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PAPER

Changing Mathematical Paradigms at the University Level: Feedback from a Flipped Classroom at a Peruvian University

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ABSTRACT

The university-level mathematics teaching adopted by many professors is still a traditional classroom, and many students' perception of mathematics is that it is a complicated subject. The operationality of the flipped classroom proposal implemented at a university has a potential that can be used to change the perception that university students and teachers have towards the mathematics course, as well as to change the methodology of many teachers on how they teach their courses in the classroom. This research is the result of the implementation of the flipped classroom methodology in the basic mathematics course that is part of the professional careers of the engineering faculty of a Peruvian university. The aim of this study was to analyze the impact of applying the flipped classroom on academic results and attitudes towards mathematics, with an experimental group of 227 students and a control group of 215 students. The academic results were measured at each of the stages indicated in the course syllabus, T1, partial exam, T2 and final exam; attitudes towards mathematics were also assessed at cognitive, procedural and affective levels at the end of the university semester. The Kolmogorov-Smirnov normality test was applied and yielded a value of $p = 0.00$, indicating that the grades obtained by the students did not follow a normal distribution. With the data obtained, the Mann-Whitney U test was performed, obtaining a $p = 0.00$ value ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ makes us conclude that there are statistically significant differences between the scores of the experimental group compared to the control group. The results show a significant improvement in the academic performance and positive attitudes of students who took the course using the flipped classroom compared to those who did not use this methodology.

KEYWORDS

academic performance, flipped classroom, students' attitudes, university level

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1 INTRODUCTION

Understanding mathematics is a challenge for many university students, as mathematics often involves abstract concepts that can be difficult to visualize or relate to real-world situations [1]. For this reason, many university students perceive the mathematics course as a difficult subject, with difficulties often attributed to a lack of preparation, practice and knowledge that would give the student the ability to solve a mathematical problem [2]. This ability should not only focus on the ability to solve a problem as a tool to practice procedures [3] but should become the means to connect mathematical work to everyday life by contextualizing the content through real problems that arise in everyday academic and professional situations [4]. This perception is reflected in poor academic results among students [5], as well as a lack of interest and motivation for mathematics among university students [6].

Many teachers feel that the use of technology in the classroom is detrimental to students' assimilation of knowledge and skills [7]. So, the mathematics teaching adopted by many teachers remains traditional [8], offering little chance for students to acquire the ability to solve real mathematical problems. This approach does not meet students' individual learning needs, leading to a lack of interest in mathematics [9], and even more so when many students had to adapt to an online learning environment due to COVID 19, which presented additional challenges for learning mathematics [10].

Advances in information and communication technologies are making it possible to promote new forms of teaching in university classrooms, opening up spaces for the democratization of knowledge [11]. Several methodologies used at university level encourage a shift from traditional to more participatory teaching, involving students in the construction of their own knowledge and generating positive impacts on their academic performance and attitudes [12]. One of the methodologies with the greatest impact on the teaching and learning process is the flipped classroom, which has an advantage over other active methodologies in terms of improving academic performance and attitudes to mathematics; this method also presents the challenge of involving more asynchronous student participation in different activities [13, 14].

The flipped classroom is a pedagogical model [15] in which the student accesses knowledge autonomously outside the classroom, practicing and questioning content in different ways, with this entire sequence of activities carefully prepared by the teacher [16]. It moves the activities that traditionally took place in the classroom to the physical space where the student is located, enabling the teacher to interact more actively with students and identify their cognitive and procedural needs when solving a mathematical problem [17]. Implementation of the flipped classroom in university teaching has increased in recent years, showing significant progress at procedural, attitudinal and cognitive levels in students who have developed the method [18]. However, there is little research showing macro-level implementation of the flipped classroom across an entire university semester in the Faculty of Engineering's Professional Studies program [19].

The most recent research on the flipped classroom shows that it has been used in several disciplines with encouraging results, becoming a determining factor in the success of student learning, as students work actively and collaboratively, being the builders of their own knowledge, enabling the teacher to guide the process effectively [20, 21]. COVID 19 had a significant impact on the perception and adoption of the flipped classroom model, as all educational institutions had to adapt to the distance model during the pandemic [22]. Among the favorable perceptions identified here are greater acceptance of online learning as it promotes autonomous learning with anytime access to educational resources [23], flexible schedules, greater virtual interaction and accelerated adoption of technological tools [24]. This has motivated the accelerated transformation of teaching practices in universities to motivate, engage and promote student success [25].

