Received: 5 August 2023 | Revised: 9 January 2024 | Accepted: 11 January 2024

DOI: 10.1111/ejed.12611

ORIGINAL ARTICLE

WILEY

Analysis of academic results from implementation of a flipped learning methodology in a subject in higher engineering education

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Abstract

Flipped learning (FL) has positive effects on the teaching–learning process. Nevertheless, and given that it is a relatively new methodology, it still raises some misgivings. This work aims to highlight the potential of FL by the analysis of academic results in a subject in higher engineering education and, thus, to contribute to overcome possible misgivings. Methods were based on statistical analysis, using Pearson's correlation coefficient (PCC), and comparative analysis using graphs. Data from eight academic years were analysed, three with traditional methodology and five with FL. Influence of specific factors, such as participation in FL activities, on students' performance over time has been identified. FL has a very positive impact on students' academic performance and the active participation of students' results in a significant increase in the pass rate as well as in the quality of learning. These improvements have increased over time despite challenges such as the COVID-19 pandemic.

KEYWORDS
COVID-19 pandemic, flipped learning, higher engineering education, learning by doing, redesign, soft skills

1 | INTRODUCTION

As shown by numerous studies, such as those carried out by Fundación CYD (2022), engineering graduates are one of the professional profiles currently in greatest demand and employability. Their demand is increasing day by day because, as pointed out by Alabadan et al. (2020), 'the current service and technological designs are unable to meet the needs of the society and the expected dramatic increase in the future'. But this reality is translating into an increase in the demands of companies towards these graduates. Ultimately, industry needs professionals who can respond to the challenges of new environments and new trends (Abelha et al., 2020), such as the one represented by the Fourth Industrial Revolution (Xu et al., 2018).

The employability of engineering graduates, and also their professional future, increasingly depends on their competencies (Römgens et al., 2019), especially their soft skills (Deepa & Seth, 2013), that is, those competencies related to personal, interaction, communication, behavioural and transversal skills (Wats & Wats, 2009). Companies need engineers capable of making creative, agile and efficient decisions that respond to the needs and problems that arise on a day-to-day basis. In other words, they need versatile, proactive and decisive professionals, capable of analysing and adapting to any circumstance, familiar with technology and its advances, prepared to work in constant cooperation in multilingual environments and with high levels of empathy and emotional intelligence.

The meeting of this need is at the basis of the Bologna reform of the European university system (Bologna Declaration, 1999), which promoted the explicit development of competencies in higher education, especially in those careers of a more technical nature. This is also observed in the EUR-ACE reference model, which emphasizes its importance in engineering curricula [European Network for Accreditation of Engineering Education (ENAEE), 2021]. In general, educational institutions are looking for students to be able to acquire knowledge and understand it at a deep level that allows them to know how to apply and transfer it to new situations, while developing the capabilities, competencies, skills and values that the labour market will demand of them.

The traditional education model, based on the simple face-to-face and unidirectional transmission of knowledge, does not contribute significantly to this purpose (Gatica-Saavedra & Rubí-González, 2020), since it relegates the student to a passive role by turning him or her into a simple recipient of information and knowledge (Anshari et al., 2016). However, the master lecture is deeply rooted in education (Gatica-Saavedra & Rubí-González, 2020) and especially in the university environment, where it is used together with a massive and intensive evaluation of knowledge in which the memory load is prioritized, ignoring that students 'erase' the pseudo-acquired knowledge as soon as they take the exam.

With the aim of solving the shortcomings of the master lecture, over the last decades a large number of student-centred active methodologies have emerged, such as (Rodríguez Sánchez, 2011) the case method, problem-based learning and collaborative group work. In particular, the methodology known as flipped learning (FL), which has its origin in the work presented by Lage et al. (2000), is becoming increasingly important, with a current presence in the most diverse educational scenarios (Ovcharuk et al., 2023).

In FL, some or all of the direct instruction is delivered through videos and other media, and class time is used to engage students in collaborative, practical activities (Flipped Learning Network Hub, 2014). Although the notion of FL is not new (Al Mamun et al., 2022), its application has increased significantly in recent years as a result of the advancement of new technologies and the huge volume of resources now available on the Internet (Cheng et al., 2019).

FL involves changing from a unidirectional content transmission model to a bidirectional one (Prieto Martín, 2017), in which the classroom can be used to develop different activities following a learning-by-doing approach, which gave such excellent results for centuries to craft guilds (Martín Llorente, 2021). In addition, LF allows for a deeper understanding of the issues and provides opportunities for meaningful learning (Requies et al., 2019). With the FL model, students are able to reason the subject matter at high levels of Bloom's Taxonomy (Krathwohl, 2002) while exercising multiple soft skills, through different active, social and inductive learning

activities. In addition, FL encourages greater teacher–student interaction, as students see the instructor as a moderator rather than a mere information deliverer (McLean & Attardi, 2023).

According to Perdomo (2022), FL is based on connectionist and constructivist theories, on problem-based learning and on the implementation of projects in an interactive and collaborative work environment. In the FL methodology, students carry out the more cognitively demanding and complex activities in class (i.e. those involving creation, evaluation, analysis and application) and autonomously develop the less complex activities (Bergmann & Sams, 2014). As indicated by Yan et al. (2018), while in traditional learning students employ more rehearsal and elaboration strategies, in FL students employ more organization and critical thinking strategies and consequently their learning motivation and self-efficacy is enhanced. As a result, FL allows students to improve their critical thinking skills, promote their creativity, develop their problem-solving skills or improve their technological competences (Aamer & EL-Zine, 2019), and even improve their emotions (Jdaitawi, 2020), which is a key aspect to achieve meaningful learning (Pintrich et al., 1993).

A review of the literature related to the application of FL shows: (i) that FL has attracted the attention of researchers from several countries (Al Mamun et al., 2022) and (ii) a lack of unanimity in establishing its effects and even divergent results across the various educational levels at which it has been applied, as reflected in Table 1, which shows the main effects of FL observed in some of the literature reviewed. The discrepancy in findings highlights the complexity of FL and underlines the need for further research to better understand the factors contributing to these variations and to identify the specific conditions in which FL may be most effective.

As mentioned earlier, FL methodology is used in a variety of educational contexts, from basic education to vocational training and higher education. Indeed, Ruiz-Jiménez et al. (2022) highlighted the positive effects of FL on the teaching–learning process of students at the university level, and Serrano et al. (2019) reported many advantages of FL such as enhancement of critical thinking, personalized learning adapted to the work rhythm of each student, deeper learning of the subject, fostering of collaboration skills, promotion of students' protagonism of their own learning and encouragement of a centred-learning model and no centred teaching.

Although FL in engineering education is a relatively new field of research, it has entered a phase of exponential growth (Al Mamun et al., 2022). Moreover, FL seems particularly suitable for engineering education (Karabulut-Ilgu et al., 2018) because of its potential to combine learning methods that were previously considered incompatible: (i) active problem-based learning activities based on constructivist approaches and (ii) lectures derived from direct teaching methods based on behaviourist principles (Bishop & Verleger, 2013).

However, research on FL in engineering education is limited. Therefore, this study aimed to highlight the potential of the FL methodology, in the context of higher engineering education, by means of a detailed and rigorous analysis of academic results, and thus overcome possible misgivings about this new methodology (Brewer & Movahedazarhouligh, 2018); furthermore, as indicated by Wilson (2023), teachers resist adopting FL when it is perceived as a methodology that diverges from the one that they follow and when it is felt that the increased workload is not offset by the obtained improvement in students' academic performance.

The implementation of this educational model requires a complete redesign of teaching, which entails a considerable effort by lecturers (Koh et al., 2022), adequate preparation (Yilmaz, 2017) and enormous resources of time (Maycock et al., 2018); for this reason, it is advisable to introduce a FL methodology in a gradual way (Hao, 2016). This is precisely what we have done in several subjects taught in different degrees in industrial engineering at the University of Valladolid (UVa) over the last few years and, in particular, in the subject that raised the need for a methodological change: Production and Manufacturing Systems (PMS).

After 5 years of applying the FL methodology in one of the three blocks that comprise the aforementioned subject, we have set out to analyse the results. More specifically, in this work we aim to find out whether its implementation has led to a significant improvement in students' academic performance and level of understanding, and to determine which variables have the greatest influence on the final results. The study is based on data collected from the subject PMS of the Degree in Industrial Electronics and Automation Engineering in the UVa.

TABLE 1 Effects of FL as reported in the literature.

	FL effects	
	Positive effects	**Negative effects**
Maycock et al. (2018)	Positive effect on continuous assessment Improved participation Differentiated effects as a function of age and gender, with greater acceptance and benefit for older and female students	Negative effect on the final exam Gradual adaptation needed Over-reliance on digital resources FL did not lead to significant benefits over the years Pedagogical strategies need to be adapted to meet objectives
Yilmaz (2017)	Direct relationship between students' prior readiness and their motivation-satisfaction with FL This readiness depends on students' online work competence, their self-directed learning skills and their ICT level Importance of content interactivity	Decrease in student satisfaction and motivation over time FL implementation requires updating of curricula and teacher training Variability in students' level of preparation needs to be taken into account
Cho et al. (2021)	Better academic performance Students' preference for FL model Promotes students' autonomy, flexibility and self-regulation Positive correlation between time spent on prior preparation and higher exam marks	FL requires careful design and planning Less than half of the students felt that their learning needs were met Some students resisted certain aspects-activities of the model Need to explain clearly to students at the beginning what is expected of them and what the method is about
Deslauriers and Wieman (2011)	Superior conceptual learning with FL versus traditional	Similar retention in both models
Koh et al. (2022)	The combination of FL with cooperative learning provides positive results FL improves practical and theoretical skills Proper integration of teaching, learning and assessment helps to improve student satisfaction and learning	Results depend on multiple factors such as appropriate design and coherence with the curriculum or the teacher's workload. There also needs to be a close connection between teaching, learning and assessment In addition, students must be helped to adapt to the culture change involved Teachers need to be supported in their transition to FL

TABLE 1 (Continued)

	FL effects	
	Positive effects	**Negative effects**
Martínez-Jiménez and Ruiz-Jiménez (2020)	FL improves student satisfaction, motivation and participation FL improves interaction and relationships between students and teachers FL enables more accurate identification of individual differences in students FL improves academic results Positive opinion of the assessment method, with summative and formative evaluation	Resistance of some students to change in their study habits Need for continuous adjustments and careful planning Transparency in assessment is needed to make students work harder Teachers need to coordinate if the methodology is implemented in several subjects to avoid student overload
Meyliana et al. (2022)	Students prefer FL over the traditional method Increases student participation and engagement Improved quantitative and qualitative results	Requires significant investment of time and resources for implementation
Ruiz-Jiménez et al. (2022)	More positive attitude of students when the FL model is applied. This attitude improves over time Positive impact on students' motivation and engagement Continuous work allows a steady pace of learning to be maintained Importance of formative assessment and continuous improvement Students' positive perception of the FL is related to better results in the final assessment	Initial resistance, so initial concerns need to be addressed and students need to be supported Equitable distribution of tasks is needed
Burke and Fedorek (2017)	FL helps to maintain attention, improves motivation and satisfaction. It also promotes some soft skills	FL does not improve students' academic performance The success of the FL depends on the student completing the required preparatory tasks and this is precisely the part that generates the most resistance, encouraging a lack of participation and isolation of the students, which results in a preference for passive teaching
Swart et al. (2022)	FL showed greater resilience when lessons had to be moved from the classroom to online training	Similar satisfaction between LF and lecture classes

(Continues)

TABLE 1 (Continued)

