Research Article/ Education in Engineering https://doi.org/10.15446/ing.investig.98094

A Hybrid-Flipped Classroom Approach: Students' Perception and Performance Assessment

Un enfoque de aula invertida híbrida: evaluación de la opinión y el rendimiento de los estudiantes

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ABSTRACT

This study presents an improved hybrid-flipped classroom (hybrid-FC) education method based on technology-enhanced learning (TEL) along with diluted classes for a course on probability and random processes in engineering. The proposed system was implemented with the participation of two student groups who alternated weekly between attending face-to-face activities and fully online classes as a sanitary measure during the pandemic. The education model was combined with the flipped classroom (FC) approach in order to improve the quality of learning and address the negative effects of remote education. Before the lessons, the students studied the course material, filled a question form, and then took a low-stake online quiz. Then, the students attended a session where the questions reported in the forms were discussed, and they took an online problem-solving session followed by an individual quiz. Class sessions were available to both online and face-to-face students, as well as in the form of video recordings for anyone who missed lessons. Qualitatively and quantitatively, the proposed education method proved to be more effective and comprehensive than conventional online methodologies. The students' performances were evaluated via quizzes and exams measuring the achievement of the course learning outcomes (CLOs). Weekly pre/post-tests were applied to examine the students' progress in each topic. Midterm and final exams were planned to measure the level of success for all course topics. Additionally, the students' perception was assessed with questionnaires and face-to-face interviews. A performance assessment showed an apparent increase in the success rate, and the students' perception was found to be positive.

Keywords: engineering education, flipped classroom, hybrid education, probability and random processes, statistical analysis

RESUMEN

Este estudio presenta un método educativo mejorado de aula invertida híbrida (hybrid-FC) basado en el aprendizaje mejorado por tecnología (TEL) junto con clases diluidas para un curso sobre probabilidad y procesos aleatorios. El sistema propuesto se implementó con la participación de dos grupos de estudiantes que alternaban semanalmente entre asistir a actividades presenciales y totalmente en línea como una medida sanitaria durante la pandemia. El modelo educativo se combinó con el enfoque de aula invertida (FC) para mejorar la calidad del aprendizaje y hacer frente a los efectos negativos de la educación a distancia. Antes de asistir a clase, los estudiantes estudiaban el material del curso, completaban un formulario de preguntas y luego tomaban un quiz en línea de bajo impacto. Luego, los estudiantes asistían a una sesión en la que se discutían las respuestas en los formularios, y tomaban una sesión en línea de resolución de problemas, seguida de un cuestionario individual. Las clases estaban disponibles tanto para los estudiantes en línea como para aquellos que asistían de forma presencial; también había grabaciones de video para quien faltara a clases. Cualitativa y cuantitativamente, el método educativo propuesto demostró ser más efectivo y completo que los métodos online convencionales. El desempeño de los estudiantes se evaluó mediante cuestionarios y exámenes que medían el logro de los resultados de aprendizaje del curso (CLO). Se realizaron exámenes previos y posteriores semanales para examinar el progreso de los estudiantes en cada tema. Se planificaron exámenes parciales y finales para medir el nivel de éxito de todos los temas del curso. Además, la percepción de los estudiantes se evaluó con cuestionarios y entrevistas presenciales. La evaluación del desempeño mostró un aumento aparente en la tasa de éxito, y se encontró que la opinión de los estudiantes era positiva.

Palabras clave: educación en ingeniería, aula invertida, educación híbrida, probabilidad y procesos aleatorios, análisis estadístico

Received: September 1st, 2021
Accepted: February 15th, 2023

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Introduction

Improving current education systems by adopting technological developments is becoming a necessity for most universities. An effective education is of great importance, especially in the field of engineering and applied education (Rodríguez *et al*., 2011). There are several methods that can assist and improve traditional teaching techniques (Merideno *et al*., 2015). For example, web-based learning, mobile learning techniques, computer-based simulation tools, and remote access laboratories are becoming very efficient educational materials (Gomez *et al*., 2014; Coruk *et al*., 2020; Kesim *et al*., 2012).