The aim of this research is to determine the impact of the application of the flipped classroom on the academic results and attitudes at the cognitive, procedural and affective levels of students enrolled in the basic mathematics course in the different careers of the engineering faculty of a Peruvian university.

The remainder of this document is organized as follows. Section 2 presents an in-depth review of the literature relevant to the questions raised. Section 3 details the materials and methods used. The main results are presented in Section 4 and discussed in Section 5. Finally, Section 6 presents the main conclusions of the study, as well as research perspectives.

2 RELATED WORK

Focusing on the effectiveness and impact of the flipped classroom model, we highlight some of the most recent work on the following topics. The authors of [26] conducted a study on the influence of the flipped classroom in the scientific training of pre-service teachers, in which they highlight that the systematization of the flipped classroom significantly influences academic performance, attitudes and positive evaluation perspectives in their university training as teachers.

Similarly, [27] analyzed the influence of the flipped biochemistry classroom on students' academic performance and perceptions of self-awareness, obtaining the result that students who participated in the flipped classroom model achieved better academic performance ($p < 0.01$) and reported a significant improvement in their perceptions of self-awareness ($p < 0.01$) compared to the control group.

The authors of [28] demonstrated that the main factor influencing educational outcomes was self-efficacy, followed by gender, educational experience in the flipped classroom, satisfaction with learning, age, ability to analyze the flipped classroom and ability to analyze the flipped classroom.

Similarly, the authors of [29] conducted systematic reviews with the aim of evaluating the application and effectiveness of the flipped classroom in the training of nursing students. After reviewing 25 articles, they concluded that the model has three key elements: pre-class activities, in-class activities and post-class activities, which, when properly guided, generate positive learning in terms of skills, knowledge and attitudes in nursing students.

In [30], the authors conducted a meta-analysis on the application of the flipped classroom in mathematics courses. After reviewing 86 articles, they concluded that the application of the method improved mathematics learning in several aspects, such as academic achievement, active participation, motivation, interest and interaction between students and teachers.

3 MATERIALS AND METHODS

3.1 Research background

The research proposed in this article is part of the Fundamental Mathematics course, which is part of the Faculty of Engineering's pathways. The implementation of the flipped classroom methodology was developed over the 16 weeks corresponding to the entire two semesters of the 2021–2022 academic year. A whole team of specialist teachers designed the operational part of the flipped classroom methodology in the course in question, and the final proposal was implemented in 2022.

Figure 1 shows a diagram of the flipped classroom implemented in the basic mathematics course. Students first examine the course material in the virtual classroom, then take a knowledge test. Once they have completed these activities, they actively participate in the development of the course.