	FL effects	
	Positive effects	**Negative effects**
Wilson (2023)		Teachers show significant resistance to FL due to concerns about its lack of connection to the reality of teaching, issues of equity of access to technological resources, student motivation to complete work before class, increased workload (for both students and teachers) and a perception that it does not really contribute to improving qualitative or quantitative results
Yan et al. (2018)	FL improves student motivation and participation FL reduces test anxiety Students feel more qualified and confident in their learning skills FL improves, in students, their organization, critical thinking, time management and effort regulation FL encourages the transition to online environments	Gender differences, especially benefiting male students
Yorganci (2020)	FL provides better academic results than e-learning or B-learning FL improves students' self-regulation and confidence to understand and address problems	
Requies et al. (2019)	FL improves understanding of the topics and promotes autonomous work FL improves students' meaningful learning FL gives rise to an improvement in students' marks compared to previous academic years in which it was not used	
Aamer and EL-Zine (2019)	FL improved critical thinking skills, fostered creativity, problem solving, information technology skills and academic performance Structuring the content helps to improve its understanding Group work and discussion are considered a useful element FL improves academic performance	Some students did not feel confident and engaged with FL model: (i) they feel it requires a lot of time and workload, (ii) there is great resistance to change, which can lead to anxiety and adoption problems

TABLE 1 (Continued)

	FL effects	
	Positive effects	**Negative effects**
Hao (2016)	Students recognized the benefits of FL, appreciating the student-centred approach	There is a gap between the perception of benefits and the overall meeting of individual educational needs
Karabulut-Ilgu et al. (2018)	Growing interest in the application of FL in engineering Multiple benefits recognized Effectiveness and quality of FL environments in higher education FL enhances professional skills, continuous learning, self-regulation and academic skills	Resistance of educators used to traditional methods Effective implementation requires continuous support and reflection Need for careful design of online materials and assignment of complex problems for face-to-face sessions
Brewer and Movahedazarhouligh (2018)	FL is an appropriate model to meet the knowledge and skill needs of students FL enhances deep understanding of knowledge and skill development Change in the role of the teacher	Resistance of educators to change towards FL Need to manage time and resources FL requires more responsibility and challenge from students compared to the traditional model Resistance to change by students Limited applicability in some contexts. Educators must clearly communicate goals and expectations.
O'Flaherty and Phillips (2015)	FL improves classroom interactivity and academic performance There are a variety of methods to support pre-preparation The key to success is the effective integration of pre- and in-class activities FL promotes flexible learning	The preparation of resources and design of activities requires significant time and effort, which becomes a challenge for implementation Funding of resource costs and continuous ICT support is required Limited evidence that this approach leads to sustained improvement over time Raises the need for curriculum redesign to integrate pre-class activities. FL cannot be applied in all subjects.
Al Mamun et al. (2022)	FL is appropriate for addressing remote learning challenges, especially during the COVID-19 pandemic	FL in engineering is a new field of research Lack of robust evidence to support the superiority of FL High effort required from teachers
Cheng et al. (2019)	Evidence of positive effect on students' cognitive outcomes Active participation of students in FL environments Importance of quality of content and activities Positive effect at primary and secondary school levels	The positive effect is modest, which raises questions about value and return on investment: what size of effect is needed to justify adopting FL? The impact on higher education may be non-significant or even negative in some cases The impact at higher education level, especially in postgraduate studies, is not significant and, in some cases, negative There are differences depending on the discipline, with more favourable results in areas such as Arts and Humanities

Specifically, there is information from eight academic years: during the first three the traditional methodology was used and in the last five the new FL methodology has been gradually implemented.

This work is organized in several sections that describe the analysis performed and all that is necessary to contextualize it. Specifically, it first briefly describes the subject under study, the problem that existed and outlines succinctly the new learning methodology that has been introduced in response to it. This is followed by a short description of the study, including the definition of the main objective, the choice of the study group, the generation of the database used, a first descriptive analysis of the selected variables and a brief description of the analysis methodology employed.

The following section describes the main results of the study, organized into three lines of investigation: (i) the relationship between the variables used, (ii) the impact on thematic block marks and (iii) the impact on the understanding of the subject. This is followed by a discussion of the results, which addresses the impact of FL on academic performance and the level of understanding of the subject, the importance of student participation and the resilience of the methodology when facing challenges. The results are validated by comparing the effects of the application of the new methodology in the thematic block under study with those obtained for the other two thematic blocks of the subject, in which the teaching method did not vary and the new FL methodology was not applied. A series of recommendations for educational practice, positive aspects and limitations of the study, future lines of research as well as the relationship between the results and the objectives of the study is also presented. The article ends with the main conclusions drawn from the conducted work.

2 | JUSTIFICATION OF THE STUDY

2.1 | The subject: PMS

PMS is a 4-month subject of 4.5 ECTS credits that is taught in most of the industrial engineering degrees offered at the School of Industrial Engineering of the UVa. The subject is divided into three thematic blocks taught, respectively, by three different departments: the thematic block I describes the technologies and elements that are part of the production and manufacturing processes in the industrial field; the thematic block II introduces the techniques and elements of automation, communication and systems integration; finally, the thematic block III presents the basics of two key tools for decision making related to production and manufacturing systems: simulation and costs.

Prior to the implementation of the new FL methodology in this last thematic block, all three blocks were taught using a traditional lecture approach. The final mark was calculated as the average of the marks achieved in each of the three blocks, and no minimum mark was required in each block. The assessment of each block was done through a final written exam, which accounted for 90% of the mark, and through the laboratory practical, which accounted for the remaining 10%. The exam for each block consisted of 20 multiple-choice questions (related to theory and problems), where incorrect answers were penalized. The laboratory mark was assessed by means of a specific machining workshop test carried out during the exam ('thematic block I') or by means of laboratory practice reports ('thematic blocks II and III').

2.2 | The issue: Lower and decreasing academic performance

From the first academic year in which this subject began to be taught, it could be seen that the results obtained by students in thematic block III were significantly worse than those achieved in the other two blocks. Over the years, this situation did not improve; indeed, a clear and worrying negative trend in the academic results in this block was evident: as will be seen next, in the first three academic years of this study (2015–2016 to 2017–2018),

in which no FL methodology but a traditional methodology was used, the pass rates for thematic block III in the ordinary call were very low (14.49% in 2015–2016, 11.27% in 2016–2017 and 8.82% in 2017–2018) and there was a downward trend.

This trend was also observed when comparing the mean mark achieved by students in thematic block III in the ordinary exam, which went from 3.62 in the 2015–2016 academic year to 3.42 in 2016–2017 and, finally, to 3.12 in the 2017–2018 academic year. These results contrast significantly with those achieved in the other two thematic blocks of the subject: in thematic block I, there was a stable behaviour with significantly better results than those achieved in thematic block III (4.63 in 2015–2016, 4.91 in 2016–2017 and 4.58 in 2017–2018), while in block II, which started from a similar level to that of thematic block III, there was a clear upward trend (3.68 in 2015–2016, 4.56 in 2016–2017 and 5.12 in 2017–2018).

It was necessary to identify the reasons for this reality, so a survey was carried out among students in various degrees, in which we found that there were two circumstances that could explain these results:

- On the one hand, and despite the effort made by all the lectures of the three thematic blocks to show the students the interrelation between these thematic blocks, the fact was that, as each block was taught by different departments and professors, the students perceived them as three independent subjects. As no minimum mark is required in any of the thematic blocks to pass the subject, many students chose to focus on two of the blocks, 'sacrificing' the third.
- On the other hand, it was clear that the traditional methodology was not the best option for teaching this block because (i) it did not allow students to develop the capacity for analysis and synthesis, creativity and critical thought required to solve the simulation problems and (ii) it did not make sure that students would dedicate effective study time to practice the problems and become more agile in solving them, which is essential for passing the exam, since no two simulation problems are the same.

In the different surveys conducted, both in class and in the virtual classroom, students claimed to understand what was explained in the classroom and in the laboratories. However, despite these good impressions, the surveys also showed that the study of the content of the block was limited to the simple 'reading' of the solutions presented in class; moreover, many students took the exam without having solved a single problem by themselves. Consequently, and according to the cognitive learning pyramid model (Letrud & Hernes, 2018), the level of learning achieved was very low.

2.3 | The solution: The methodological shift towards FL

It was obvious that the solution had to come primarily from a methodological transformation aimed at getting students to reason the subject matter at high levels of Bloom's Taxonomy and at the same time develop their soft skills. Key to this was the provision of mechanisms that encouraged dialogue and peer learning, and ensured that the students themselves were the problem solvers in a learning by doing approach. In this way, they could check their level of understanding of the subject matter, enabling them to identify errors and gaps in knowledge.

For this reason, and coinciding with the change of coordinator of thematic block III, in the 2018–2019 academic year, a new methodology based on FL began to be implemented in this block, with the aim of solving the problems encountered and improving learning, the development of competences and, in short, academic results. Currently, FL is the central methodology applied in thematic block III, though it is not the only one. Consequently, the learning sequence has been changed, distinguishing three learning periods: before, during and after class.

Before class, students prepare for classroom activities by reviewing the didactic material available in the virtual classroom and on the web. They have messages and infographics to guide them in reviewing the content, which are available in different formats (presentations and videos with the fundamental information, micro

pills, videos with problem solving, podcasts, documents, etc.). Each class session focuses on a central thematic element following a microlearning approach, so the review of the material prior to each class usually requires approximately 20 minutes for each hour of class time; students are only asked to do a simple visualization reading. After reviewing the content, students are asked to complete an H5P quiz in the virtual classroom. This quiz, with no limit to the number of attempts, contains questions of various types (multiple choice, drag and drop, fill in the blanks, mark the words, drag the words, true/false question, essay and image choice) focusing on the most important content.

By taking the transmission of knowledge outside the classroom, it has been possible to free up 'classroom time' to develop different active, social and inductive methodologies that allow for a better understanding of the content and the development of soft skills. Specifically, *during class*, both in the classroom and in the laboratory, they work cooperatively (Foldnes, 2016) using different techniques with the aim of solving problems and challenges following the learning by doing approach. We also carried out some cooperative gamification tests using digital platforms such as Socrative (Pryke, 2020) or Mentimeter (Pichardo et al., 2021).

Socrative is a really interesting online platform for introducing gamification in the classroom. It allows us to design tests and exams for students to take in the classroom, or even at home, using a digital device. In addition, this tool offers teachers the possibility of knowing the results of the evaluation in just a moment. We use these tests either at the beginning of class, when we want the students to refresh the knowledge that, theoretically, they have previously consulted at home, or at the end of the class, to find out to what extent they have internalized the contents worked on in the classroom.

For example, a typical class might begin with a Socrative 'space race' in which students collaborate within each team, and compete with the other teams, to answer a time-limited set of basic questions and problems based on previous study content. Students who have reviewed the content put their knowledge to the test and teach their teammates who have not (p2p peer-to-peer learning) while they all work on their soft skills (teamwork, communication skills, leadership, empathy, listening skills, respect, sociability, creativity, problem solving, analysis and synthesis, assertiveness, pressure tolerance, etc.).

Each question has feedback that allows students to know the correct answer and the corresponding explanation, favouring the learning of the key aspects that we want students to have before performing the rest of the classroom activities. The resolution of the students' doubts and the analysis of the results after the Socrative tests allow us to identify the teacher's blind spots and ensure that the students are better prepared for the next phase of the session.