Measuring the effectiveness of new education methods is also an important aspect that must be taken into account. It was reported by several studies that teaching with the help of some student-centered methods such as remote teaching practices, group-based problem-solving, and project-based learning is much more effective than employing classical teaching methods (Cigdemoglu *et al*., 2014).

Due to the recent pandemic, education processes in universities have been greatly affected. As courses were planned for face-to-face tutoring, the closing of universities made it a necessity for instructors and students to rapidly adapt to remote teaching methods (Carrillo *et al*., 2020; Moorhouse, 2020); instructors had to change to online teaching, which required them to implement a number of digital tools and several new resources to teach the course concepts, solve problems, and grade students (Almaiah *et al*., 2020; Assunção Flores *et al*., 2020; König, 2020; Watermeyer *et al*., 2021). Additionally, the effects of pandemic conditions, the transition to remote education, and the use of digital assistive technologies on students have been analyzed in the literature (Iglesias-Pradas *et al*., 2021).

However, the extent to which instructors have successfully mastered online education approaches remains unknown (König, 2020). Moreover, there are several other shortcomings of moving towards fully online teaching, such as inexperience, difficulties associated with poor infrastructure (limited Internet access in rural areas), an uncomfortable environment at home, and the lack of support and mentoring for students during exams (Zhang *et al*., 2020). Therefore, it is essential to go beyond emergency online teaching practices and come up with new teaching methods that enable sufficient learning outcomes while following careful planning and cautious instructional designs (Hodges *et al*., 2020).

The flipped classroom (FC) approach is a course delivery education method that has recently gained popularity (Chiquito *et al*., 2020). In this method, the classical in-class and out-of-class activities exchange places. In general, the course lecture delivery is performed in terms of self-study materials, such as presentations and video lectures. Moreover, there can be some supplementary evaluation exams, *i.e.*, short online quizzes to track student discipline and to encourage lecture collaboration between instructors and students (Öncel *et al*., 2019).

Studies on the FC method have presented promising improvements in student performance when compared to traditional methods (Bishop *et al*., 2013; Kim *et al*., 2014; Mason *et al*., 2013; O'Flaherty *et al*., 2015; Öncel *et al*., 2019). In García-Ramírez (2019), the implementation and improvement of the FC model in a pavements course are evaluated using the students' final grades. Recently, a bibliometric review method was used to map the conceptual, intellectual, and social structure of research development regarding flipped learning (Al Mamun, 2021). In addition, a pedagogical FC model with an online learning management platform was proposed as an alternative for virtual teaching (Vilchez-Sandoval *et al*., 2021).

The pandemic era has shown that even well-practiced education methods – including FC – have been mostly unsuccessful under current conditions. Considering the difficulties that may arise in the education process, improving new alternative approaches is an important issue. During the pandemic, most schools switched to remote education. However, it has become a great necessity to develop novel approaches that both minimize any problems encountered with regard to remote education and comply with the health measures in effect. Developing a system where students partially attend face-to-face classes while some technology-enhanced educational methods are implemented may provide solutions to the problems that arose during these times. A hybrid education system, where pandemic cautions are implemented even though students are partially allowed to continue face-to-face education, has not been studied in the literature. Enhancing this hybrid method with improved learning approaches such as FC can pave the way for effective learning under such challenging conditions. It is also critical to measure the success of said method, as well as the perception of students.

This study presents an efficient and comprehensive education method of teaching Probability and Random Processes (PRP) based on the flipped or inverted classroom technique and technology-enhanced learning (TEL), combined with a hybrid (online and in-class) method to address the challenges of the pandemic. The proposed hybrid-FC approach aims to ensure effective learning in the pandemic era, during which most schools have switched to remote education in order to maintain the rigid health measures implemented by the authorities.

This study aimed to increase student performance and minimize the negative effects of remote learning with the improved hybrid-FC education model in a basic engineering course. Extensive measurements were conducted to demonstrate that the proposed method is quite practical and efficient, and it can be implemented as an improved version of the FC approach, not only in the pandemic era, but also in the face of other conditions such as overpopulated classes or schools.