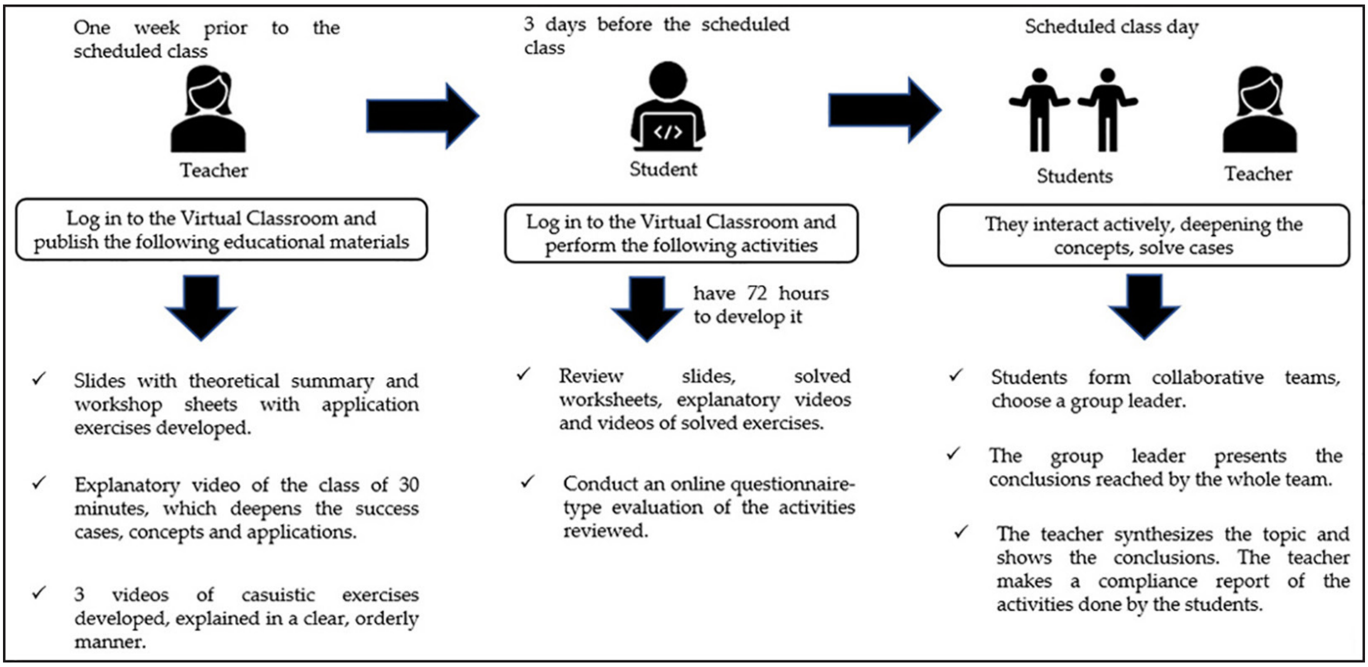

Fig. 1. Implementation of the flipped classroom

The basic mathematics course is divided into two units: linear algebra and limits. Students are required to take interim assessments in both semesters and a final assessment at the end of the second semester. Each student must have an average grade of 12 or above to pass the course. The Blackboard Collaborate platform was used to set up the virtual classroom where students can access asynchronous resources such as explanatory videos of the course, extended video exercises, slides with theoretical summaries of the material, and worksheets. There have been no updates to the career programs mentioned above; consequently, the themes developed are identical to those used during the two semesters of the 2020–2021 academic year. The same resources and materials were used in all sections during all sessions of the corresponding cycle. For research purposes, the 227 students enrolled in the two semesters of the 2020–2021 academic year constitute the control group. The 215 students enrolled in the two semesters of the 2021–2022 academic year constitute the experimental group.

Figure 2 shows a diagram of the academic resources designed and implemented in the virtual classroom of each of the classes where the flipped classroom was conducted. The resources were developed for the 16 weeks of the academic semester, the material (see Figure 2a) for each week consists of slides with theoretical summaries, worksheets of the exercises developed, an explanatory video of the class and videos of the exercises developed. Figure 2b shows the login message, the design of the learning session and the activities for testing learning using educational games.