In particular, after this gamification stage, students usually face a complex problem, also in a cooperative way, using all the knowledge acquired in the previous stages and actively working on their competences. As indicated earlier, various techniques are used at this stage to enhance cooperation and competence development such as Jig-saw (Costouros, 2020; Rohmat et al., 2019), peer instruction (Mazur & Hilborn, 1997), Think-Pair-Share (Lyman, 1981), Round Robin (Delina & Refelita, 2021) and Numbered Heads (Zarti & Khairani, 2020). During this stage, the teacher asks questions that guide the development and allow students to know if they are working in the right direction; these questions are asked directly or through queries via Mentimeter.

After class, students complete various tasks and questionnaires related to the work done in the classroom, allowing them to consolidate their knowledge. In addition, they are given reflection surveys to, among other things, assess their level of understanding and identify their educational needs. Generally, a single compulsory revision task is set for each activity carried out in the classroom. This task can be of different nature (completing a questionnaire, participating in a discussion forum, completing a task and uploading the document, etc.) and all of them are conducted in the virtual classroom of the subject. Compulsory assignments can be completed during the week in which the activity takes place, as they are solved in class the following week. Students can also complete optional tasks that help them to consolidate knowledge or to work on content not covered in the classroom and of lesser relevance; as these tasks are optional, students are allowed to complete them during the whole period of the teaching of the thematic block III.

The application of the new FL methodology has required a change in the assessment criteria and tools of the thematic block III, though always within what is established in the verification document of the subject. For this reason, if before the exam accounted for 90% of the final mark, it now accounts for 70%, and the remaining 20% is distributed among the different tasks, questionnaires, activities, etc., linked to the FL methodology.

Finally, there are two aspects to highlight. Firstly, the implementation of the methodology has been carried out progressively over the last academic years, changing contents, creating attractive audiovisual material, adapting the virtual classroom. On the other hand, the effort required by the methodology from students has increased, though not exaggeratedly: on average, and according to the surveys, students spend 1.5 hours of independent work per week, considerably less than the 4.5 hours that correspond to them in the framework of the European Higher Education Area (EHEA).

3 | STUDY DESCRIPTION

3.1 | Aims

From the very moment the new FL methodology began to be applied, an improvement in the academic results of Block III could be observed, a fact which was associated with a better assessment and satisfaction on the part of the students. At the present time, and after several academic years of application, we wish to know in greater detail the degree of performance of the implementation of the new FL methodology. Therefore, we propose to analyse the results of its application, comparing them with those achieved with the previous methodology with the aim of finding out whether the introduction of the new methodology has led to a significant change in the improvement of results and the acquisition of learning. The aim is also to find out which elements can best explain, or have the greatest influence on, the final results.

3.2 | Choice of study group

PMS subject has been taught in seven of the nine engineering degrees offered by the School of Industrial Engineering of the UVa, specifically in the following degrees: Industrial Organization Engineering (IOE), Mechanical Engineering (ME), Industrial Technology Engineering (ITE), Chemical Engineering (CE), Electrical Engineering (EE), Industrial Electronics and Automation Engineering (IEAE) and Energy Engineering (ENE). Although we want to conduct a global study that includes all of them, as a first approximation we decided to carry out the analysis in a single degree. This decision aims to obtain an initial understanding of the challenges and benefits of applying the FL methodology, laying the groundwork for more extensive research in the future.

The choice of the particular grade in which the study was conducted was based on an evaluation of two strategic criteria: (i) size and (ii) application conditions. A large sample size improves statistical representativeness, thus increasing the reliability of the results. In addition, it allows the detection of real effects, contributes to the generalization of results to larger populations, reduces the probability of statistical errors and allows for more detailed analyses. Ultimately, a large sample size strengthens the validity and credibility of the research, by offering a solid basis for drawing meaningful conclusions about the impact of the FL methodology in the context studied. In this regard, the degrees with the most students are ME and IEAE, which usually have more than 100 students per academic year.

By choosing, to study the implementation of the FL methodology, a group with less favourable application conditions can offer various advantages and provide a richer and more complete understanding of the challenges and benefits of the application carried out. On the one hand, the results obtained under challenging conditions may be more representative of the real effectiveness of the methodology, since it faces adverse conditions. In

addition, it allows assessing the resilience of the methodology, providing valuable information about its adaptability. On the other hand, results achieved under less favourable conditions also have the potential to be more generalizable to other environments. This strategic choice makes it easier to identify areas for improvement, understand potential obstacles and develop more effective strategies to improve students' academic performance, thus contributing to continuous improvement.

To identify the grades that face the most adverse conditions, we consider two key elements: the academic affinity of the grade with respect to the content of block III and the availability of time to address the aforementioned content. In terms of thematic affinity, degrees in CE, EE, ME, IEAE and ENE exhibit less academic affinity with the content of the block III. Furthermore, during the last weeks of the semester, all students have a greater workload due to the concentration of tests and task from other subjects. In this period, block III is taught specifically in the degrees in IEAE and ENE.

As a result of this analysis, it was determined that the only grade that (i) has an adequate number of students, (iia) with less thematic affinity with the content of block III and (iib) in which students have greater restrictions to dedicate their time to working on the aforementioned content is the degree in IEAE. Therefore, this grade has been selected as the object of study to carry out the research.

3.3 | Database generation

We used data from four sources, which provide a large number of variables with a high information content: the lecturers' spreadsheets, the virtual classroom of the subject, the Socrative application and the SIGMA platform of the UVa. Lecturers' spreadsheets have been for many years the main medium where assessment information was collected, both for exams and laboratories. It was also the medium used to store information on the different activities during the first years of implementation of the new FL methodology.

However, in recent years the main way of recording information has been the virtual classroom of the subject, included in the Virtual Campus (Moodle platform) of the UVa. This tool not only allows teachers to provide information to students (documents, videos, infographics, podcasts, etc.), but also hosts the evaluation associated with the various tasks performed by students, both individual and collective (questionnaires, surveys, classroom activities, laboratories, etc.). Through the mark book, students can consult the marks achieved, as well as the final mark of the thematic block.

Another important source of information is the Socrative application, which has been used in the gamified assessment conducted in the classroom. This tool saves the marks obtained by the students in these tests. After retrieving it, the percentages of success are dumped in the Virtual Campus, where the final mark is calculated and finally transferred to the SIGMA application.

SIGMA is precisely the last source of information. It is the platform to which the final results of each of the thematic blocks of the subject are transferred. In addition, it has academic information on the students.

3.4 | The study variables

For this study, we have used information from students enrolled in the subject/degree from the 2015–2016 academic year to the 2022–2023 academic year. Two types of data are available for each student: on the one hand, academic information and, on the other, information associated with the evaluation. Most of the variables used in this study correspond to the latter group and include both variables that reflect the assessment of the different activities and tests carried out, mainly associated with thematic block III, in which the FL methodology has been implemented, and support variables created to be able to analyse in detail some of the aspects related to the evaluation. In total, we have a total of 64 study variables, which are shown in Table 2.

TABLE 2 Description of the variables used in the study.

Type	Category	Variable	Description
Academic	Subject	Academic year	Academic year in which the student is enrolled
		Group	Within the degree there are two groups: morning group and afternoon group
		Lecturer	Lecturer teaching thematic block III during the academic year
	Access	Access type	Student's access route to university studies
		Years in degree	Number of years the student has been enrolled in the degree course, including the current academic year
	Record	Times enrolled	Number of times the student has been enrolled in the subject
		Exam calls consumed	Number of exam calls consumed by the student in previous academic years
		Credits passed	Number of ECTS credits that the student has passed in the previous academic years
		Credits enrolled	Number of ECTS credits that the student has enrolled for during the current academic year
Evaluation	General	Ordinary final mark	Mark obtained by the student in the thematic block III in the ordinary call as a result of the weighted sum of the mark of the activities, the mark of the ordinary exam and the laboratories. The weighting is different before and after the application of the FL methodology
		Extraordinary final mark	Mark obtained by the student in the thematic block III in the extraordinary call as a result of the weighted sum of the mark of the activities, the mark of the extraordinary exam and the laboratories. The weighting is different before and after the application of the FL methodology
		Ordinary exam mark	Mark obtained by the student in the ordinary exam of thematic block III
		Right questions in ordinary	Number of questions correctly answered by the student in the ordinary exam of thematic block III
		Wrong questions in ordinary	Number of questions incorrectly answered by the student in the ordinary exam of thematic block III
		Extraordinary exam mark	Mark obtained by the student in the extraordinary exam of thematic block III
		Right questions in extraordinary	Number of questions correctly answered by the student in the extraordinary exam of thematic block III
		Wrong questions in extraordinary	Number of questions incorrectly answered by the student in the extraordinary exam of thematic block III
		Laboratory mark	Mark obtained by the student in the laboratory practices of the thematic block III. This value is the same for both calls
		Activities mark	Mark obtained by the student in the set of activities associated with the FL methodology (before, during and after class)

(Continues)

TABLE 2 Continued

Type	Category	Variable	Description
	Activities	Before	Mark achieved by the student in the activities performed before class in the thematic block III
		During	Mark achieved by the student in the activities performed during class in the thematic block III
		After	Mark achieved by the student in the activities performed after class in the thematic block III
		Extra	Mark achieved by the student in the optional activities in thematic block III
	Ordinary final	Very goods in ordinary final	Number of students who obtain a 'Very good' in the final mark of the ordinary call of the thematic block III
		Goods in ordinary final	Number of students who obtain a 'Good' in the final mark of the ordinary call of the thematic block III
		Sufficients in ordinary final	Number of students who obtain a 'Sufficient' in the final mark of the ordinary call of the thematic block III
		Fails in ordinary final	Number of students who obtain a 'Fail' in the final mark of the ordinary call of the thematic block III
		'Not taking the exam' in ordinary final	Number of students who have not taken the ordinary exam
	Extraordinary final	Very goods in extraordinary final	Number of students who obtain a 'Very good' in the final mark of the extraordinary call of the thematic block III
		Goods in extraordinary final	Number of students who obtain a 'Good' in the final mark of the extraordinary call of the thematic block III
		Sufficients in extraordinary final	Number of students who obtain a 'Sufficient' in the final mark of the extraordinary call of the thematic block III
		Fails in extraordinary final	Number of students who obtain a 'Fail' in the final mark of the extraordinary call of the thematic block III
		'Not taking the exam' in extraordinary final	Number of students who have not taken the extraordinary exam
	Ordinary exam	9–10 Ordinary exam	Number of students with a mark ranged from 9.1 to 10 in the ordinary exam
		8–9 Ordinary exam	Number of students with a mark ranged from 8.1 to 9 in the ordinary exam
		7–8 Ordinary exam	Number of students with a mark ranged from 7.1 to 8 in the ordinary exam
		6–7 Ordinary exam	Number of students with a mark ranged from 6.1 to 7 in the ordinary exam
		5–6 Ordinary exam	Number of students with a mark ranged from 5.1 to 6 in the ordinary exam
		4–5 Ordinary exam	Number of students with a mark ranged from 4.1 to 5 in the ordinary exam
		3–4 Ordinary exam	Number of students with a mark ranged from 3.1 to 4 in the ordinary exam
		2–3 Ordinary exam	Number of students with a mark ranged from 2.1 to 3 in the ordinary exam

