Impact of Project-Based Learning methodology on the academic performance of engineering students during the COVID-19 pandemic

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***Abstract*—During the pandemic period and the forced implementation of online education, an imminent need to renew teaching practices arose. Virtuality called into question the methodologies used and the learning assessment systems, since it was not sufficient to transfer the face-to-face class to a remote synchronous system. Aware of this limitation, a proposal for the renovation of mathematics subjects for the engineering degree focused on active and student-centered learning arose. For the purpose of the analysis, we collected data from 2020 to 2021, considering different groups of students who have taken the Integral Calculus subject. The results indicate that there is a slight positive effect on students with previous experience with the Project Based Learning methodology over those who did not use it previously. These findings reveal that this methodology is accessible to the students. We observed that performance on individual standardized tests was equivalent or slightly lower in the experimental group with the PBL methodology in the first subject. However, this process was reversed over a more advanced course. Even though individual written evaluations do not allow us to determine and quantify skills related to project-based learning methodology, such as responsibility, self-regulation, and critical thinking, the effects of applying an active student-centered methodology have positive long-term effects that can be transferred from one subject to another..**

***Index Terms*—Project Base Learning, innovation, mathematics, education, engineering**

I. Introduction

In the face of a catastrophic event such as the COVID-19 pandemic, the educator assumes a paramount role as a mediator in facilitating the interface between technology and student engagement. Although technology makes it possible to overcome distance barriers and improve connectivity in communication, a fundamental point is related to students' mental health. According to Karlalainen [1], "Educators have a critical role to play in building the skills to cope, shape and live in an uncertain futur".

The ramifications of the global COVID-19 pandemic on the sphere of global education have given rise to a significant diminution in student academic accomplishments, particularly evident in domains such as mathematics and reading comprehension, as attested by Konig [2], [3]. Empirical evidence distinctly signifies that the demographic segment most profoundly impacted encompasses students in their early scholastic years, a contrast observed when juxtaposed with their elder counterparts, as corroborated by Hammerstein [4] and Tomasik [5]. Other results indicate that economic status negatively affects the most disadvantaged compared to higher-income socioeconomic groups [6]. Certain fields of education, such as music and medicine, have encountered pronounced detriments during the transition to remote learning modalities. This can be attributed primarily to the inherent inadequacy of verbal communication as well as the absence of physical interaction between educators and learners, posing significant challenges in the transfer of intricate technical proficiencies [7], [8].

At the university level, some researchers have revealed that those students who attended at least one year before the onset of the pandemic performed better than those who started online [9]. Aspects such as fatigue, exhaustion, eye problems, and physical exhaustion have been highlighted as some of the difficulties that students face in carrying out their subjects [10], [11]. Despite the progressive enhancement of global online connectivity and communication capacities, several studies have indicated that the dearth of in-person social interactions has engendered sentiments of isolation and diminished motivation. These effects are discernible not only among students but also within the academic community [3], [12].

Despite the chaotic nature of the pandemic and its effects still present today, some authors suggest that in the face of chaos, new opportunities emerge to generate new orders, with new opportunities flourishing from the imbalance [13]–[18]. According to Bennett [13], the pandemic has revealed three positive aspects. First, it reveals the inequities in daily life in each country and proposes new educational models to settle this debt [19]. Second, to accelerate the debate on education in general (admission processes, evaluations, and performance indicators), and third, to update and rethink evaluations for a multicultural society. In the pre-pandemic period, evaluation and admission systems for higher education institutions were subject to regulation by governmental entities

in each country. However, COVID-19 has made it possible to relax these regulations by assigning them to the authorities of schools or universities. This has made it possible to create new and much broader admission criteria and to redesign new evaluation systems, taking into consideration other factors not previously considered. In retrospect, the pandemic has allowed educational authorities and academics to design new educational strategies that allow them to face constant and permanent changes, favoring the use of new strategies that would not have been employed or considered [14].