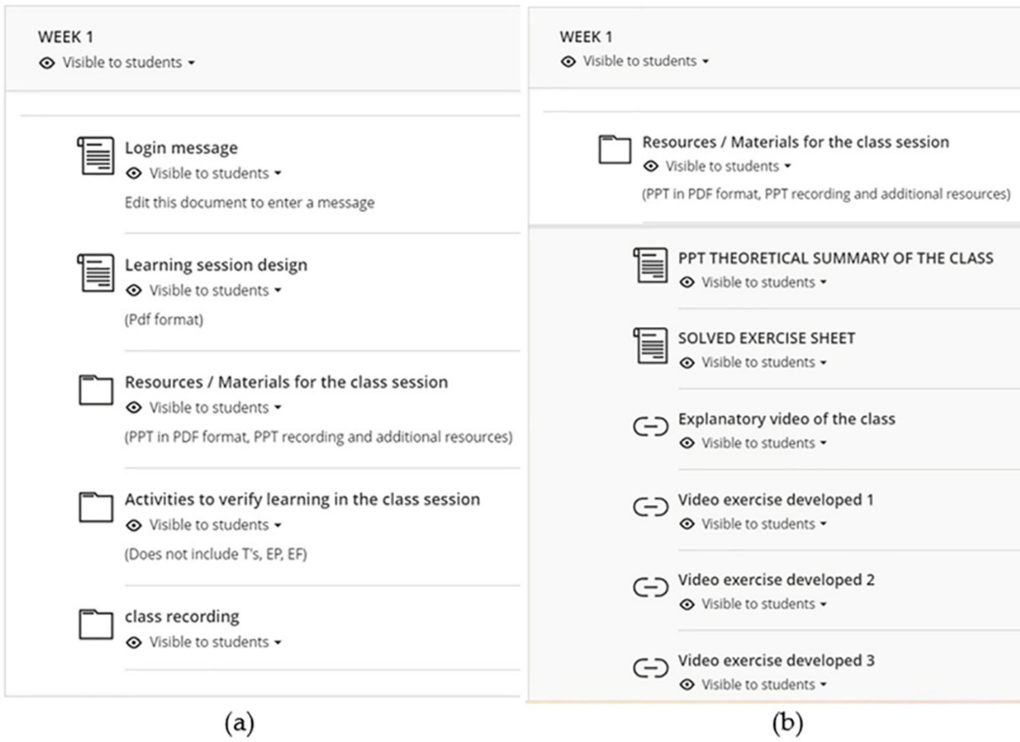

Fig. 2. Diagram of resources used: (a) Material for the session; (b) Resources sent in advance each week

Similarly, attitudes towards mathematics [31] were assessed at cognitive, procedural and attitudinal levels [32], in a questionnaire applied at the end of the academic semester. For each dimension, eight questions were asked, of which we can highlight some of the most frequent responses.

Figure 3 shows the diagram of the questionnaire on attitudes to mathematics at cognitive, procedural and affective levels. The questions with the most positive responses are shown below.

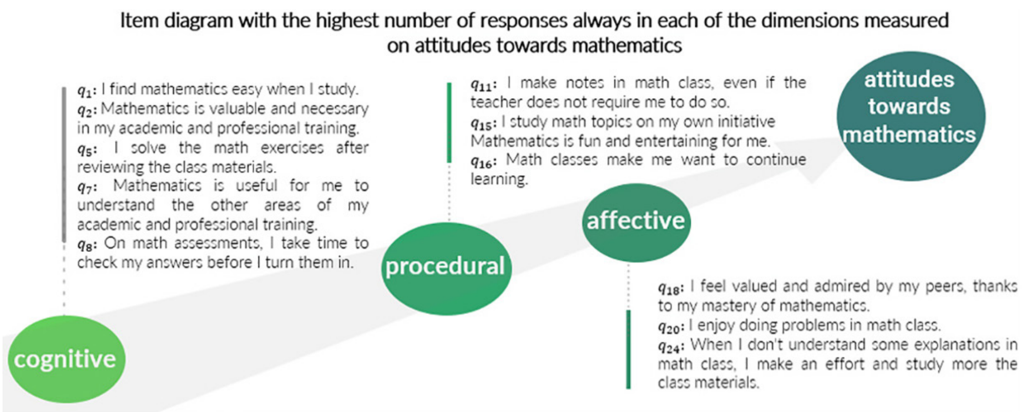

Fig. 3. Diagram of student attitude dimensions

3.2 Research design

This research was designed to be quasi-experimental [33]. The independent variable was the flipped classroom methodology, which framed the participants' asynchronous learning autonomy. The dependent variables were academic achievement and attitudes to mathematics.

To analyze the differences between students who used the flipped classroom methodology and those who did not, we compared the marks obtained in four assessments: two assessments graded T1 and T2, an intermediate exam and a final exam. These assessments were carried out during weeks 4, 8, 12 and 16, respectively, in accordance with the course syllabus that corresponds to the university's study plans. Similarly, at the end of the university semester, a Likert-scale questionnaire was conducted on students' cognitive, procedural and affective attitudes.

3.3 Data collection procedure

Measurement of academic results. The aim was to measure the impact of the flipped classroom on the academic results of students in the complementary mathematics course. Data were collected using the assessments defined above in accordance with the curricula for each course, for both the control (227 students) and experimental (215 students) groups. The results were analyzed using SPSS Statistics 26 [34].

Measuring student attitudes. The aim was to measure the impact of the flipped classroom on students' attitudes to mathematics. To this end, the research team developed and applied a questionnaire on attitudes to mathematics at cognitive, procedural and affective levels at the end of the academic semester in each of the groups. The questionnaire consists of 28 questions, the first four of which are framed by the demographic profile of all participants, and the remaining 24 questions were divided into three blocks of 8 questions each to assess cognitive, procedural and affective attitudes. Each question was measured using a 5-point Likert-type [35] rating scale, where 1 = Never; 2 = Almost Never; 3 = Sometimes; 4 = Almost Always; 5 = Always.