Probability and random processes (PRP) was selected in this work because it is one of the most important courses; it is a must in the commonly overpopulated sophomore classes of the undergraduate curricula of Electrical (EE), Electrical and Electronics (EEE), Electrical and Computer (ECE), and Computer Engineering (CE) departments. This course serves as a foundation for a variety of subjects, specifically signal analysis, signal processing in communication applications, and biomedical and control systems in EEE. The topics of the course are considered to be an integral part of engineering curricula by most engineering accreditation organizations, as is the case of the ABET (Accreditation Board of Engineering and Technology). On the other hand, most students tend to find this course difficult to understand; they sometimes fail to develop an interest in pursuing careers in these areas of EE, as well as in other similar disciplines.

In light of the above, a practical system was first developed in which students could alternately attend face-to-face classes. In this study, two groups attended classes biweekly. This, in order to allow them to continue their formal education and keep the social aspects of campus life active to a certain extent. Then, the FC approach, which has been verified in previous research, was combined with the proposed diluted or de-populated classes methodology to improve the students' learning process. To evaluate the effectiveness of the model, qualitative (interviews), and quantitative (questionnaires, quizzes, and exams) assessment methods were employed. Unlike many studies in the literature, along with the students' perspectives, their achievements in the course were taken into account.

Course activities framed within the FC approach were created in two sections, *i.e.*, before and during the lesson hour. Before the class, the students studied the course materials, which included lecture notes, recorded course videos, and supplementary videos as out-of-class activities. In addition, the students' knowledge was evaluated via online quizzes (pre-tests). The lesson hour was divided into three sections: a discussion with the instructor, problem-solving accompanied by the instructor, and individual quizzes (post-tests). The proposed hybrid-FC approach was implemented with the alternated participation of two student groups. Thus, half of the class attended in-class activities, while the others took online lessons. This, as a measure against crowded classes in the context of a pandemic. Both online and in-class students attended the class sessions at the same time. Additionally, the lessons were video-recorded and were made available to those who had missed the classes or for later study. The students' perception of the hybrid-FC education method was assessed in detail. To this effect, questionnaires and face-to-face interviews were applied several times during the semester. Furthermore, the students' performance was also evaluated using their quizzes and exam results, which were calculated based on the Course Learning Outcomes (CLOs) and their regular participation. The effectiveness of the hybrid-FC approach was also evaluated according to these results.

Related literature

During the first two years of their undergraduate engineering studies, students are usually taught to deal with deterministic problems in the form of mathematics and physics courses. This causes many students to have difficulties in the PRP course, as they tend not to have a good probabilistic intuition (Sheikh, 2019).

From class observations, it was reported by Erjongmanee (2019) that students tend to perform poorly in this course due to a lack of reflection on mathematical concepts and their applications. Thus, the traditional technique used in teaching probability has been replaced by alternative approaches. Another technique used by Erjongmanee (2019) is to enhance application skills when dealing with probability concepts. In this method, students are further engaged in class activities by doing exercises.

The study by Nascimento *et al*. (2016) aimed at evaluating students' performance in written exams in order to identify their difficulties when dealing with probability courses. The authors suggested that adopting a double-blind peer review process can enhance the students' understanding of the topics.

The textbooks and examples used in teaching probability to EEE/ECE undergraduates were characterized and assessed in Nagy *et al*. (2008). The results show that there is a conflict between the preferences of students and those of the instructor. However, there were some examples that were appreciated by both.

Modern visualization and simulation tools such as Mathematica and MATLAB offer an interactive way to develop probabilistic intuition. Sheikh (2019) presented an approach to teach PRP to EEE/ECE juniors, which was based on using MATLAB simulations to emphasize real-world problems from areas related to signal processing and communications. Similarly, Mezhennaya *et al*. (2018) studied the influence of using computer algebra systems (CAS), along with supplementary educational materials such as computer modeling patterns and complementary tasks created in Mathematica.

A different method for teaching probability to graduate students in engineering departments was proposed by Richards *et al*. (2012). The delivery method for this graduate course switched from real-time education methods to a fully asynchronous approach. In their study, the authors explored the impact of this new method on students' perceptions and learning outcomes.