Regarding online work, we must differentiate between those done prior to the pandemic and those done during the pandemic period, referred to by some authors as Emergency Remote Teaching (ERT). Online work mediated through Learning Management System (LMS) tools focuses on the interaction between the student and the instructor, combined with an important collaborative ecosystem. In contrast, the work developed in the ERT scheme focused on replicating the face-to-face work experience in a digital medium with a low level of experience for students [20]. The reasons for this scheme are explained by the short time required to prepare a robust interaction model. Despite the above, the rapid proliferation of tools has led instructors to employ a large set of activities such as small group work development, surveys, online workrooms, real-time instructor videos, and recorded material prior to the start of each class in a flipped learning scheme [17], [21].

In relation to student perception, Chavez and Mitchel [22] reported that if the instructor was female or of color, their evaluation was lower compared to a white male for identical subjects; that is, students applied a difference only by gender. These findings were previously reported by MacNeel et al. [23], reinforcing the findings on instructors' perceptions [24]. According to Cavanaugh et al. [20], students' perception of difficulty about online subjects in the ERT mode is lower than that of a face-to-face subject. This perception is explained by multiple factors, including poor preparation, lack of knowledge of pedagogical tools, types of interaction between students and teachers, lack of feedback, lack of non-verbal communication, and difficulties inherent in the communication medium [25].

A very important obstacle in face-to-face education in relation to distance education is related to the educational experience in which communication between peers, problem solving, and camaraderie prevail [26]. Students with a lower level of autonomy or regulation have great difficulty advancing in their studies, as they generally require instructor assistance in the classroom [27]. Evidence has shown that online materials, the use of discussion forums, and digital content do not allow achieving a holistic view that favors teaching-learning outcomes [27], [28].

A key insight learned from the pandemic pertains to the significance of education in utilizing remote communication technologies. Despite the existence of substantial evidence surrounding e-learning platforms (LMS) and its partial integration within the academic sphere, the majority of students found themselves unprepared, left with no alternative but to engage with these technologies [29]. In a face-to-face environment, students can share their emotions and quickly seek solutions to different problems. These characteristics can be replicated in a virtual environment, which is a process that is not always efficient, as previously pointed out.

A key aspect of learning is the perception of students in virtual classrooms. Aspects such as attention, motivation, emotion, and satisfaction in response to learning were modulated by student perceptions. According to Curelaru et al. [29], there are three factors that affect learning in the online modality: (1) technology, such as home internet connection, platform design, access to asynchronous and synchronous material [7], (2) instructor characteristics, e.g., teaching style, attitude towards students, digital skills, language used [30], and (3) student characteristics, among them are personality, digital skills, and main intrinsic characteristics of students such as their motivation, discipline, time management [20], [31].

Information and Communication Technologies (ICTs) have been key to maintaining education when the pandemic keeps people under strict health control. However, ICTs alone cannot replace education because learning requires two essential aspects: student behavior and interaction among students, which allows the detection of students who present difficulties [3], [28], [31]. Different researchers have revealed that students' perceptions of the learning process have relevant effects on their own performance. Students with lower self-regulatory capacities fail to achieve high levels of performance in an online learning model. Therefore, it is essential for educators to be aware of students' ability to interact in an online environment, their time of concentration, and the schemes of work employed in the online modality [32]. The effects of the pandemic on higher education are still a matter of study and deep discussion. However, there is no clarity about its medium- and long-term effects on future graduates in relevant aspects such as analytical and synthesis skills, problem solving, socialization, and soft skills development [33].

We have previously discussed aspects of technology and the perception of student learning in their individual work during the pandemic, which has caused a decline in the quality of education in different areas of knowledge. One of the most widespread learning methods in the university environment to address these problems is Project-based Learning (PBL) as a learning tool. PBL seeks to promote and provoke interest and deep learning, as students acquire and apply new knowledge in a given context. The teacher's role focuses on being a facilitator, providing information and knowledge, recommendations, and structure to students, and assessing what knowledge they have acquired and have yet to acquire. PBL allows students to acquire knowledge through collaborative projects, which require the application of applied knowledge in a concrete context. The literature points out two relevant aspects of PBL: first, the development of interactive learning [34], [35] and second, the construction of knowledge through exploration [36], [37]. These two aspects will be relevant to our study.