TABLE 2 Continued

Type	Category	Variable	Description
		1–2 Ordinary exam	Number of students with a mark ranged from 1.1 to 2 in the ordinary exam
		0–1 Ordinary exam	Number of students with a mark ranged from 0 to 1 (out of a maximum of 10) in the ordinary exam
	Extraordinary exam	9–10 Extraordinary exam	Number of students with a mark ranged from 9.1 to 10 in the extraordinary exam
		8–9 Extraordinary exam	Number of students with a mark ranged from 8.1 to 9 in the extraordinary exam
		7–8 Extraordinary exam	Number of students with a mark ranged from 7.1 to 8 in the extraordinary exam
		6–7 Extraordinary exam	Number of students with a mark ranged from 6.1 to 7 in the extraordinary exam
		5–6 Extraordinary exam	Number of students with a mark ranged from 5.1 to 6 in the extraordinary exam
		4–5 Extraordinary exam	Number of students with a mark ranged from 4.1 to 5 in the extraordinary exam
		3–4 Extraordinary exam	Number of students with a mark ranged from 3.1 to 4 in the extraordinary exam
		2–3 Extraordinary exam	Number of students with a mark ranged from 2.1 to 3 in the extraordinary exam
		1–2 Extraordinary exam	Number of students with a mark ranged from 1.1 to 2 in the extraordinary exam
		0–1 Extraordinary exam	Number of students with a mark ranged from 0 to 1 n the extraordinary exam
	Thematic block I	Ordinary final mark BI	Final mark of the student in the thematic block I in the ordinary call
		Ordinary exam mark BI	Exam mark of the student in the thematic block I in the ordinary call
		Ordinary laboratory mark BI	Laboratory mark of the student in the thematic block I in the ordinary call
		Extraordinary final mark BI	Final mark of the student in the thematic block I in the extraordinary call
		Extraordinary exam mark BI	Exam mark of the student in the thematic block I in the extraordinary call
		Extraordinary laboratory mark BI	Laboratory mark of the student in the thematic block I in the extraordinary call
	Thematic block II	Ordinary final mark BII	Final mark of the student in the thematic block II in the ordinary call
		Ordinary exam mark BII	Exam mark of the student in the thematic block II in the ordinary call
		Laboratory mark BII	Laboratory mark of the student in the thematic block II. This value is the same for both calls
		Extraordinary final mark BII	Final mark of the student in the thematic block II in the extraordinary call
		Extraordinary exam mark BII	Exam mark of the student in the thematic block II in the extraordinary call

With regard to the academic data, we distinguish between qualitative variables (group, type of access, academic year and lecturer) and quantitative variables (years in the degree course, times enrolled, time spent in the course, credits passed and credits enrolled).

Regarding the assessment data, there are 25 main quantitative variables: 14 associated with the main thematic block of study or thematic block III (categories General and Activities), in which the FL methodology has been applied, and 11 related to the other two blocks (categories Thematic Block I and Thematic Block II). These variables show, both for the ordinary and extraordinary exams, the partial marks and the final mark for each thematic block.

In thematic block III, there is also information available on the overall mark of the FL activities. This variable starts to be computed from the academic year 2018–2019, which is when the methodology under study was implemented for the first time. The mark for these activities is composed of the evaluation of the different tasks, activities, etc., both individual and group, related to the application of the new methodology.

To complement the analysis, a series of secondary quantitative variables have been created related to the evaluation of the main thematic block of study (thematic block III), which allow an in-depth study of the results obtained in the final mark and in the exams of this block in both exam calls (both ordinary and extraordinary). Associated with the final mark, the number of Fails (qualitative mark corresponding to a numerical mark ranged from 0 to 4.9 out of a maximum of 10), Sufficients (qualitative mark corresponding to a numerical mark ranged from 5 to 6.9 out of a maximum of 10), Goods (qualitative mark corresponding to a numerical mark ranged from 7 to 8.9 out of a maximum of 10) and Very Goods (qualitative mark corresponding to a numerical mark ranged from 9 to 10 out of a maximum of 10) has been identified, as well as the number of students 'Not taking the exam'. Therefore, the numerical mark for passing students is ranged from 5 to 10 out of a maximum of 10 (in the following, the numerical marks, if nothing to the contrary is indicated, will be out of a maximum of 10). On the other hand, to study only the evaluation of the exams, variables that group the marks into 10 ranges of values have been created.

3.5 | Descriptive analysis of study variables

As mentioned earlier, the time frame under study covers the academic years from 2015–2016 to 2022–2023. On the other hand, the number students of the Degree in Industrial Electronics and Automation Engineering enrolled in the subject PMS during that period is 654. Due to the size of the database (there are 64 variables for each student), it is not possible to show all the information, though some relevant indicators will be highlighted. In addition, in order to achieve a more efficient analysis of the information collected in the database, the mean, median and maximum–minimum values of each of the data per academic year have been calculated.

Firstly, a general review of the sample is made. As can be seen in Figure 1, which shows the number of students enrolled in the subject in recent academic years, the number of students has not varied significantly over the years, though a decrease is noticeable after the COVID pandemic.

With respect to thematic block III, an increase in the final mean mark is observed: before applying the new FL methodology, the average of the mean marks in the ordinary call was 3.39 (3.38 in the extraordinary call) and it has reached 4.66 in the ordinary call after its implementation (4.38 in the extraordinary call). Another data that confirm the improvement are the maximum mark achieved by the students: before the application of the new FL methodology, the highest marks in an ordinary and extraordinary call were, respectively, 6.3 and 6.8; however, with the new methodology, the maximum mark in both calls has been significantly raised to 9.5 in the ordinary call and 8.3 in the extraordinary call.

With regard to the different marks that make up the final mark:

- In the laboratory marks, of the 654 students in the sample, 418 (64%) achieved a mark of 9 or higher. Furthermore, it can be noted that there is no significant variation in this laboratory mark between before and after the implementation of the new FL methodology.

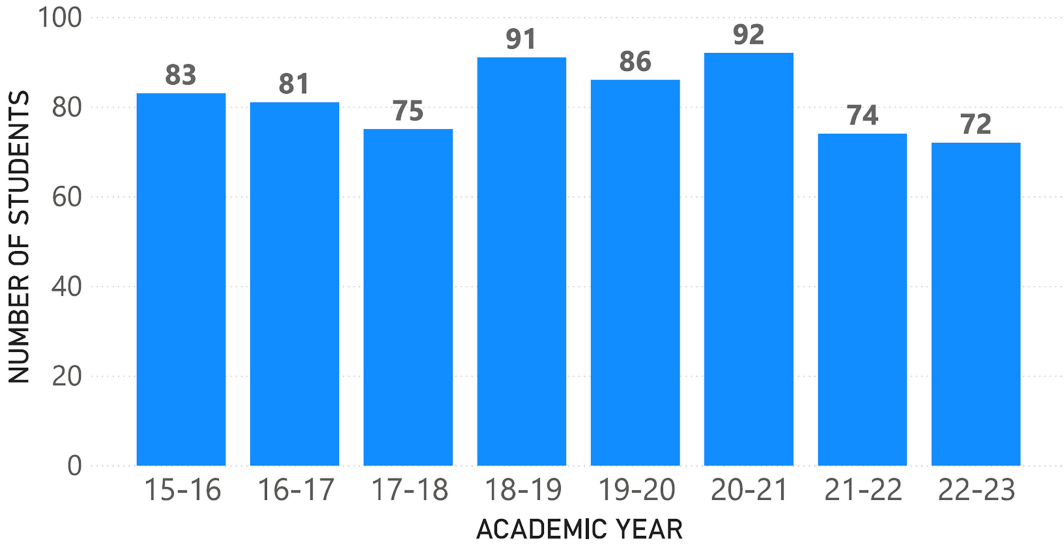

FIGURE 1 Number of students enrolled in the subject as a function of academic year.

- Regarding the activities and their evaluation, only 0.04% of students decided not to do any type of activity. There were compulsory and optional activities: in the former, there was high participation, and the average mark was 7.47, while in the latter, participation was low, though it is important to note that 71.85% of the students did at least one optional activity.
- When analysing the evaluation of the ordinary exam, it is noteworthy that, before applying the new FL methodology, the percentage of students who passed the exam did not exceed 10%, increasing to 39.9% after the change to the new methodology. The difference is also reflected in the quality of these passes: before applying the new methodology, there were no 'Goods' or 'Very goods' in the exam; however, after the implementation, there were 41 'Goods' and 4 'Very goods' distributed homogeneously throughout the academic years of application of the new methodology. About the evaluation of the extraordinary exam, the same pattern is observed, both in terms of the percentage of passes (from 12.16% to 32.22%) and in terms of the quality of the marks. The information related to the exams can be completed by considering the answers that are answered correctly. For example, before the new FL methodology, in the ordinary exam the average number of correct answers was 7.45, which rises to 8.76 after the application of the method.

3.6 | Methodology of analysis

Two analytical methods will be used to evaluate the impact of the FL methodology on students' academic performance and subject comprehension. Firstly, a statistical analysis will be carried out using Pearson's correlation coefficient (PCC) to assess the relationship between variables.

The PCC provides a quantitative measure of the strength and direction of the linear relationship between two variables, which will allow us to identify the relative influence of each variable on the final mark. By using this quantitative analysis, we will be able to identify which variable has a greater influence on students' final marks.

Next, a graphical approach will be followed to show the effect of the FL methodology versus time. Specifically, the results will be compared over several academic years in order to identify the effectiveness of the

implementation of the FL methodology in Block III compared to the traditional methods that were initially used. The Microsoft Power Bi tool will be used to carry out this analysis.

The combination of the two aforementioned methods provides a comprehensive assessment of the relationship between the application of the FL methodology and the students' academic performance, by combining a quantitative analysis of correlations with a graphical representation of the observed impact.

In order to validate the performed analysis, we will compare the results obtained in Block III with those achieved in the other two blocks of the subject, in which there has been no methodological change. This inter-block comparison approach provides an internal and cross-validation of the results, which contributes to support the validity of the conclusions obtained.

4 | RESULTS

The analysis model is based on the application of a comparative process, assisted by graphical elements, between the old and the new educational methodology, in terms of the variation of key variables in student learning over a period of time between the academic years 2015–2016 and 2022–2023. The presentation of the results will focus on three fundamental pillars:

- To analyse the relationship between the variables, using 'Ordinary final mark' as the dependent variable, with the aim of detecting which variable has the greatest influence on it.
- To show the impact that the new educational methodology has had on the marks obtained by students since its application in the academic year 2018–2019.
- To determine the impact of this new FL methodology on students' level of understanding of the subject.

The study of the relationship between the variable 'Ordinary final mark' and the rest of the variables was performed by means of two different methods: (i) PCC and (ii) Study of the impact of the implementation of the new FL methodology on students' marks.

4.1 | Study of the relationship between variables

The first method was based on the analysis of PCC *r*, since it is a dimensionless index that allows a clear and coherent interpretation of the relationship between variables. Pearson first developed the mathematical formula for this coefficient in 1895, the expression of which is shown in Equation (1), which describes *r* as 'the centered and standardized sum of cross-product of two variables' (Rodgers & Nicewander, 1988):

$$r = \frac{\sum (X_i - \overline{X})(Y_i - \overline{Y})}{\left[\sum (X_i - \overline{X})^2 \sum (Y_i - \overline{Y})^2\right]^{1/2}} \quad (1)$$

The range of values for PCC *r* is between −1 and +1. The magnitude or intensity of the correlation is determined by the numerical value. In this sense, a relationship of +1 is as strong as a relationship of −1: in the first case, there is a perfect positive linear association, while in the second case the association is perfect but negative. Conversely, a value of 0 represents that the variables are uncorrelated (Benesty et al., 2009); that is, there is no linear relationship between the characteristics of interest, though some other type of dependence or relationship may exist.

The calculation of PCC *r* was performed using the open-source programming language R (R Core Team, 2021). Table 3 shows the values of PCC *r* for the six correlations between the dependent variable 'Ordinary final mark'

on the one hand, and each of the six independent variables, which according to PCC *r* have the greatest influence on the dependent variable, on the other.