Method

The authors of this paper have been studying the concepts of *flipped classroom* (FC), *collaborative learning*, and *remote laboratories* in engineering education for more than

ten years. When the pandemic started, this study started with the following research questions based on previous experiences:

- Can we develop a hybrid educational method, encompassing flipped classrooms (FC) and diluted or depopulated classes in order to improve learning processes in pandemic era?
- Can we measure the effectiveness of this method and its applicability to meet the requirements of different contexts such as overpopulated classes and schools in engineering education both during and after the pandemic era?

This section describes the improved hybrid-FC structure of the PRP course. With the concept of *FC*, the differences in the perspective of the students towards this course and the change in their success rates are measured.

Course structure

In this section, previous developments regarding the traditional FC structure and the proposed hybrid-FC approach are presented. PRP is an obligatory undergraduate course in the EEE curriculum. It is a one-term course for second-grade students. The course consists of three hours of theoretical teaching per week. A total of 90 students take the course every semester.

A traditional FC educational method similar to that of Öncel *et al*. (2019) has been used in PRP courses in Atilim University for several years. However, innovations are added in this study, and course activities are carried out in a hybrid fashion with diluted classes and employing TEL. A hybrid education procedure means that in-class course activities are divided into smaller sessions (in terms of a number of students), and sessions are carried out face-to-face on campus, as well as online using real-time educational software. This proposed hybrid-FC educational method can be regarded as a solution to the spread of the pandemic and its effect on continuing face-to-face teaching activities.

Hybrid-flipped classroom

The FC activities were divided into two categories: before and during the lesson hour each week. Before class, the students had to complete pre-class activities by accessing the online course materials. After studying the materials, the students were expected to fill in the *Ask Questions to the Instructor* online form. This form guides the instructor on which points to focus on during the discussion hour. Furthermore, in this way, students attend the lectures well prepared. The online pre-test was carried out with the aim of following up on student's participation and encouraging them to take interest in the lesson. During the lesson hour, a discussion was first held using a hybrid system. The questions previously posted on the *Ask Questions to the Instructor* form were discussed, as well as some additional ones. Thus, discussion provided students with the opportunity to easily ask questions seeking to better understand the topic. Additionally, students gained practice with the problem-solving hours, consolidating the knowledge they acquired from theory. Finally, the post-test activity evaluated how well the students had learned the topic. Post-tests were also carried out in a hybrid fashion. The hybrid-FC method was implemented with an odd number of students online and an even number in-class for one week, which was alternated on a weekly basis. In addition to all of these activities, a midterm and a final exam were held face-to-face on campus.

The hybrid-FC activities conducted in the studied year were different to those of previous years (*i.e.*, the traditional FC structure) in order to add innovation and overcome the shortcomings of fully online learning methods. These differences can be listed as follows:

- Instead of using well-known online lecture videos from other institutions, course videos created by the instructors and based on the students' needs and feedback from previous years were used.
- Supplementary videos elaborated by other instructors were presented to provide students with a better understanding and to teach the topics more comprehensively.
- Problem-solving hours were implemented to fill the gap between theory and practice, which was one of the main difficulties that students had in previous years.
- Discussion hours and post-tests were carried out in a hybrid fashion with diluted classes (online and in-class).
- Individual-specific quizzes (post-tests) were included in the hybrid-FC structure in order to evaluate the performance of the students both face-to-face and online on a weekly basis.
- The proposed method used TEL more effectively when compared to classical FC implementations.
- Online course platforms and digital course materials were provided to be used in hybrid-FC education. The online parts of the discussion and problem-solving hours were conducted via Zoom. Live online and recorded video lessons, supplementary videos, lecture notes, additional course materials, the *Ask Questions to the Instructor* form, and the online part of the pre-tests/post-tests were made available on the Moodle platform. Through Moodle, students could access all the materials they needed. Interaction between the students and the online course platforms used is another key parameter of the learning process. The contribution of these digital platforms to learning was also thoroughly considered in the effectiveness measurements.

Although FC activities were conducted weekly, questionnaires and interviews were periodically applied with the aim get feedback from the students.