Our research focuses on the effect of applying Project-Based Learning (PBL) methodology to first-year university

students from the beginning of the pandemic. For this purpose, we analyzed academic performance on a set of assessment instruments in cohort 2020 in the Integral Calculus subject, considering a control group and an experimental group. Subsequently, we evaluated the effects of the methodology in Multivariable Calculus on the same cohort in 2021 using the same previous analysis. This article presents the standardized test performances in both groups so that the results are comparable between groups, even though the experimental group has not been prepared under this modality. The remainder of this paper is structured as follows. First, the methodology is applied, the experimental results are presented, and finally, the discussion and conclusions of the research are presented.

II. Proposed Methodology

We separated this analysis into two parts. First, we briefly discuss the analysis process conducted for data collection for 2020 and 2021. Then, we discuss the specific objectives of the study with the research questions that we seek to address through evaluation instruments.

A. Analysis performed

As previously stated, virtuality called into question the methodologies used and the learning evaluation systems because it is not obvious to transfer the face-to-face class to a remote synchronous system. Aware of the great difficulties faced during the pandemic, a proposal for the renovation of mathematics courses for the Engineering career at the Universidad Adolfo Ibáñez (Chile) focused on active and student-centered learning. To analyze these changes, we collected data from 2020 to 2021, considering different groups of students who have taken the Integral Calculus and Multivariate Calculus. The analysis was conducted in the following chronological order:

- At the beginning of 2020, the Project-Based Learning (PBL) methodology was implemented partially, only in half of the sections. In the control group, no changes were made, preserving the instructional methodology prior to the pandemic, while in the experimental group, PBL was implemented with group work and presentations. This is an online modality with remote work through the Zoom platform in both groups. In the control group, the students took individual written evaluations online during the semester. These evaluations consisted of solving a set of exercises and then scanning and uploading their developments to a virtual office, where each professor corrected the deliveries. In the PBL modality, 50 percent of the evaluations were replaced by three projects, one for each unit of the subject, where students had to develop real context problems using Integral Calculus tools. These projects had a limited period of three weeks for their development and ended with the delivery of a report and group presentation. The projects dealt with three fundamental topics of the subject: the use of the integral through the development of the equation of motion for sliding systems, the applications of the integral through a modeling problem of a real object, and improper integrals and series in a research project on income distribution in Chile.
- From 2021, the PBL methodology was applied in the Multivariable Calculus course in a transversal way, considering the subject evaluations: group projects and individual tests. Gradually, there is a return to face-to-face activities; however, evaluations continue in the online modality.
  In 2021, students were evaluated 50% individually and 50% by project.

  According to ABET and expected student outcomes, with this methodological implementation it was possible to develop the following competences:
  - an ability to communicate effectively with a range of audiences.
  - an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
  - an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
  - an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

  These competencies were evaluated during the development of the project, in the report, in the presentation, and through co-evaluation using rubrics that were previously presented to the students.

B. Research questions

Considering the methodological change implemented in the Integral Calculus course, corresponding to the second semester of the Civil Engineering course. Our primary objective is to comprehensively assess the influence of this instructional shift on students and their academic outcomes, as it diverges from their prior experiences in the mathematics courses within their curriculum. Specifically, our project aims to quantitatively investigate and assess two key research inquiries.

Q1 How does the implementation of Project-Based Learning (PBL) methodology in Integral Calculus compare to the traditional educational approach in terms of its impact and effectiveness? This analysis will serve to understand if the methodology has had the expected effect in the short and medium terms, and if the students have developed competencies complementary to those declared for the subject in the graduation profile taxation matrix.

Q2 What is the extent of the impact of implementing Project-Based Learning (PBL) methodology in Integral Calculus for the cohort of 2020 on students' academic performance in Multivariate Calculus compared to a traditional approach? This analysis will serve to determine whether there are differences in the application of the methodology in both online and face-to-face modes.

III. Results

This section presents the results in two ways. First, the evolution of student performance according to the evaluation instrument(s) in 2020 and 2021 is presented. Second, the impact of PBL methodology on students with previous experience is analysed.