The internal consistency test using Cronbach's alpha for items in the cognitive dimension was 0.801, for items in the procedural dimension 0.878, for items in the affective dimension 0.927, similarly, for all items we have an alpha of 0.950. As all alpha values are above 0.7, this Cronbach's alpha test proves that the data collected in the questionnaire are internally consistent and reliable [36].

4 MAIN RESULTS

4.1 Impact of the flipped classroom on the academic results

Once data collection was complete, the Kolmogorov-Smirnov normality test was carried out on the entire data set and yielded a value of $p = 0.00$, indicating that the grades obtained by the students did not follow a normal distribution [37].

Figure 4 shows the quantile-quantile (Q-Q) plot for the entire data set with a Pearson linear coefficient of determination of 0.68 ($R^2 = 0.68$). The results show that the scores clustered around the solid line are scattered relative to each other, indicating that the data do not have a normal distribution.

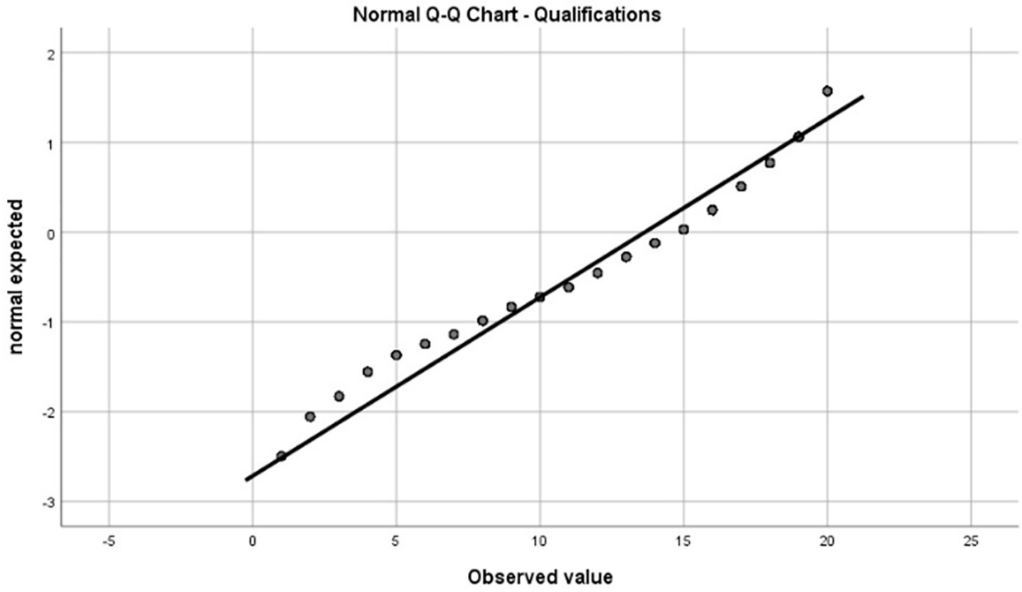

Fig. 4. Results of normality test (Q-Q plot) for the total data

As the data do not follow a normal distribution, a more practical non-parametric test was chosen to analyze the results. In this research, we used the Mann-Whitney *U* test [38], for which means, medians, standard deviations and variances were calculated for each of the T1, T2, partial and final assessments for both groups. To determine whether there was a significant difference between the two groups, a significance level of 0.05 or 95% reliability was established ($\alpha = 0{,}05_{2\ tails}$) with the aim of comparing the homogeneity of the data obtained.

Table 1 shows the results of the T1 evaluation. The control group obtained a mean of 14.61, a median of 16.00 and a standard deviation of 4.20. For this group, there were 19 missing data. The experimental group had a mean of 16.27, a median of 17.00 and a standard deviation of 3.85. For this group, there were 17 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining a value of $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced by the change in the weighting of positive attitudes towards the course, essentially in the procedural level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 1. Analysis of academic results following the T1 evaluation

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	208	19	14.61	16.00	4.20	17.64
Experimental	198	17	16.27	17.00	3.85	14.84

Table 2 shows the results of the partial evaluation. The control group obtained a mean of 13.88, a median of 16.00 and a standard deviation of 4.64. Similarly, the experimental group obtained a mean of 15.65, a median of 16.00 and a standard deviation of 4.09, with 22 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced in the evolution of the weighting of positive attitudes towards the course, fundamentally in the cognitive and procedural level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 2. Analysis of academic results following the partial evaluation

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	204	23	13.88	15.00	4.64	21.50
Experimental	193	22	15.65	16.00	4.09	16.75