Assessment methods

Assessment methods based on both student perception and performance were essential for improving the course and

measuring the effectiveness of the hybrid-FC model. This study employed qualitative (interviews) and quantitative (anonymous class and university-wide questionnaires, as well as the evaluation of both quizzes/exams and CLOs) assessment methods. While quantitative assessment provides the opportunity to analyze numerical data, interviews can be interpreted using qualitative assessment. The implemented university-wide questionnaires and CLOs were also compared against the previous year in order to analyze the students' performance.

Face-to-face interviews containing open-ended questions were held twice, in the middle and at the end of the semester. A total of 40 students were selected, considering different Cumulative Grade Point Averages (CGPA), skill levels, and lesson participation. Attention was paid to the fact that 30 of the students attended both interviews, whereas 10 were randomly selected. Thus, a variety of student perspectives was considered. The questions covered a wide range of aspects regarding the course, such as students' opinions about the workload, the content of the course, the adequacy of the course materials, the comprehensibility of the topics, and the contribution of the course method to the learning process.

Questionnaires: To obtain the students' opinions about the hybrid-FC structure, two different questionnaire types were designed: anonymous class and university-wide questionnaires. The questions employed a 5-point Likert scale and were open-ended. Anonymous class questionnaires were applied twice in the middle and at the end of the semester. The common questions of the two questionnaires were elaborated based on the content, quality, and contribution to the learning process of the proposed hybrid-FC course activities. These course activities include course videos, supplementary videos, discussion hours, problem-solving hours, pre-tests/post-tests. In addition to the common ones, specific questions were included in both questionnaires with the aim to evaluate the students' perspectives on a variety of aspects. In the first questionnaire, information about the students and their workload, background, opinions about the course, and future projects were requested. The second questionnaire included questions aimed at evaluating the course and the students' knowledge levels. These questions are shown in Table 1. Additionally, the university-wide questionnaire was implemented online and anonymously in order for the students to evaluate the instructor and the course at the end of the semester.

Quizzes and exams: While weekly pre/post-tests were conducted to track the students' progress in each topic, midterm and final exams were carried out to measure the overall student success. Pre-tests were performed before the lesson hour with the aim to encourage the participants to study the topic with the provided lecture notes, video lessons, and supplementary videos. These tests included 10 multiple-choice questions about basic concepts. Post-tests were performed to evaluate the knowledge acquired by the students during the lesson hours. These tests included one or two open-ended questions.

The midterm and final exams (*i.e.*, the main exams) were conducted face-to-face while complying with the pandemic sanitary measures. The success of the students and the effectiveness of the hybrid-FC education method were evaluated by calculating CLOs with the results obtained from the pre-test/post-tests and the exams at the end of the semester.

Table 1. Anonymous in-class questionnaires

	1st questionnaire	**2nd questionnaire**
Different questions	Position goal and sectoral preference after graduation	How useful did you find course activities? (1: Useless, 5: Useful)
	Any previous work or experience on PRP before taking the course?	Have you spent enough time to learn the topics? (1: Could not spend enough time, 5: Absolutely spent enough time)
	Hours to be spent weekly on this course	Evaluate the difficulty of the subjects in the course (1: Easy to learn, 5: Difficult to learn)
	Expectations from the course	Do you think you have acquired enough knowledge in the course? (1: Certainly did not learn, 5: Absolutely learned)
	CGPA and gender	N/A
Common questions	Content of activity* Quality of activity * Contribution of activity* to your learning process. How many activities** of PRP course did you attend? Any other suggestions? Comment briefly.	

*Activity: Course videos, supplementary videos, discussion hours, problem-solving hours, pre-tests/post-tests.
**Activities: Discussion hours, problem-solving hours, pre-tests/post-tests.
Source: Authors

Course Learning Outcomes (*CLOs*)*:* CLOs determine what abilities the students will have when they have successfully completed a course. CLOs are defined under the MUDEK accreditation in effect in the EEE Department (national accreditation organization endorsed by ABET). The goal is to provide the same standards every year, matching the exam questions with the CLOs. The success level of the students in the course is defined in terms of the CLOs. This provides the opportunity to compare the students' success levels interannually.

