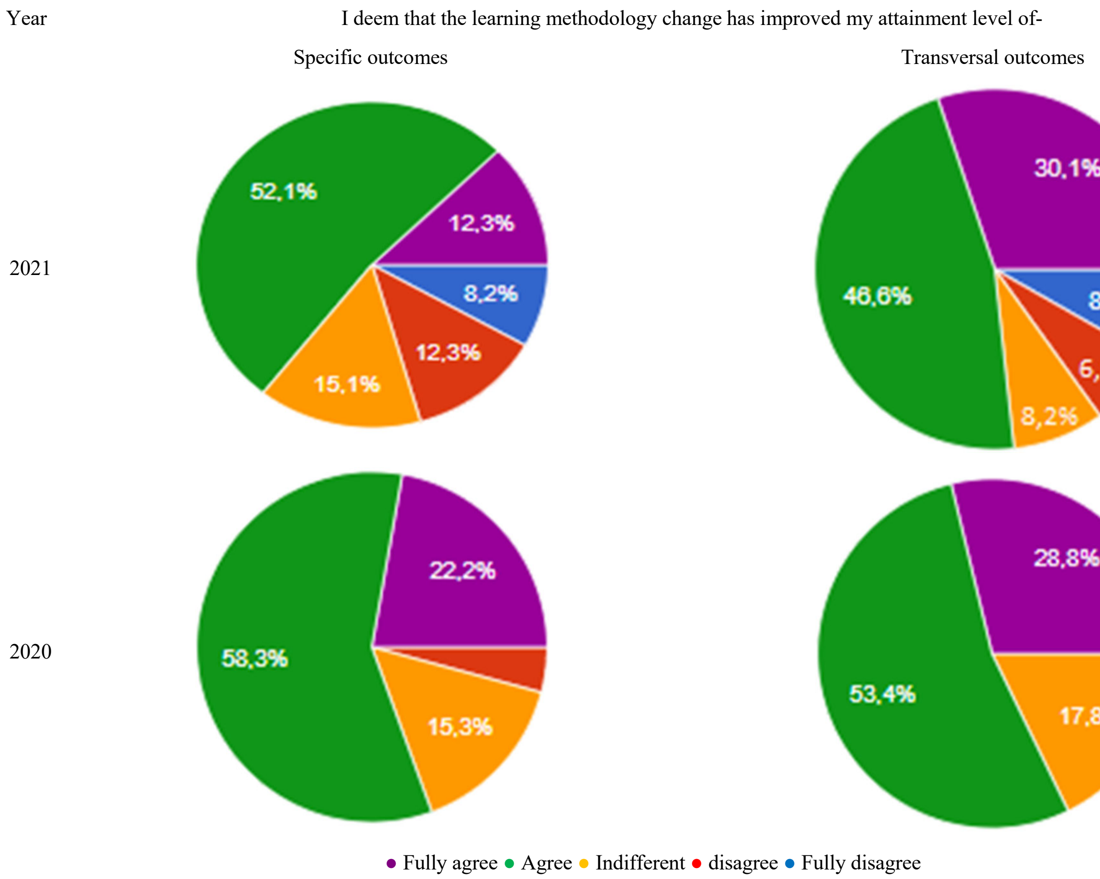


Fig. 7. Evolution of the applied skills grades distribution before (up to 2018) and after (from 2020) the actuation.

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.

TABLE II. APPLIED SKILLS GRADES EVOLUTION

Year	2016[a]	2017[a]	2018[a]	2020[b]	2021[b]
Enrolled	451	349	280	307	328
Weak no-pass	18,0%	19,5%	8,6%	0,0%	1,5%
No-pass	20,2%	38,4%	12,5%	2,6%	0,3%
Pass	39,7%	34,4%	29,6%	45,3%	25,9%
High pass	18,8%	6,3%	36,8%	48,9%	68,6%
Excellent	3,3%	1,4%	12,5%	3,3%	3,7%