Table 3 shows the results of the T2 evaluation. The control group obtained a mean of 11.51, a median of 12.00 and a standard deviation of 5.254, with 31 missing data. The experimental group obtained a mean of 12.63, a median of 14.00 and a standard deviation of 4.980, with 26 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced in the evolution of the weighting of positive attitudes towards the course, fundamentally in the cognitive and procedural level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 3. Analysis of academic results following the T2 evaluation

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	196	31	11.51	12.00	5.25	27.60
Experimental	189	26	12.63	14.00	4.98	24.80

Table 4 shows the results obtained in the final evaluation, with the control group obtaining a mean of 10.20, a median of 10.00 and a standard deviation of 5.519, with 26 missing data. Similarly, the experimental group obtained a mean of 13.94, a median of 16.00 and a standard deviation of 4.812, with 31 missing data. With the data obtained, the Mann-Whitney *U* test was performed, obtaining $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ leads us to conclude that there are statistically significant differences between the scores of the experimental group compared to the control group, after application of the independent variable. This is evidenced in the evolution of the weighting of positive attitudes towards the course, fundamentally in the cognitive and affective level of students enrolled in 2021–2022 compared to students who took the course in 2020–2021.

Table 4. Analysis of academic results following the final exam

Group	*N*		Mean	Median	Standard Deviation	Variance
	Valid	Lost				
Control	190	37	10.20	10.00	5.52	30.46
Experimental	184	31	13.94	16.00	4.81	23.15

4.2 Impact of the flipped classroom on student attitudes

Once the data collection was complete, the Kolmogorov-Smirnov normality test was carried out on the entire data set and yielded a value of $p = 0.00$, indicating that the grades obtained by the students did not follow a normal distribution [37].

Table 5 shows the percentage weights of the cognitive, procedural and affective dimensions of attitude for the control and experimental groups. For the cognitive dimension of attitude, there was a 7.86% decrease in the "Never" rating, a 21.15% decrease in the "Almost Never" rating and a 10.4% decrease in the "Sometimes" rating. Similarly, there was an 18.16% increase in the weighting of the "Almost Always" rating and a 21.35% increase in the "Always" rating. For the procedural attitude dimension, there was a decrease of 18.94% in the "Never" rating, 20.22% in the "Almost Never" rating and 1.89% in the "Sometimes" rating, as well as an increase of 21.00% in the "Almost Always" rating and 20.05% in the "Always" rating. For the affective attitude dimension, there was a decrease of 22.47% in the "Never" rating, 16.37% in the "Almost Never" rating, and an increase of 6.17% in the "Sometimes" rating, 17.66% in the "Almost Always" rating and 15.01% in the "Always" rating. It should be understood that the sustained increase in higher grades is due to the effect of implementing the flipped classroom in the basic mathematics course.

Table 5. Analysis of student attitudes by dimension

	Dimensions							
	Cognitive (%)		Procedural (%)		Affective (%)		Total (%)	
	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
Never	8.79	0.93	20.16	1.22	27.45	4.98	18.80	2.37
Almost Never	26.25	5.00	28.61	8.39	25.68	9.31	26.85	7.56
Sometimes	39.52	29.12	37.26	35.37	35.82	41.99	37.50	35.47
Almost Always	14.32	32.48	8.34	29.34	8.46	26.12	10.37	29.32
Always	11.12	32.48	5.63	25.68	2.59	17.60	6.48	25.28

Figure 5 shows the evolution of the weighting of cognitive, procedural and affective attitudes towards mathematics of all students belonging to the control and experimental groups, confirming the differences or weighting margins in the assessments given to the group that implemented the flipped classroom. The results show that most of the students who took the basic mathematics course using the flipped classroom methodology improved the development of their attitudes towards mathematics in the cognitive, procedural and affective domains.

Analyzing the data obtained at inferential level, the Kolmogorov-Smirnov normality test was performed for the total number of answers given by students in the attitude questionnaire, yielding a value of $p = 0.00$, indicating that the total number of evaluations made by students does not follow a normal distribution. Next, the Mann-Whitney U test was performed, obtaining a value of $p = 0.00$ ($\alpha = 0{,}05_{2\ tails}$). $p < \alpha$ makes us conclude that there is a statistically significant improvement in the evaluations of attitudes towards mathematics at the cognitive, procedural and affective levels of the students who performed the flipped classroom.