Results and discussion

This section presents the results of the quantitative/qualitative assessments conducted to measure the effectiveness of the hybrid-FC education method. The students' perspectives

and performance were analyzed and compared to those of previous years. The results of the questionnaires were analyzed via a t-test. The students' success levels were evaluated in terms of the CLOs.

Interviews

Some students stated that they spent more than six hours a week, so the workload was heavy. On the other hand, some students stated that, even though they spent a lot of time per week on this course, this workload was normal, considering that there was no need to study heavily before the main exams. Moreover, they found the online course platforms used in the lectures to be user-friendly, easy to access, and supportive in their learning. They added that, when these course materials are adequately studied, there is no need to attend the discussion hour. Some other answers to the questions are discussed below:

- Since the hybrid-FC education method is new, the students underwent an adaptation process. However, they stated that this adaptation required a shorter time than other courses that are completely online.
- It was stated that the example questions given in the course videos had a great effect on learning.
- Most of the students stated that, even though they attended the course face-to-face, the recorded course videos made a great contribution to their understanding of the topics they missed.
- While some students reinforced their knowledge with these videos, others found them more complex and difficult.
- The students declared that, if they attended the discussion hour without having studied the course materials, this activity was inefficient.
- The students stated that the problem-solving hours were the most effective activity with regard to understanding the topics, and they suggested solving more problems. This was found to be more efficient since it took place before the post-test.
- The students believe that the pre-tests/post-tests are useful for weekly work, but the number of quizzes is high. They noted similarities in the difficulty of the online and in-class quizzes.

Improvements were made to the videos, as there were comments regarding poor sound quality. The post-test durations were adjusted. The students emphasized that the hybrid-FC activities were carried out in the best way during the pandemic. Most of them stated that they had no difficulty in following the lectures; they did not experience any negative effects associated with reduced direct contact and procrastination, which are the common deficiencies of a fully online education.

Questionnaires

A total of two anonymous in-class questionnaires were carried out during the semester. In the first questionnaire, general information about the students was asked in the form of open-ended questions, and questions about course activities using 5-point Likert scales were included. Accordingly, 38% of students had a CGPA above 3, 36% of them had between 2,5 and 3, 24% scored between 2 and 2,5, and the remainder had less than 2 out of 4. 24% of students spent 1-2 hours per week, 55% of them spent 2-4 hours, and 21% spent more than 4 hours per week in this course. 91% of the students answered "No" and 9% of them answered "Yes" to the question "Have you had any previous work or experience on PRP before taking the course?"

Some questions were common to both questionnaires, with the aim to detect any changes in the students' opinions. The mean and standard deviation (SD) results are given in Table 2.

Table 2. Analysis of the common questions in the questionnaires

#	ITEM ASKED		1st		2nd	
			Mean	SD	Mean	SD
1	Course videos	Content	3,37	1,04	3,71	0,91
		Quality	3,47	1,04	3,82	1,00
		Contribution	3,28	1,12	3,49	1,09
2	Supplementary videos	Content	3,25	1,15	3,42	1,05
		Quality	3,22	1,20	3,53	1,00
		Contribution	3,14	1,25	3,16	1,23
3	Discussion hours	Content	3,57	1,08	3,65	0,89
		Quality	3,65	1,13	3,95	0,85
		Contribution	3,44	1,01	3,52	1,14
4	Problem-solving hours	Content	4,04	1,08	4,27	0,95
		Quality	3,60	1,19	4,16	0,90
		Contribution	4,02	1,14	4,25	0,90
5	Pre-tests	Content	3,44	0,91	3,76	0,94
		Contribution	3,74	1,16	3,91	1,01
6	Post-tests	Content	3,51	1,10	3,62	1,10
		Contribution	3,60	1,23	4,00	0,91

Source: Authors

The results show a moderately positive perception of the pro-posed method. The overall mean score of the activities increased from 3,56 to 3,73. At the end of the semester, some additional questions were asked in the second questionnaire, aiming to further understand the students' opinions. The results of four questions (81 students) answered with a 5-point Likert scale are shown in Figure 1. For example, the question "How useful did you find course activities?" was rated with 1 by four students, with 3 by 28 students, and with 5 by 12 students.