As shown in Table 3, the most influential variable in the final mark in the ordinary exam is the mark for the activities associated with the new FL methodology, even more than the one that could be considered, a priori, the most influential: the number of questions correctly answered in the ordinary exam. This result highlights the importance of these activities and, therefore, of the participation and involvement of students that, as pointed out by Meyliana et al. (2022) and Cho et al. (2021), the methodology FL promotes; this finding is consistent with that of Deslauriers and Wieman (2011), which demonstrated that educational methodologies that has the students actively engaged and interacting in the classroom, and provides ongoing formative evaluation, give rise to better conceptual learning than that obtained by traditional methodologies. For this reason, from now on we will focus on this variable, giving it greater importance within the study.

Using Microsoft Power BI software, the impact of the independent variable 'Activities mark' on the dependent variable 'Ordinary final mark' has been studied. As can be seen in Figure 2, which shows the relationship between the completion of the activities associated with the FL methodology and the number of students who pass

TABLE 3 Values of PCC *r* for the correlations between the dependent variable 'Ordinary final mark' and each of the six independent variables that have the greatest influence on the dependent variable.

Relationship between variables		
Dependent variable	**Independent variable**	**PCC *r***
Ordinary final mark	Activities mark	0.75
	Right questions in ordinary	0.53
	Laboratory mark	0.34
	Times enrolled	−0.17
	Exam calls consumed	−0.25
	Wrong questions in ordinary	−0.34

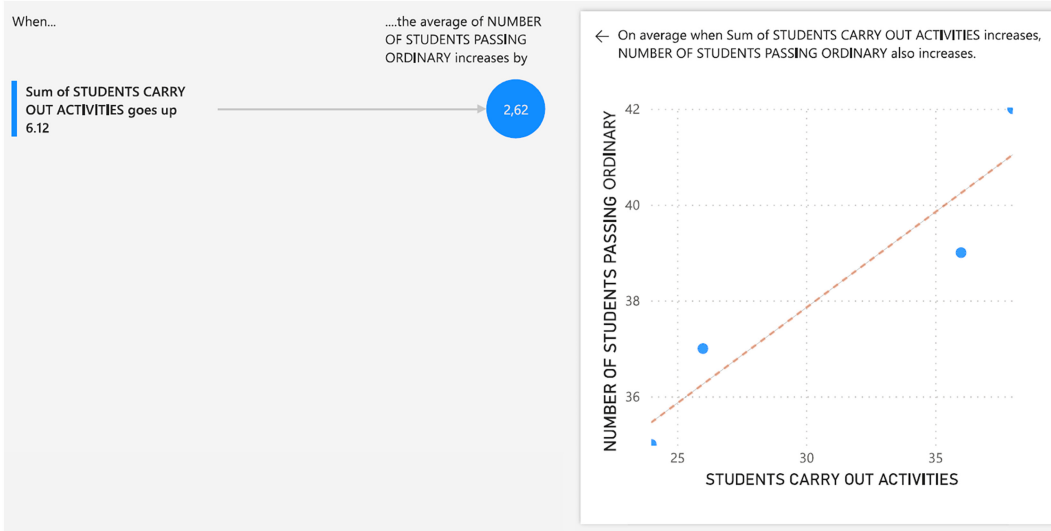

FIGURE 2 Relationship between the completion of the activities associated with the FL methodology and the number of students who pass thematic block III in the ordinary call.

thematic block III in the ordinary call, the average number of students who pass the thematic block III increases by 2.62 points when the student participates and completes the activities associated with the FL methodology.

4.2 | Impact on the marks of thematic block III

The second method of analysis aims to graphically show the impact of the application of the new FL methodology on students' marks. Therefore, several key ratios will be analysed. Firstly, the ratio 'Number of students that passed the thematic block III in the ordinary call' versus 'Number of students who have taken the ordinary exam' is calculated to assess whether the new FL methodology has a positive influence on the marks achieved by the students. Figure 3 shows the evolution of this ratio over the study period.

As Figure 3 shows, in the period from 2015–2016 to 2017–2018, the pass rates are very low and, in the ordinary call, there is a downward trend that takes the ratio to levels below 10%. It is noteworthy the great improvement brought about by the application of the new FL methodology in the 2018–2019 academic year, in which the ratio reaches a value that is practically five times higher than that achieved in the 2017–2018 academic year.

The results are even better in the second academic year of application (2019–2020), in which a pass rate of over 50% is achieved. It should be noted that, in this academic year, the development of the methodology was not affected by the global pandemic of COVID-19 and by the confinements that this caused in Spain, as the subject has always been taught in the first 4-month term, that is, between the months of September and December, and the state of alarm was declared by the Spanish government on 14 March 2020.

In the academic year 2020–2021, although a decrease in the ratio can be seen, it falls back to levels close to those of the academic year 2018–2019 and, therefore, still much higher than the values recorded prior to the implementation of the new FL methodology. This decrease is mainly explained by the effect of the COVID-19

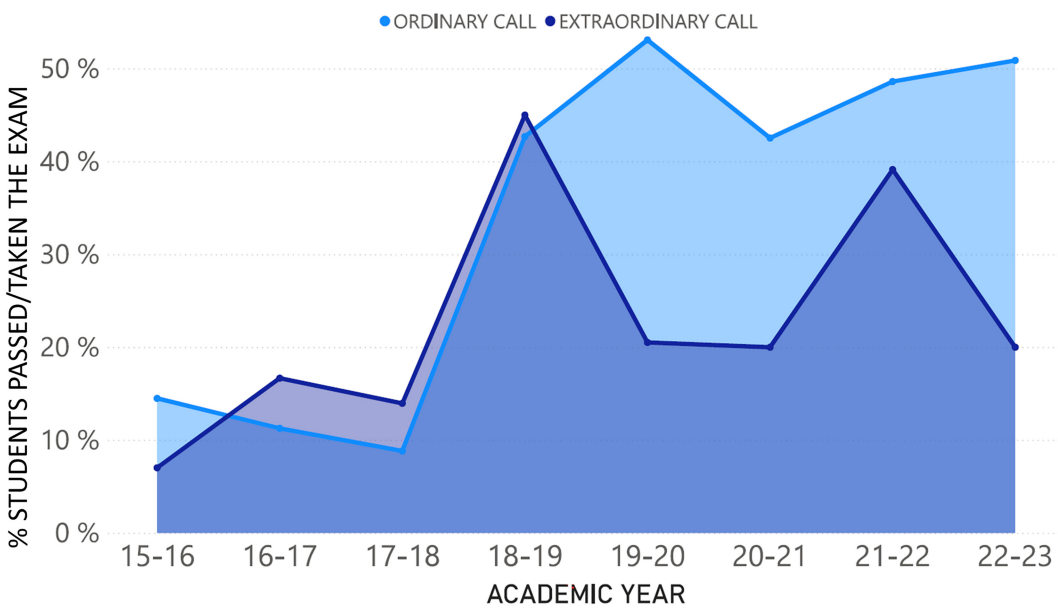

FIGURE 3 Ratio 'Number of students that passed the thematic block III in the ordinary call' versus 'Number of students who have taken the ordinary exam' and ratio 'Number of students that passed the thematic block III in the extraordinary call' versus 'Number of students who have taken the extraordinary exam' are compared as a function of academic year.

pandemic, as the subject had to be taught in a mixed face-to-face/distance mode and quite a few students stopped attending classroom, which limited the benefits of the new FL methodology.

Over the last two academic years, the ratio has risen again, though without reaching the levels reached in the 2019–2020 academic year. However, overall, Figure 3 shows a clear upward trend, mostly as a consequence of continuous improvement.

To analyse the results of the extraordinary call, the ratio 'Number of students that passed the thematic block III in the ordinary call' versus 'Number of students who have taken the ordinary exam' is compared with the ratio 'Number of students that passed the thematic block III in the extraordinary call' versus 'Number of students who have taken the extraordinary exam' (Figure 3).

As can be seen, the pass rates achieved with the traditional methodology in the extraordinary call were also low, though in two academic years they increased significantly. The implementation of the FL methodology led to a very notable increase in the value of the ratio corresponding to the extraordinary call during the first year of application (2018–2019), even surpassing the percentage achieved during the ordinary call. However, from this time onwards, the values achieved in the extraordinary call are clearly lower than those of the ordinary call. In fact, in the following academic year (2019–2020) this percentage decreases notably, down to 20%, a value at which it remains for the rest of the academic years, except for the course 2021–2022.

Two important results can be seen from Figure 3:

- The new methodology has contributed to a drastic reduction in the failure rate of thematic block III due to the active participation of the student in the learning process. This greater participation clearly explains the significant improvement in the results in the ordinary call. The extraordinary call also contributes to this reduction in the failure rate, though to a lesser extent.
- As can be seen, although the results in the extraordinary call improve with the new FL methodology, they are not very different from those achieved with the traditional methodology, with two exceptions (academic years 2018–2019 and 2021–2022). This fact could be due precisely to the success achieved in the ordinary call, where the bulk of the positive effects of the new FL methodology were collected. As for the origin of the two exceptions: (i) the 2018–2019 academic year was the first in which the new FL methodology was applied, and this novelty may have motivated students, encouraging them to participate; (ii) the improvement seen in the 2021–2022 academic year may have been due to the students' willingness to return to normality after the COVID-19 pandemic.

On the other hand, the new FL methodology not only contributes to more students passing thematic block III, but also manages to improve the 'quality' of these passes, as can be seen in Figure 4, which shows the variation, over the different academic years considered in this study, of the percentage of 'Very goods', 'Goods' and 'Sufficients' (vs. students who have taken the exam) in the ordinary call.

Before the implementation of the new FL methodology, no student had achieved a mark of 'Good'; however, after its implementation, the percentage of students who achieve this mark in thematic block III ranges between 8% and 18%, showing a clear upward trend. It can also be observed that some students have achieved a mark of 'Very good'. Consequently, the implementation of the new FL methodology has contributed to improving the academic results both in quantity and quality.

4.3 | Impact on the understanding of the subject

The third type of analysis of the results aims to show that the new FL methodology also makes it possible for students to achieve better academic marks due to an improvement in their understanding of the knowledge of the thematic block, a fact that is a determining factor when taking the exam and which is evidenced by the number of questions answered by the students, as well as by the percentage of correct and incorrect answers.

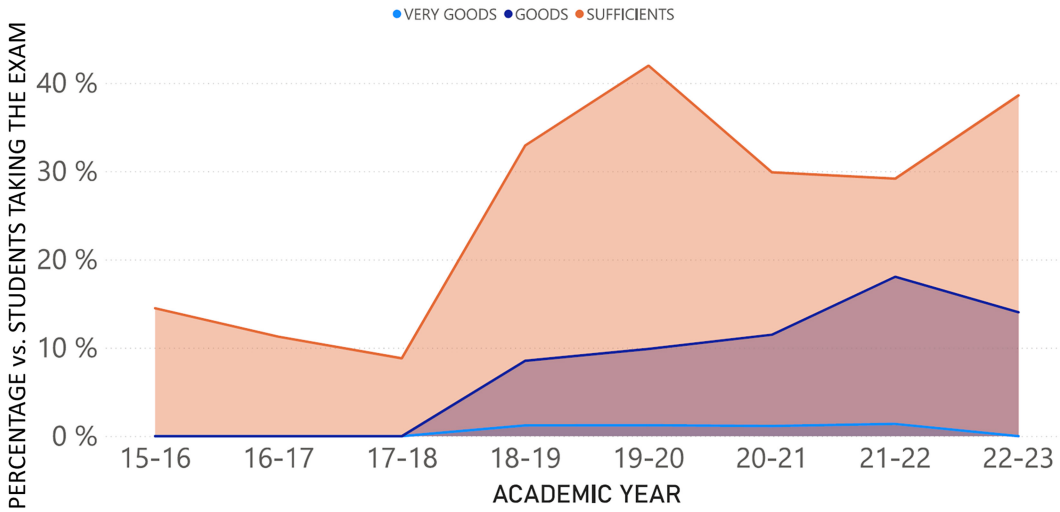

FIGURE 4 Variation, over the different academic years considered in this study, of the percentage of 'Very goods', 'Goods' and 'Sufficients' (vs. students who have taken the exam) in the ordinary call for the thematic block III.