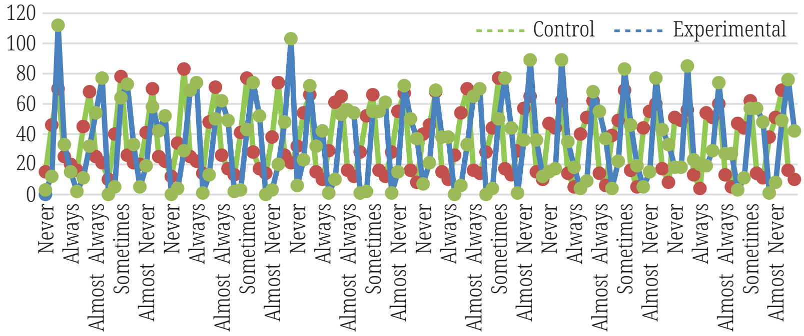

Fig. 5. Evolution of the weighting of cognitive, procedural and affective attitudes towards mathematics of all students belonging to the control and experimental groups

5 DISCUSSION

The aim of this study was to analyze the impact of the flipped classroom methodology on students' academic performance and attitudes in the basic mathematics course. This course is part of the professional careers of the engineering faculty of a Peruvian university. The academic results were measured at each of the stages indicated in the course syllabus, i.e. intermediate assessment T1, partial examination, intermediate assessment T2 and final examination. Similarly, attitudes towards mathematics were assessed at cognitive, procedural and affective levels by means of a questionnaire at the end of the academic semester.

The results of the study showed that implementing the flipped classroom in the basic mathematics course had a significant impact on improving students' academic performance. The results show a 2.07-point increase in the overall average grade of the group in which the flipped classroom was implemented, compared with the group that did not develop the methodology. These results are in line with those found in previous research on the application of the flipped classroom to improve students' academic performance in mathematics courses [39] in the same way [40].

The results also showed that the implementation of the flipped classroom had a positive impact on students' cognitive, procedural and affective attitudes towards mathematics. The results of the questionnaire conducted at the end of the semester showed that more students in the group that took the course with the flipped classroom methodology indicated that mathematics is useful and necessary for their professional academic training, they also mentioned that they study the course topics on their own initiative and that they enjoy learning in mathematics classes. In addition, after following the flipped classroom method, fewer students reported that mathematics was difficult. These results are consistent with those of previous studies on the application of the flipped classroom to improve students' attitudes to mathematics [41].

In conclusion, the students who took the basic mathematics course using the flipped classroom methodology achieved numerous benefits, not only improving their academic grades, but also strengthening their commitment to the development of the course and increasing their level of satisfaction at the end of the academic semester. Consequently, we can mention that the results obtained confirm the high potential of the flipped classroom methodology as a teaching and learning strategy, not only in mathematics courses, but also in other courses delivered as part of students' university education.

Among the limitations that emerged during the course of the research, we can mention that during the planning phase, we had little time to develop standardized material within the deadlines set by the university's teaching specialists, given that the teaching resources were used by all sections of the Faculty of Engineering. During implementation, as the flipped classroom largely requires the use of electronic equipment and access to the Internet, some students limited their participation because they did not have adequate access to these resources. It was also observed that many students are not able to manage their time for independent learning. Other limitations encountered are that even the way we assessed remained a traditional approach, which may not fully reflect the learning acquired through the flipped classroom.

6 CONCLUSIONS

The implementation of the flipped classroom elicited a positive response from the students and teachers who applied the methodology, as it enabled more participative interaction in the university classrooms, increased students' efficiency when solving the various problems in their assessments and also improved the attitudinal perception of the mathematics course. In conclusion, students who took the basic mathematics course using the flipped classroom methodology achieved numerous benefits, not only improving their academic grades, but also enhancing their engagement in the development of the course and increasing their level of satisfaction at the end of the university semester. Consequently, we can mention that the results obtained confirm the high potential of the flipped classroom methodology as a teaching and learning strategy, not only in mathematics courses, but also in other courses delivered as part of the academic training of university students.

Future work could firstly focus on updating the teaching materials used. Secondly, it might be interesting to replicate the procedural part of the flipped classroom, obtain results and find the correlation between academic performance and positive attitudes towards mathematics. Pearson's or Spearman's correlations could be used depending on the data obtained, and we could also apply this method not only to the Faculty of Engineering in later cycles, but also extend it to other specialties.

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