[a] Before methodology change

[b] After methodology change

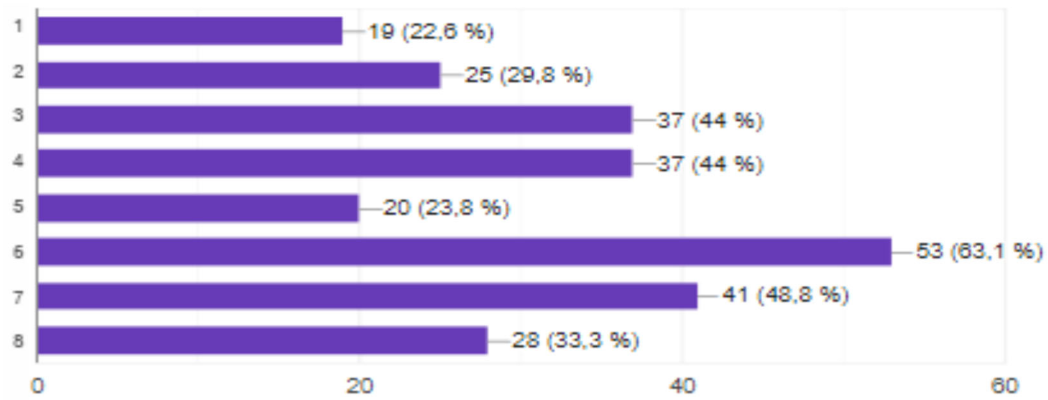
A. *Analysis of the student attainment*

In relation to the student attainment, the data best suited to establish a valid comparison is the result of the applied skills evaluation system used each year: open answer exam up to the introduction of the methodology change vs. the grades obtained for the analysis project after it. 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 result of more complex and elaborate thinking when compared with multiple choice or short numeric questions. As a result, the final grades, comprising the results of different evaluation systems, should neither provide results as reliable as the chosen ones. It must be stated also that the academic year 2018-19 has been excluded of this analysis due to a transient change in the subject instructors and contents that regard its results not comparable.

The results of the stated comparison are summarized in Table II and in figures 5 and 6. The grades are stated in a 0-10 scale where under 3 is a weak no-pass, under 5 is no-pass, under 7 is just pass, under 9 is high pass and under 10 is excellent. A direct comparison of the subject grades comprising the learning outcomes stated achievement before (up to 2018) 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. 5 shows grades distribution with a clear decrease of pass and below grades showing a large general increase in the high attainment levels from 26,4% to 62,2% or a strong increase in the total pass grades from 61% to 97,8%. This, for example, can be taken as a clear indication that the change from a more traditional learning to active methodologies like PBL and FT helps those students who find the subject especially difficult or less interesting to achieve a basically acceptable outcome level thus contributing to an increase in the degree's effectivity rate. Fig. 6 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 better attract less convinced students.

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 two academic years that had been subject to the methodology



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. 8. Student perception of the methodology change side-effects, 2021.

change. The survey included only three questions: 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. The results of this survey are summarized in figures 7 and 8, having an overall answer rate of 22% of the subject's enrolled students, conferring the results a high reliability and representability. Overall, in both years, close to 75% of the students attest the positive impact of PBL on their attainment of the specific and transversal student outcomes, while roughly only 1 in every 8 students do not perceive that positive impact.

It is interesting to notice also the difference between both academic years: the 2020 (full pandemic confinement) students clearly show a better perception of the positive impact of the methodology change, probably due to the fact that they were more mature students that have been able to apply the better attainment levels in further subjects or even in their degree's thesis (the survey was issued for both groups at the end of 2021's spring semester).

Fig. 8 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 positive perception on the self-responsibility of the learning process, or the fact that it helps develop more proficiency on the subject or on the students' problem solving abilities, although pointing out already known drawbacks like the perception of a higher work-load or, sometimes, of a more superficial learning or even an insecurity feeling.

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.