Figure 5 shows the variation of the percentage of correct and incorrect answers in the ordinary exam over the period studied.

In the academic year 2018–2019, it is evident the positive effect that the implementation of the new teaching methodology had on the behaviour of students in the exam, going from an average of 35.33% of correct answers before the implementation to an average of 44% after the implementation, reaching a maximum of 47% during the last academic year 2022–2023. Therefore, the results show that with an assessment-learning system that rewards dedication, active participation and responsible leadership, students assimilate the subject more effectively.

Another approach would be to analyse what happens with those students who enrol for the first time in the subject, since they are usually the ones who attend class more regularly and, therefore, can benefit more from the different tasks of the FL methodology. Thus, the variation over the academic years of four indicators, such as the mean mark (Figure 6), the median mark (Figure 7), the highest mark (Figure 8) and the passed versus students who have taken the exam ratio (Figure 9), is studied, comparing the results of students enrolled for the first time with the rest of students in the ordinary call.

Figures 6–9 show the positive impact of the new FL methodology since its implementation in the 2018–2019 academic year (the results in this academic year are much better than in previous academic years). This positive impact is much greater in first enrolment students, which may be due to the fact that these students attend class regularly and actively participate in the different activities associated with the FL methodology, activities that contribute to achieving a higher degree of knowledge assimilation than in traditional education.

Figure 9 shows a very interesting finding: the results of students enrolled more than once show a significant improvement in the academic year 2019–2020, that is, with a delay of 1 year with respect to the academic year of implementation; this may be due to the fact that in the academic year 2019–2020, many repeat students had already experienced the FL methodology in the previous academic year.

The mean mark (Figure 6) and the median mark (Figure 7) vary with the academic year in a similar way, except in the 2020–2021 academic year, in which, despite the fact that the pass rate decreased compared to the previous academic year (Figure 3), the median increased, which may be due to the fact that the marks of the students who failed were higher than in previous courses, which is confirmed when comparing the mean marks of the students who failed in the ordinary call (Figure 10).

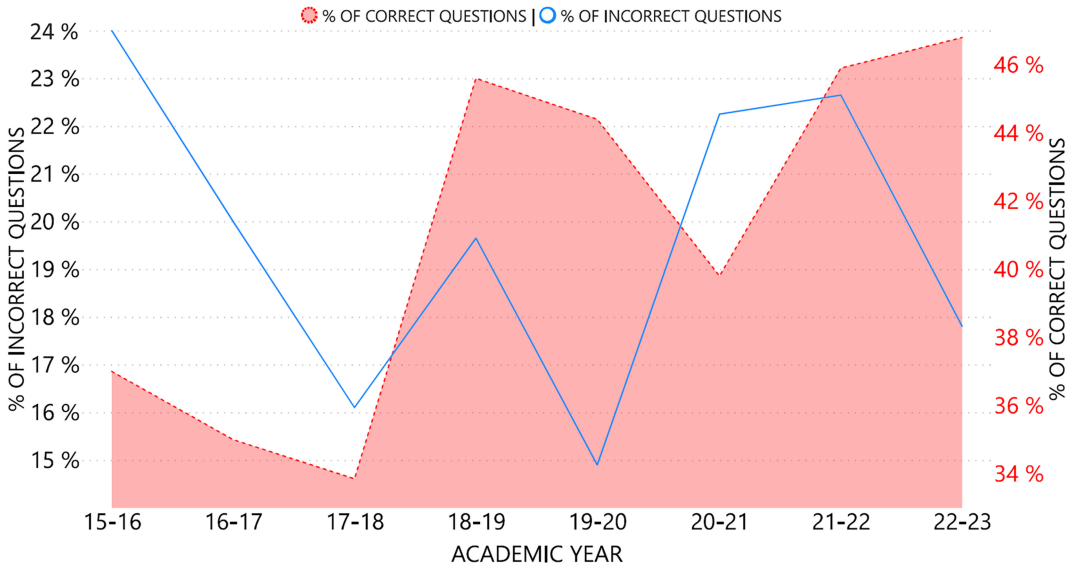

FIGURE 5 Variation of the percentage of correct and incorrect answers in the ordinary exam.

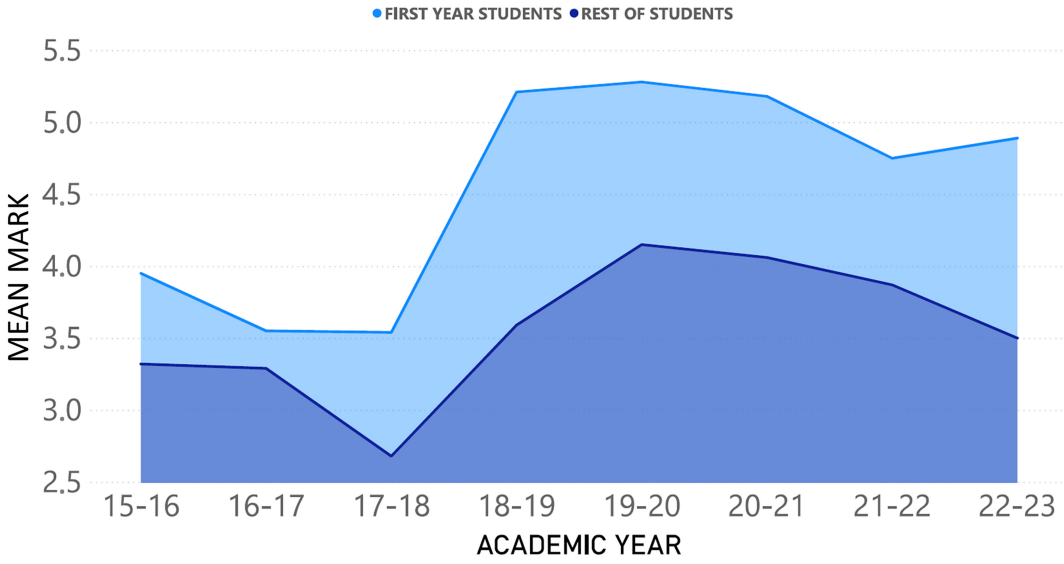

FIGURE 6 Variation, over the academic years, of the mean mark in the thematic block III in the ordinary call of students enrolled for the first time versus the rest of students.

However, in the 2021–2022 academic year, the situation changes: both the mean and median marks decreases significantly while the pass rate increases (Figure 3), which may be due to the fact that the mean marks of the students who failed (Figure 10) decreases to a greater extent than the increase of the mean marks of students who passed (Figure 11). Therefore, in this academic year, there was a greater dispersion of marks towards the extremes: positive marks were better and negative marks were worse (this is also the reason for the decrease of the mean mark is not as pronounced as that of the median mark, since the mean is more sensitive to the presence of extreme values).

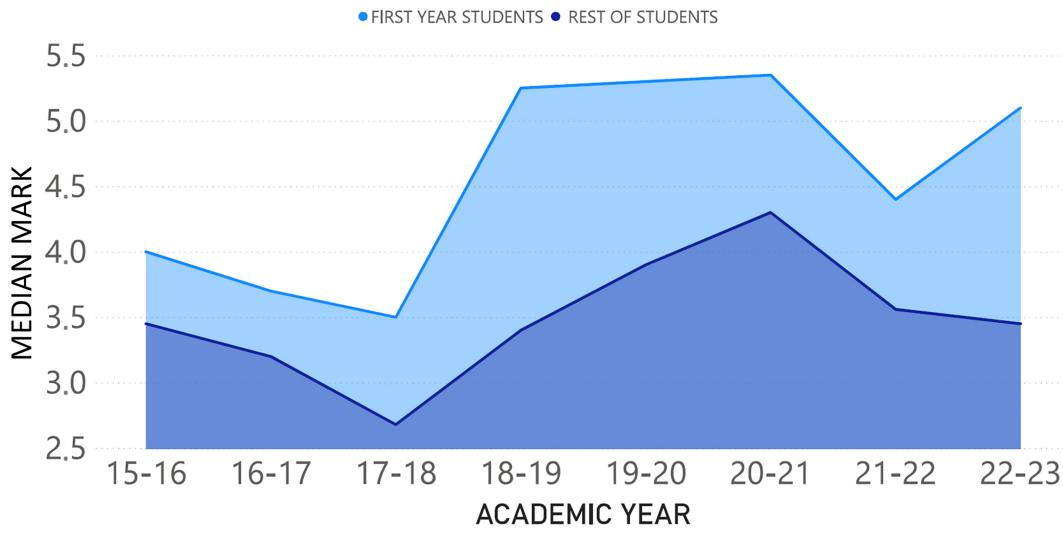

FIGURE 7 Variation, over the academic years, of the median mark in the thematic block III in the ordinary call of students enrolled for the first time versus the rest of students.

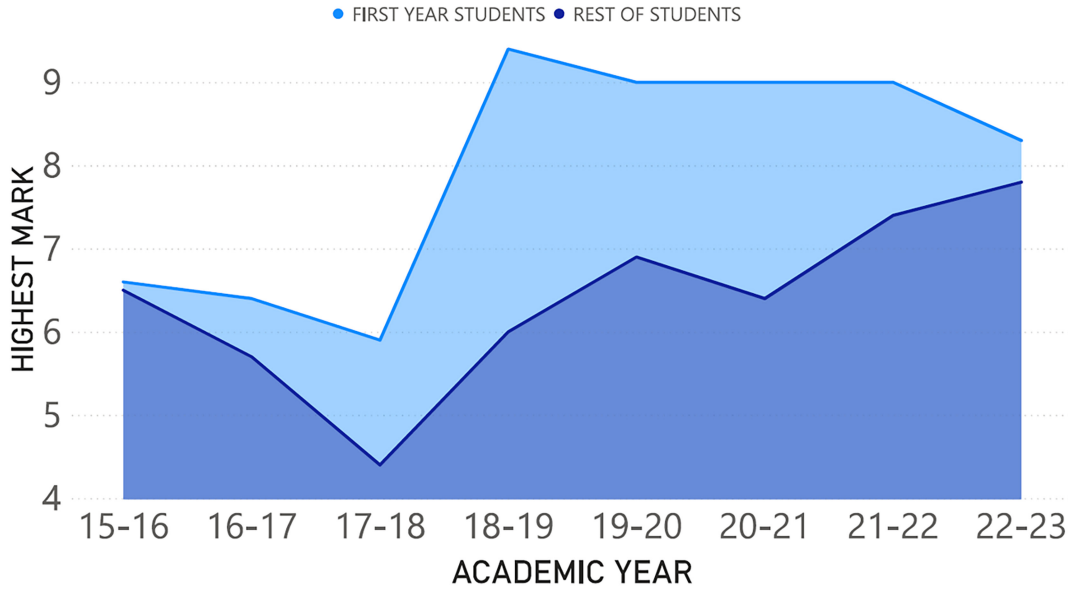

FIGURE 8 Variation, over the academic years, of the highest mark in the thematic block III in the ordinary call of students enrolled for the first time versus the rest of students.