Students evaluated whether they had acquired enough knowledge at the end of the semester, with a 3,17 mean score. Since 37% of the answers have 4-5 points, the results can be considered positive. The students graded the difficulty

of the course with a mean score of 3,78. This course seems to be quite difficult for students, which is why alternative approaches such as FC have emerged.

FC activities minimize the difficulty of this course, in light of the fact that the students rated their knowledge level with a high score. The students spent enough time on this course (3,4 mean score), and they found its activities useful (3,3 mean score). Since 45% of the students rated this question with 4-5 points, this research finds hybrid-FC activities to contribute positively to the learning process.

The results were analyzed with a t-test to determine the difference between several questionnaires. The degree of coincidence in the results is determined by the p-value. If the p-values are less than 0,1, the results are reliable (Lakens, 2017). As an example, p-values were calculated as 0,08 for "Content", 0,001 for "Quality", and 0,09 for "Contribution to the learning process" regarding the "Problem-solving hours". Therefore, the answers given to these questions were reliable. Similarly, the p-value of the "Contribution to the learning process" for "Post-tests" was calculated as 0,02. The fact that the two most important activities have high mean values was statistically proven by the t-test, as well as the reliability of the results, which constitutes a significant result.

The university-wide questionnaire is applied every year to students of all courses and faculties. In this type of questionnaire, the instructor and the course are evaluated by the students. Table 3 shows the results (mean score between 1 and 5) obtained for the previous (59 students) and the studied years (69 students).

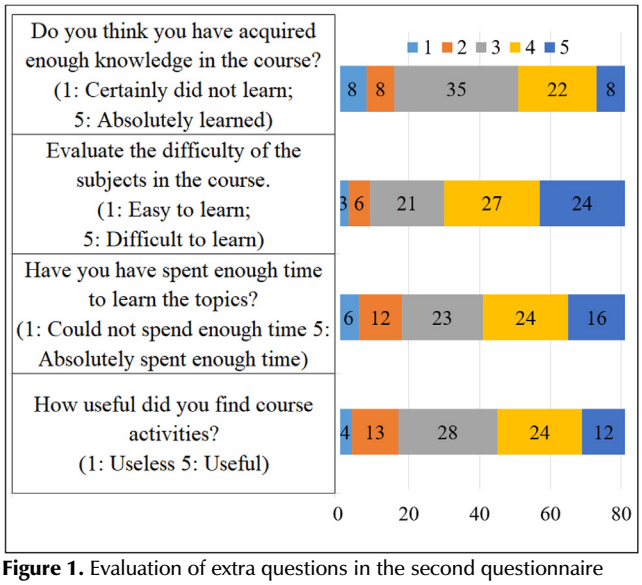

Figure 1. Evaluation of extra questions in the second questionnaire
Source: Authors

Quizzes

Seven topics were covered, with course activities for one. Pre-tests/post-tests were used to evaluate students before and after the lesson hour. In the pre-tests, more than 70% of the students scored over 80/100. In three subjects, 80% of the students achieved this level of success. The average grade in the post-tests of five topics was about 70, and it was about 50 points in two topics. These differences led to differences in the CLO results.

Table 3. University-wide questionnaire results

Assessments	Previous Year	Current Year
The course activities contributed to the learning process.	3,38	4,07
The course gave me knowledge, skills, and abilities	3,23	3,90
The course activities met the demands of the students.	3,11	3,77
Satisfied with the course activities	3,25	4,03

Source: Authors

Course Learning Outcomes (CLOs)

Quiz and exam questions were matched with the CLOs, and their success scores were calculated by the instructor in order to determine the students' performance. With these results, the improved hybrid-FC method used in the studied year was compared against the FC education approach employed in the previous year. The results are shown in Table 4.

It was observed that the success of the students increased in comparison with that of the previous year. The highest increase was reported for CLO-5, which increased from 2,4 to 3,4. Only the CLO-2 result slightly decreased. It can be interpreted that this decline occurred because the topics covered by CLO-2 were taught at the beginning of the semester, while the students were adapting to the inverted classroom activities. Generally speaking, the positive effect of the hybrid-FC education method is confirmed by these results.