A. Experimental and control group analysis

The experimental design considered dividing the students of the Integral Calculus course into an experimental group and a control group in both campuses (Santiago and Viña del Mar). The experimental group used PBL methodology with a high component of group work and personal research. An expository methodology was used in the control group, with a low level of group participation and high component of individual work. To compare both groups of students in both campuses, intermediate written evaluations were carried out at three moments during the semester (C1, C2, C3), which used problem solving and analysis. The results indicated that at the beginning of the Integral Calculus course, performance was significantly higher for students in the experimental group (Table. I); however, as the semester progressed, it was significantly higher in the control group (Table.II. Integral Calculus: C2, Hedges G:0.53, C3: Hedges G:0.7006). When performing a hypothesis test in relation to the means (Welch's test), we observed the same differences between the groups, which is consistent with the Hedges' G test. This implies that the evaluation instrument applied to students in the experimental group was not effective in determining the competencies developed by this group. This confirmed that the instrument must be calibrated using an appropriate learning methodology.

After passing the Integral Calculus course, the next course in the curriculum corresponds to Multivariate Calculus. In the latter, we used the PBL methodology for all students (regardless of whether they had used the PBL methodology in the previous course). The methodology was accompanied by three intermediate evaluations (P1, P2, P3)[1] in which group research and development work was applied with intermediate presentations and a final written evaluation that covered all the content of the semester (PG). For the purposes of our research, we had the identity of the students of the experimental group and the control group of the previous course (Integral Calculus). Thus, we analyzed the behavior of students who previously knew the PBL methodology (experimental group) compared to those who used an expository methodology (control group). The results indicated that, on average, the performance of the students in the experimental group was slightly higher than that of the control group (see Table.I). To analyze this difference, we performed a test to compare means with different variances (Welch's test) and a test to evaluate the effect of the PBL methodology on the control group (Hedges G). Surprisingly, the results did not indicate large differences between the two groups. Only in the case of the Viña del Mar Campus was there a slight effect in favor of the experimental group in relation to the control group (Table. II). To evaluate the performance of both groups individually through the General Test (PG) evaluation instrument, we observed that the performance of the experimental group was slightly higher than that of the control group. This was observed at both the Santiago and Viña del Mar campuses. On the Santiago campus, a difference was observed, but it was still slight (see Table. I. Multivariate Calculus. PG: Hedge G: 0.1931). The same was observed on the Viña del Mar campus (Table. II. Multivariable Calculus. PG: Hedge G: 0.1713).

[1]The grading scale in Chile ranges from 1.0 to 7.0 with one decimal number, where 1.0 is the minimum grade and 7.0 is the maximum. A minimum of 4.0 is required to pass a subject.

B. Distribution analysis

Although the above calculations allow us to understand the differences between the experimental and control groups, the histogram graph allows us to understand the distribution of each evaluation instrument used. As previously stated, we used intermediate individual evaluations in both study groups for Integral Calculus. We observed that in the case of the control group on the Santiago campus, the performance had a negative skew (Fig.1. Integral Calculus: C1, C2, C3), and the experimental group had a more uniform distribution. The Viña del Mar campus presents a similar situation to Santiago, slightly more clustered in certain intervals (Fig.2: Integral Calculus: C3). However, in certain evaluations, the distribution is more uniform (Fig.5. Integral calculus (C1). For this study, we did not make an inter-campus comparison because students have a differentiated entrance score between campuses. Historically, the performance of students at the Viña del Mar campus is slightly lower than in Santiago; since Santiago is the capital city, the volume of students is greater, which implies a higher university entrance score.

It is important to highlight that in Multivariable Calculus, the distributions are quite similar between the experimental and control groups, and even between campuses, especially in relation to the PG test, which is a written evaluation instrument that measures all competencies developed during the semester (see Fig.1 and Fig.2 Multivariate Calculus). However, we observed that students' performance in this evaluation was normally distributed (Fig.3). Only in the tails of all groups and campuses do we observe some dispersion, which is generally explained by the fact that some students drop out of the course at the end of the semester, not taking this final evaluation.

The BoxPlot graph shows that the greatest dispersion in student performance is found in the Integral Calculus subject at both campuses, specifically for instruments C1, C2 and C3 (Fig. 4 and Fig.5). It is interesting to note that in the subject of Integral Calculus, there is a great dispersion around the second written evaluation (C2) in the Santiago campus versus the Viña del Mar campus. It was even observed that as the semester progressed, the performance of the control group for this course was slightly higher than the experimental one and with a lower interquartile range; the results are described in Tables I and II. This situation changes and normalizes in the subject of Multivariable Calculus, where there is a higher interquartile

TABLE I

PERFORMANCE OF STUDENTS AT THE SANTIAGO CAMPUS ACCORDING TO THE EXPERIMENTAL AND CONTROL GROUPS APPLIED TO THE INTEGRAL CALCULUS AND MULTIVARIABLE CALCULUS TOPICS.