VI. Comments on the Covid-19 Pandemic Effect on the Methodology Change Implementation

The proposed methodology change was scheduled to be firstly introduced in the student activities during the second half of the winter-spring semester of the 2019-2020 academic year. Then, in march 2020, the Spanish Government declared a nation-wide Alarm Condition (AC) as a result of the growing incidence of the first wave of the Covid-19 pandemic in Spain. The main restriction associated to this AC where a strict confinement (prohibition to exit from home except on essential activities and for specific jobs). The UPV had already set special measures in-line with the expected AC days before it was installed, including the suspension of all academic activity requiring getting to the university (for students, but also for teachers and for academic and non-academic personnel). This measure was kept with some minor relaxing from March the 14th 2020 and up to June 2020, thus affecting the first planned introduction of the methodology change.

Then, the academic year 2020-2021 started with a clear uncertainty as to the gravity of the expected further pandemic waves. The Spanish Government, in coordination with local authorities, had already relieved the strict confinement but kept instead some level of mobility restrictions to towns or regions. At the academic level, the new condition was described as limited face-to-face activity, involving, among other measures, the following:

a) physical attendance was prioritized for evaluation and laboratory activities,

b) theory and practice classroom activities will be performed with full attendance as long as the classroom allowed safe distance between students,

c) in case of insufficient allocated classroom surface, the activities where to be performed in mixed mode: as many as possible students were granted classroom access, while the rest should follow the activities on-line.

All these points were then to be graduated as a result of changes in the pandemic incidence and other sanitary parameters, like the ICU occupancy on local hospitals. As a result of this, in fact, during the first three weeks of the winter-spring semester 2021, the face-to-face academic activity had to be excluded in academic activities in the Comunidad Valenciana, where UPV is located. This, however, had a reduced impact on the methodology change implementation during its second instalment, as it was planned to happen during the April-June period. This period saw a somehow reduced incidence, and, thus, permitted the already described limited face-to-face activity. This resulted, considering the available classrooms for the 5 subject groups, in the mixed mode activities described above, with most students being allowed to attend the classroom activities and some following them on-line.

As the planning and preparation tasks to be performed by the instructors were already completed by February 2020, we decided to go on with the plan and start on full on-line basis the first installment of the methodology change beginning on April 2020. With regard to this, some main aspects of the full on-line implementation must be considered:

a) the UPV had already deployed a collaborative distance working platform (Office 365 and especially Teams), which was used both for staff planning meetings and for learning activities,

b) as a general rule, both instructors and students had had almost no degree of preparation in this distance working platform, but the need to use it from the veru beginning of the confinement resulted in an accelerated training stage (which didn't prevent a varied degree of clumsiness feeling on both sides),

c) student assistance was deemed in general to be poor, which was favored by the fact that on-line sessions were recorded and could be reproduced afterwards on-demand by the students,

d) this resulted in a clearly reduced level of interaction between students (which were allowed to keep their cam and mic off and often did) and instructors,

e) however, it must be said that the general perception from instructors was that the on-line attending students presented enough interaction for the important questions to be presented during the sessions,

f) the organization of the sessions, allowing the instructor for some time to devote to direct mentoring of the different groups allowed for an effective supervision of the group project in all cases were the interest of the group participants demanded it, resulting in an overall very satisfactory progress of the project activities,

g) the increased availability of the instructors during the strict confinement, together with the time flexibility the on-line platform gives to the tutoring activities, meant that the students were almost free to undergo mentoring activities with a very extended and flexible schedule.

Then, during the second installment of the methodology change, which was executed during the period of April-June 2021, the limited face-to-face model meant, generally speaking, little incidence in the student-instructor activities as, in fact, almost all students which decided to attend the classroom activities were allowed to.

Finally, some level of additional uncertainty in the described results in Section III 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 remebering 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 conducted under a full on-line scenario, as already described above, as the return of the students to the University was not possible until September 2020. 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. This, however, did affect marginally the second year's installment of the methodology change, which took place under a slightly limited face-to-face model.

VII. CONCLUSIONS

The main conclusion of this work is that this experience mirrors the main results 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), the ability to solve problems or also the student motivation. However, this study reminds also some well-known drawbacks like the work-load increase, or sometimes a relative lack of security in the results of the learning process.

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