Table 4. Course learning outcomes

#	Outcome	Previous Year	Current Year
1	Describe the fundamental concepts of the theory of probability, including conditional probability, random variables, probability distributions, and expectation.	2,4	2,6
2	Identify the probability mass function, the probability distribution function, the cumulative distribution function, expected value, variance, and standard deviation.	2,6	2,4
3	Perform a wide variety of probability calculations and derivations.	2,2	2,4
4	Solve practical problems consisting of genuine data through probabilistic reasoning.	2,3	3,0
5	Identify random processes and their characterization, the autocorrelation function, and the cross-correlation function.	2,4	3,4
6	Discuss the results of statistical analyses through graphical and verbal means.	2,5	3,3

Source: Authors

For the sake of comparison, in Rodríguez-Paz *et al*. (2021), the flipped classroom approach was applied to both online and face-to-face education during an engineering course. Instead of diluted classes, according to the spread of the pandemic, lessons were taken fully online or fully face-to-face. In our study, online and in-class sessions were held in parallel, with two student groups alternately participating in the sessions on a weekly basis. This helps students to adapt to changing conditions while keeping social life active, giving them the opportunity to interact with classmates, which reduces the negative effects of online learning, as well as pandemic stress. In the study by Rodríguez-Paz *et al*. (2021), a survey was applied to the students in order to measure the effectiveness of the proposed method. It was reported that 42,90% of the students agreed that they would not prefer to take online courses. When the students were asked to examine their own performances, 46,90% did not find any difference between online or in-class learning. 39,30% of the students said that their marks got better, which is consistent with our questionnaire results (Table 3). In our study, the effectiveness of the proposed educational method was measured using not only surveys, but also additional comprehensive quantitative and qualitative techniques in order to obtain more reliable results.

For further comparison, another study (Öncel *et al*., 2019) presented an FC approach for Communication Systems, which is also a core course in the EE curriculum. The efficiency of the proposed method was also measured through both qualitative and quantitative methods. Along with the interviews and surveys, CLO scores showed that flipped learning (FC) is more efficient than traditional learning methods. In this study, as complementary research, further improvements are presented in order for the FC approach to meet the requirements of effective learning under challenging conditions such as a pandemic. Our method can be applied in overpopulated engineering classes or schools, especially in developing countries.

Conclusions

This study presents an improved hybrid-FC education method and measures its effectiveness in a PRP course held during the pandemic at the EEE department of Atilim University. Therefore, based on extensive measurements, it aims to demonstrate that the proposed method is quite effective and may work under various conditions, including populated classes and schools and the pandemic era. Students' perspectives and performance were evaluated with quantitative/qualitative measurement methods according to the feedback received. The answers given to the questions in the interviews were interpreted, the results of the two questionnaire types were statistically analyzed (t-test), and students' achievement levels were evaluated in terms of the course learning outcomes, which were calculated based on the quiz and exam results. By comparing the results with those of the previous year, a significant increase was observed. Based on the obtained results, the proposed education model can be adapted to most classes in engineering, with the aim to improve learning processes under challenging conditions. The proposed method also improves the students' performance while minimizing the negative effects of remote education, even if rigid health measures are taken. To the authors' knowledge, this is the first applicable method of its kind in engineering education.

As a conclusion, the improved hybrid-FC education method based on TEL with diluted classes benefits students' perspectives and performance in PRP, which students generally define as a difficult course. The proposed method was introduced during pandemic days, when alternative educational methods became necessary. Thus, several negative effects of remote learning were eliminated while complying with all procedures aimed at mitigating the spread of the pandemic. Even though the proposed method and its effectiveness are confirmed for the PRP course in this paper, its structure can be adapted to other courses and engineering disciplines. Our approach could provide solutions to the negative effects of fully online learning while preserving its educational and systematic benefits. This study may guide researchers and instructors to follow such an approach for a variety of courses during pandemic times, as well as after lockdowns. However, it should be noted that the proposed hybrid-FC method cannot replace the classical, fully face-to-face teaching models. Nevertheless, the results show that it is applicable to major engineering courses in case of a pandemic or in overpopulated classes or schools, which is very common in developing countries.

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