			Experimental group (PBL) *Campus Santiago*			**Control group** *Campus Santiago*			Population Welch t-test	Effect size Hedges G
Topic	Test	Year	Mean	σ	n	Mean	σ	n		
Integral Calculus	C1	2020	5.943	1.277	134	5.168	1.457	255	5.4115	0.5545
	C2	2020	4.620	1.816	132	5.025	1.476	257	2.2151	0.2532
	C3	2020	4.881	1.591	131	4.798	1.562	258	0.4928	0.0528
Multivariable Calculus	P1	2021	5.765	0.649	123	5.742	0.959	297	0.2947	0.0261
	P2	2021	6.093	0.847	122	5.921	1.036	294	1.7577	0.1747
	P3	2021	6.124	0.735	121	5.947	1.142	293	1.8745	0.1701
	PG	2021	3.804	1.094	121	3.6027	1.020	294	1.7353	0.1931

C1, C2, C3 Intermediate written assessments. P1, P2, P3. Intermediate presentations of projects with PBL methodology or intermediate written assessments without PBL methodology; PG: general written test.

TABLE II

PERFORMANCE OF STUDENTS AT THE VIÑA DEL MAR CAMPUS ACCORDING TO THE EXPERIMENTAL AND CONTROL GROUPS APPLIED TO THE INTEGRAL CALCULUS AND MULTIVARIABLE CALCULUS TOPICS.

			Experimental group (PBL) *Campus Viña del Mar*			**Control group** *Campus Viña del Mar*			Population Welch t-test	Effect size Hedges G
Topic	Test	Year	Mean	σ	n	Mean	σ	n		
Integral Calculus	C1	2020	5.6750	1.2980	148	4.7341	1.878	44	3.1098	0.6490
	C2	2020	4.8973	1.6380	147	5.7442	1.312	43	3.5080	0.5391
	C3	2020	4.7338	1.2160	148	5.5907	1.247	43	3.9886	0.7006
Multivariable Calculus	P1	2021	5.7384	1.0090	138	5.5151	1.188	53	1.2109	0.2104
	P2	2021	5.7446	0.9470	138	5.6941	0.949	51	0.3249	0.0532
	P3	2021	6.0445	1.1950	138	5.7196	1.472	51	1.4135	0.2548
	PG	2021	3.5826	1.1880	138	3.3784	1.202	51	1.0399	0.1713

C1, C2, C3 Intermediate written assessments. P1, P2, P3. Intermediate presentations of projects with PBL methodology or intermediate written assessments without PBL methodology; PG: general written test.