5 | DISCUSSION

5.1 | Impact of the FL methodology

It can be observed that the new FL methodology has been a turning point, making it possible to improve academic results considerably, which is consistent with the work of Martínez-Jiménez and Ruiz-Jiménez (2020), where

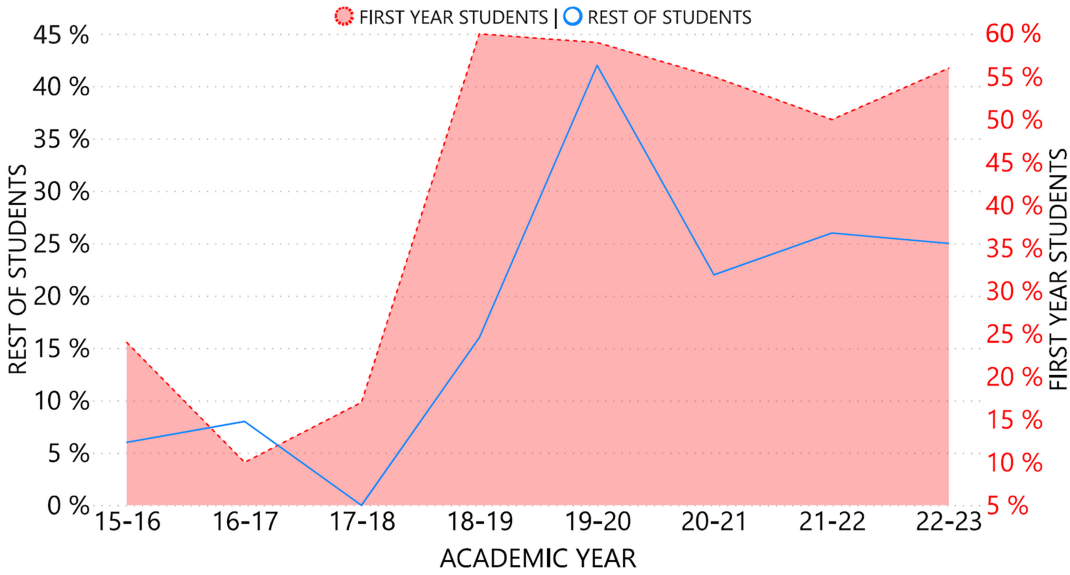

FIGURE 9 Variation, over the academic years, of the passed versus students who have taken the exam ratio in the thematic block III in the ordinary call of students enrolled for the first time versus the rest of students.

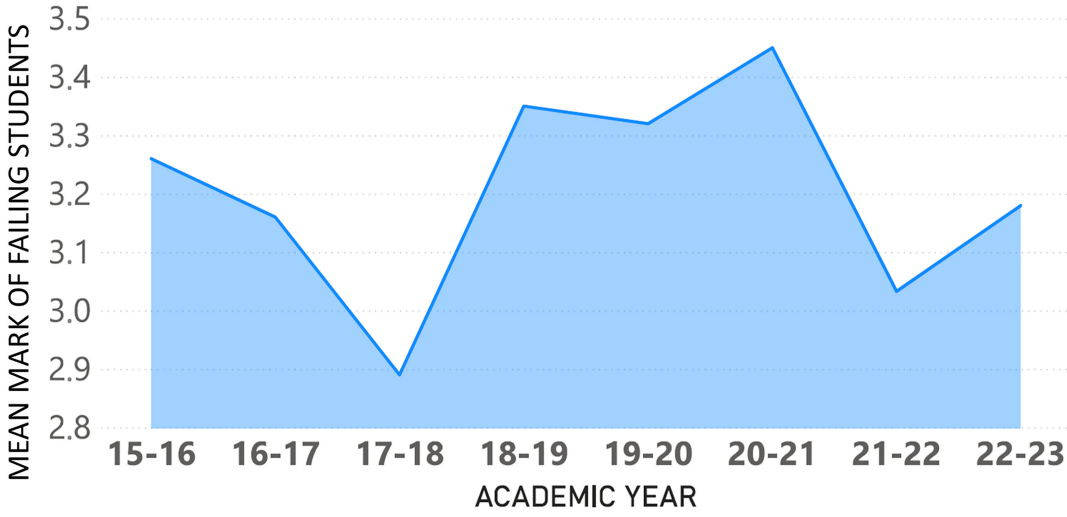

FIGURE 10 Variation, over the academic years, of the mean mark of failing students in the ordinary call of thematic block III.

academic results improved with FL, compared with traditional learning. As shown in Figure 3 (ratio of number of passed students in the ordinary call vs. number of students who have taken the ordinary exam), with the traditional methodology there was a negative trend, but in the 2018–2019 academic year, and due to the implementation of the new FL methodology, this negative trend was reversed, consolidating in the subsequent academic years a positive trend which was only slightly interrupted by the effects of the COVID-19 pandemic.

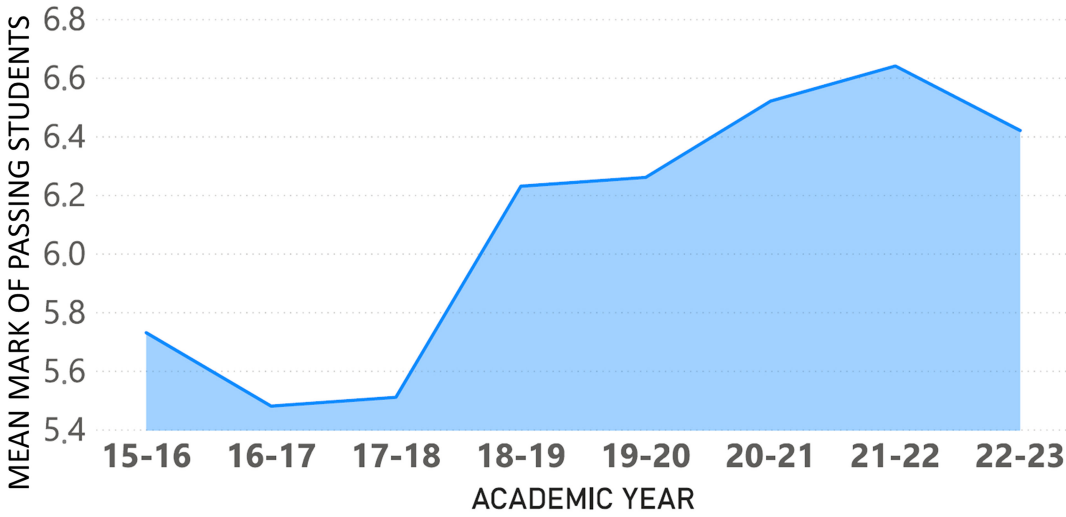

FIGURE 11 Variation, over the academic years, of the mean mark of passing students in the ordinary call of thematic block III.

The implementation of the FL methodology has also had a positive impact on students' comprehension of the subject, as evidenced by a significant increase in the percentage of correct answers in the exams, as shown in Figure 5, which reported the variation of the percentage of correct and incorrect answers in the ordinary exam. The percentage of correct answers increased significantly after the implementation of the FL methodology, indicating that students assimilate the content more effectively with this new educational approach.

This impact is even more pronounced in students enrolling for the first time in the subject, who are the ones who tend to attend class more regularly and therefore benefit more from the tasks associated with the FL methodology. Figures 6–9 show that the impact of the methodology on these students is even greater, suggesting that regular attendance and active participation in FL activities contribute to a greater assimilation of knowledge compared to traditional education.

5.2 | Validation of results

To show the improvement in context, the results of thematic block III are longitudinally (over eight academic years) compared with those of the other two blocks of the subject (thematic blocks I and II) in which no methodological change was made. The aim of this comparison is to show that with the new methodology FL, the academic results in the three thematic blocks have been equalized.

As can be seen in Figure 12, which shows the variation over the academic years of the mean mark in the ordinary exam in each of the three thematic blocks that make up the subject, prior to the implementation of the FL methodology (academic year 2018–2019) the results of thematic block III are significantly worse than those of the other two thematic blocks, but after applying the methodology FL, the results of thematic block III reach, and in some academic years even surpass, those obtained in thematic blocks I and II.

Therefore, by adopting the learning by doing or hands on models, students shift their attitude from a passive reception of knowledge to a self-learning commitment based on experimentation and exploration where the student is the architect of his or her own knowledge.

The new FL methodology has improved the understanding of the subject and, consequently, the academic results of the students. This improvement in the results of thematic block III is reflected in the subject as a whole, as can be seen in Figure 13, which displays the variation of the average number of times that students need to

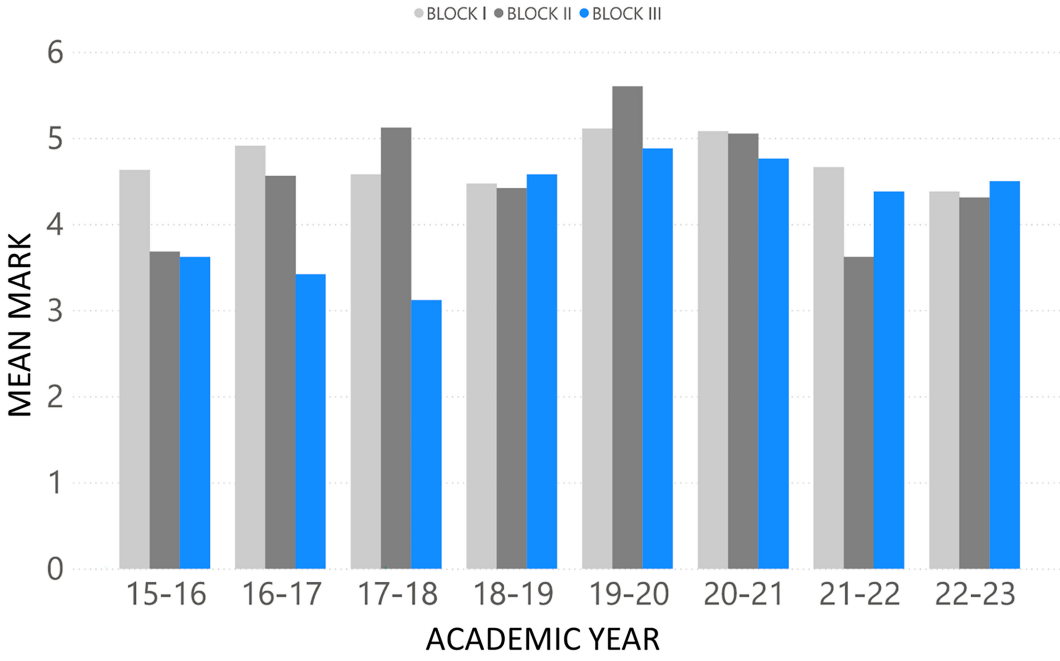

FIGURE 12 Variation, over the academic years, of the mean mark in the ordinary exam in each of the three thematic blocks (TBs).