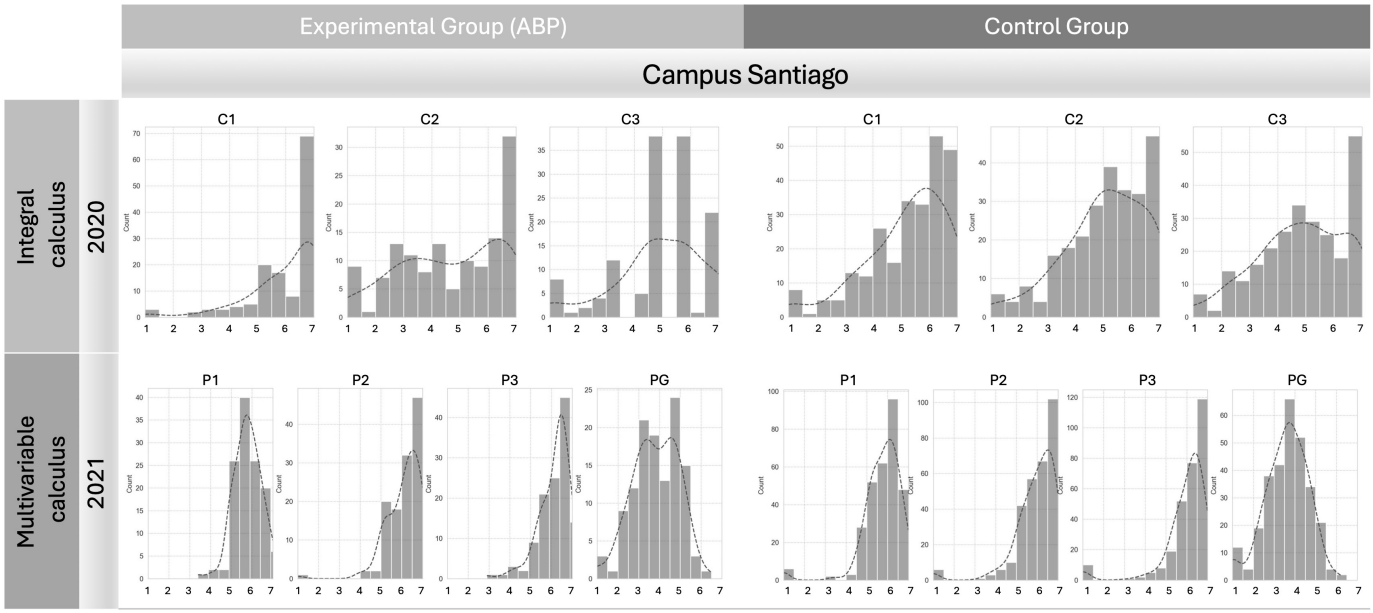

Fig. 1. Comparative performance between experimental and control groups applied to Integral Calculus and Multivariable Calculus topics at the Santiago' campus according to the experimental and control groups applied to the Integral Calculus and Multivariable Calculus topics. C1, C2, C3 Intermediate written assessments. P1, P2, P3. Intermediate presentations of projects with ABP methodology; PG: general written test.

range in the study group coming from the experimental group than in the control group.

IV. DISCUSSION

In this section, we discuss the research questions posed in the second section.