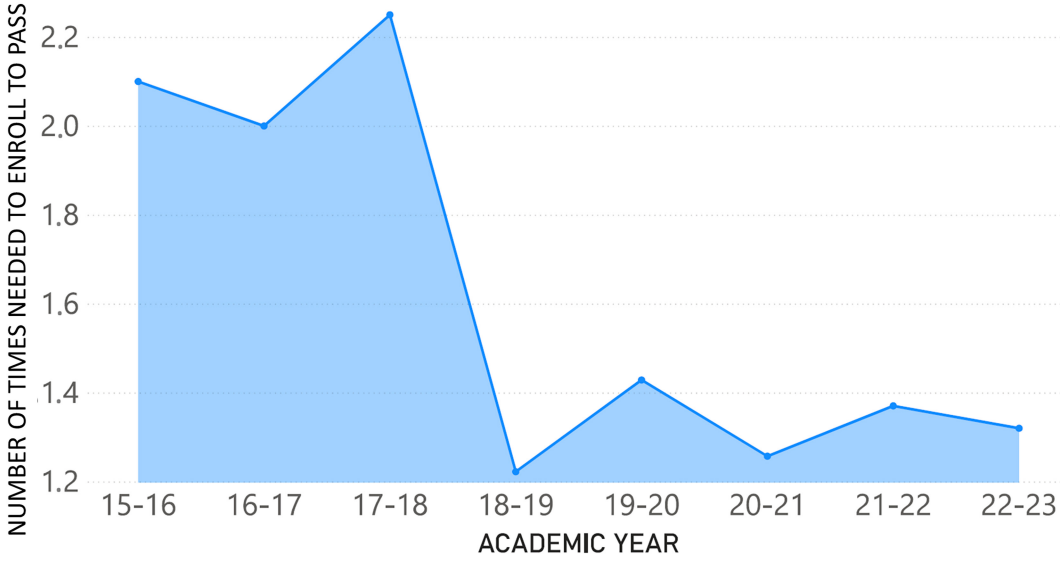

FIGURE 13 Variation, over the academic years, of the average number of times that students need to enrol in the subject to pass it.

enrol in the subject to pass it. As can be seen, this average number has almost halved: from almost 2.3 times in the 2017–2018 academic year to an average slightly above 1.3 in the last academic years. This demonstrates, once again, that the new FL methodology has led to significant advances in improving the academic results of the students, not only in the thematic block III, but also in the subject as a whole.

5.3 | Importance of participation in FL activities

The improvement in the final mark is based on a key element: participation in the activities, both group and individual, associated with the FL methodology. The results show that those students who made a greater effort in these activities achieved a substantial improvement in their exam results, increasing the number of correct answers and decreasing the number of incorrect ones. In particular, as pointed out by Burke and Fedorek (2017), the level of prior preparation undertaken by students is of great importance.

The new FL methodology has turned students into active participants and protagonists of their own learning process, thus acquiring a deeper understanding of the knowledge of the subject, as they are not limited to reading the notes or observing how the problems are solved. They now train themselves and their classmates to try to solve the problems themselves, in a critical way, which allows them to easily identify gaps in knowledge during the teaching period, and not just a few days before the exam, as was previously the case. All this work has also allowed them to develop skills and competences that are difficult to acquire with traditional methodology.

These findings are consistent with those of (a) O'Flaherty and Phillips (2015), who showed that FL methodology fosters critical and independent thought in students, providing them with lifelong learning and preparing them for a future working environment, and (b) Yorganci (2020), who concluded that FL gives students an active role in their learning process, enables them to handle their learning experiences different manners and provides a learning environment that supports students in proactively getting external help when needed.

In short, all the evidence indicates that students' formation, their evolution and the quality of the knowledge acquired are highly conditioned by the learning system used. But this is not the only key element to consider: the evaluation system used significantly influences the way in which students approach the subject, affecting their learning process (Murphy, 2006). By including simple weekly activities in the evaluation system, we have required students to spread out their study and preparation time, as opposed to a model in which most students only studied a few days before the exam. In this way, we have achieved a high level of student involvement in the subject, enabling an improvement in their understanding of the subject, which has translated into significant progress in academic results.

5.4 | Resilience of the FL methodology to challenges

The FL methodology has shown remarkable resilience to the challenges caused by the COVID-19 pandemic, which is consistent with the results of Swart et al. (2022). Despite the widespread disruption to education caused by the pandemic, this longitudinal study demonstrates that the methodology has been able to maintain its effectiveness and even continue to improve.

It is true that during the 2020–2021 academic year there was a temporary drop in pass rates, which can be attributed to the complications arising from the pandemic and the impossibility of being able to carry out all the designed learning activities. However, the system not only recovered quickly, but continued to improve in subsequent academic years, and always with results far superior to those achieved with the traditional methodology. This adaptability highlights the robustness of FL as a teaching method and its inherent flexibility, as it has been able to adapt easily and maintain its effectiveness in challenging situations.

Undoubtedly, the FL's ability to foster students' active participation and continued engagement in self-directed activities contributed to maintaining and strengthening the positive results. In this way, the FL methodology not only enabled a smooth transition from exceptional circumstances, but also consolidated the benefits observed in previous academic years. The adaptability of the FL and its ability to maintain high levels of participation were essential to counteract the possible negative impacts of the pandemic. Consequently, the FL methodology applied not only withstood the challenges, but continued to be effective, supporting the

idea that this methodology can deliver positive long-term results even in dynamic and changing educational situations.

5.5 | Recommendations for educational practice

A series of recommendations for educational practice arise from all this work. Firstly, it is essential to promote active student participation by incorporating methodologies such as FL, which has been shown to be very effective in this regard. Results indicate that active student participation is positively correlated with improved performance in exams, highlighting the importance of involving students in their own learning process.

It is also advisable to include weekly activities in the assessment to encourage the organization of study and its distribution over time. This approach contributes significantly to greater student engagement and improved understanding of the content.

The ability of the FL methodology to remain effective in exceptional circumstances is rooted in its ability to adopt flexible pedagogical approaches that can adapt to unforeseen situations. However, we also need to adapt our activities to the characteristics of the learners, to the objectives we want to achieve and to external constraints.

On the other hand, rather than seeking an increase in pass rates, the emphasis should be on achieving high-quality learning, which should be a key indicator of success. Pedagogical strategies should focus on improving the understanding and retention of knowledge.

A final recommendation arising from this research is oriented towards the importance of a process of continuous improvement. It is advisable to constantly monitor academic results, identifying and addressing those areas or activities that need improvement; obviously, it is also necessary to be willing to make adjustments in methodology as needed. This will undoubtedly ensure better results in educational practice over time.

5.6 | Positive aspects of the study

The study has several positive aspects that confirm the robustness of its findings and the relevance of the FL methodology in the academic context.

The deliberate choice of a significant group with less favourable conditions for the application of the FL methodology is a strategic approach that provides a deeper understanding of the challenges and benefits of the methodology under adverse conditions.

The analysis has been carried out in a rigorous manner, using statistical methods such as the PCC. This approach provides quantifiable results and offers a more accurate representation of the relationship between variables.

The study shows that the FL methodology not only contributes to an increase in the pass rate, but also improves the quality of academic results.

The research addresses the evolution of academic results over several academic years, providing a longitudinal view of the impact of the FL methodology. This temporal approach makes it possible to observe trends and changes over time, which contributes to a deeper understanding of the effectiveness of the FL methodology. Indeed, this longitudinal study has allowed us to address the impact of the COVID-19 pandemic on the application of the FL methodology, showing its resilience and ability to maintain positive results even in challenging circumstances. This highlights, as mentioned earlier, the adaptability of the methodology to unforeseen situations.

In addition to the longitudinal perspective, a comparative analysis is carried out between the different thematic blocks that make up the subject. This comparison helps to validate the consistency of the research results and provides valuable information on the effectiveness of the methodology.

Thus, the earlier positive aspects support the robustness of the research and provide the academic community with valuable insights into the implementation and results of the FL methodology at university level.

5.7 | Limitations of the study and future research

Despite the efforts in the design and implementation of the study, potential limitations and biases need to be identified and addressed, which, though they may affect the interpretation of the results, may also be the seed for future research.

Firstly, the choice of a single degree, while a strategic decision, limits the generalizability of the findings. Extending the research to include multiple degrees would allow for a more holistic understanding of the impact of the FL methodology; furthermore, comparing the results across different degree–disciplines would provide valuable information and insights. A multi-degree study would, for example, provide an insight into the influence of lecturers and their adaptation to the methodology on the results; this is a perspective that has not been explored in this study as the lecturer was always the same in the degree period under consideration. Differences in implementation by various lecturers could introduce variability in the students' experience. Even the lecturers' satisfaction and perception of the implementation of the FL methodology could be analysed, which would offer additional insights into the feasibility and acceptance by the educators.

Finally, the analysis focused on quantitative measures, such as exam results, as the main indicators of academic success. This decision may introduce biases, as not all aspects of student learning and achievement can be captured through quantitative measures alone. The inclusion of a more holistic approach that incorporates qualitative data about other dimensions could enrich the understanding of the effects of the FL methodology. For example, direct feedback from students about their experience with the FL methodology could be incorporated, including their perception of their own engagement and participation and of the usefulness of the activities conducted. In this way, it would be possible to analyse, always from the students' perception, how the methodology has helped them to understand the contents at a high level or to improve their competence development. In particular, it would be interesting to address their perception of the influence of the methodology on the development of their soft skills (creativity, critical thinking, problem solving, sociability, teamwork, etc.), which would be relevant to assess an impact beyond academic results.

5.8 | Relationship between the results and the objectives of the study

The improvement in the pass rate is very significant since the FL methodology was implemented. Despite the challenges encountered during the COVID-19 pandemic, this pass rate has shown an upward trajectory, consolidating the lasting effectiveness of this educational approach. But not only has there been an increase in the number of students passing thematic block III, but the FL methodology has also raised the quality of these passes, reflecting an overall improvement in student performance.

In addition, there is a strong correlation between students' performance and their participation and engagement. The average number of students who pass this thematic block III increases significantly when they participate in and complete the activities associated with the FL methodology. The transformation of students into active elements of their own learning process is one of the most outstanding achievements of the FL methodology.

It should be noted that, despite starting from a significantly negative situation in terms of results, thanks to the application of the FL methodology, academic results in subject block III have been brought into the same level as those of other thematic blocks (I and II), which have not undergone methodological changes. This result supports the overall effectiveness of the FL methodology as an instrument to improve educational quality.

Even faced with the disruption caused by the COVID-19 pandemic, the FL methodology has proven to be resilient. Despite a slight temporary decline in the pass rate during the 2020–2021 academic year, the system successfully recovered and continued to improve in subsequent academic years.

Finally, in the light of the obtained results, it can be confirmed that the present work has achieved the proposed objectives that were to highlight the potential of the FL methodology by means of a detailed and rigorous analysis of academic results and, thus, to overcome possible misgivings about this new methodology.

6 | CONCLUSIONS

This work studies the impact of the FL methodology on the academic performance of a thematic block of an industrial engineering subject over several academic years, with the following main conclusions:

- FL methodology has a key role to play in improving academic performance. The implementation of FL not only reversed a negative trend in pass rates, which improved significantly, but also contributed to students' deeper understanding of the content. Furthermore, active student participation in the activities associated with FL is shown to play a crucial role in this improvement, underlining the importance of encouraging such participation.
- This study strongly supports that the substantial benefits of this methodology at the academic level offset the additional workload it entails. In particular, the resilience of FL to challenges, as evidenced during the COVID-19 pandemic, highlights its ability to adapt to changing environments and sustain positive results.
- The benefits obtained with the implementation of FL allow, in an objective manner, to overcome possible misgivings and, in short, it can be concluded that the FL methodology pays off.

FUNDING INFORMATION

The authors received no financial support for the research, authorship and/or publication of this article.

CONFLICT OF INTEREST STATEMENT

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

DATA AVAILABILITY STATEMENT

Data are not available because they are part of an ongoing study.

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How to cite this article: Galindo-Melero, J., Sanz-Angulo, P., De-Diego-Poncela, S., & Martín, Ó. (2024). Analysis of academic results from implementation of a flipped learning methodology in a subject in higher engineering education. *European Journal of Education*, *59*, e12611. https://doi.org/10.1111/ejed.12611