- ***To evaluate the effect of applying Project-Based Learn-***

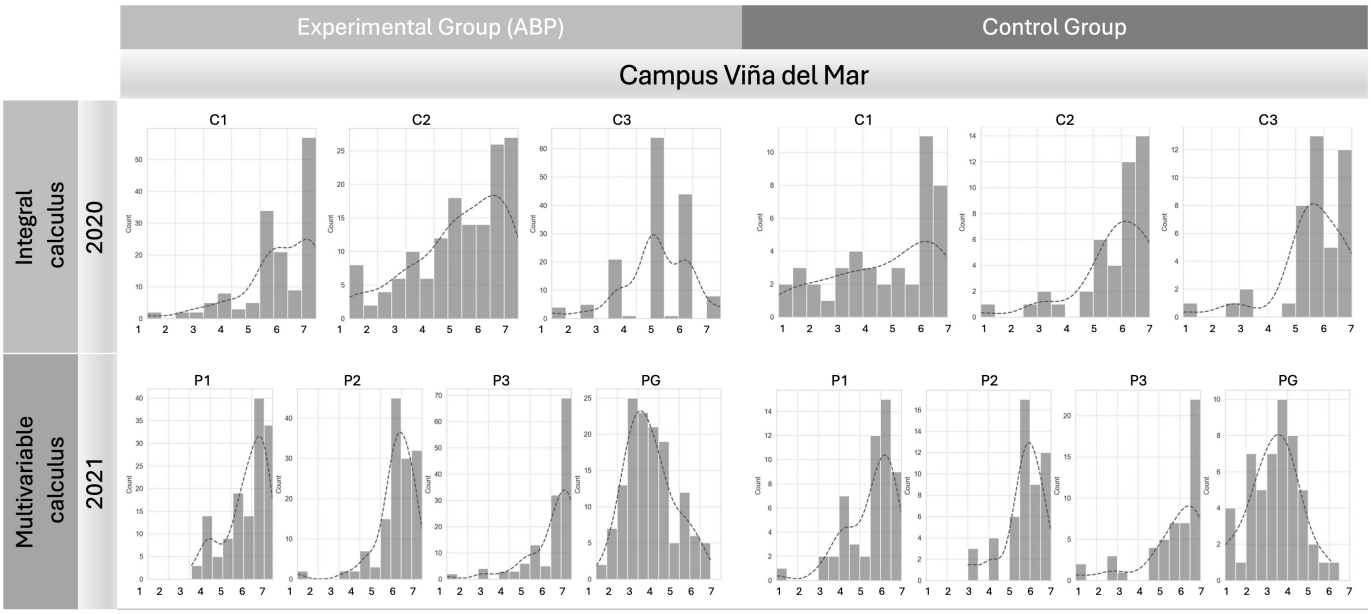

Fig. 2. Comparative performance between experimental and control groups applied to Integral Calculus and Multivariable Calculus topics at the Viña de Mar' campus according to the experimental and control groups applied to the Integral Calculus and Multivariable Calculus topics. C1, C2, C3 Intermediate written assessments. P1, P2, P3. Intermediate presentations of projects with ABP methodology; PG: general written test.

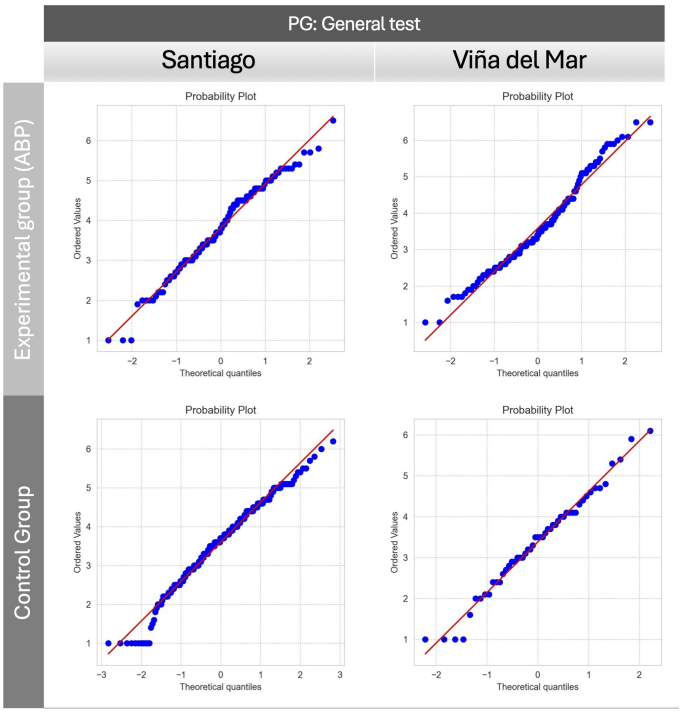

Fig. 3. QQ-Plot with General Test performance by campus and study group

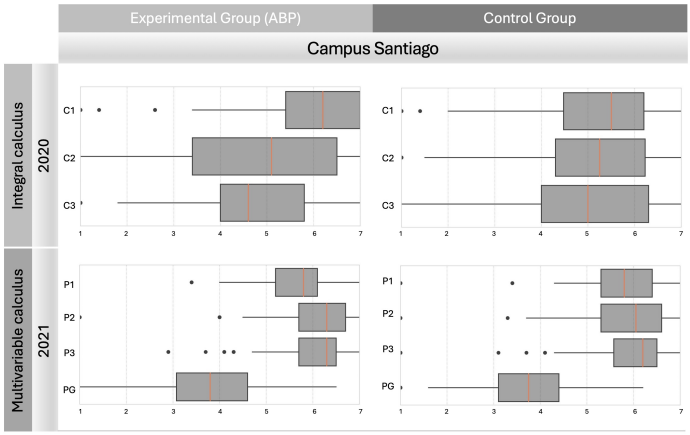

Fig. 4. Bloxplot of student performance according to the experimental and control groups applied to the topics Integral Calculus and Multivariable Calculus at the Santiago' campus. C1, C2, C3 Intermediate written assessments. P1, P2, P3. Intermediate presentations of projects with ABP methodology; PG: general written test.

ing (PBL) methodology in Integral Calculus versus the traditional model of education. In general, we observed that the PBL methodology has had a positive effect among students of different cohorts, those who experienced it in the online modality (2020 and 2021). As classes transition from an online to a face-to-face mode, the PBL methodology is favored as collaborative work among students increases and project evaluation is appropriately measured, according to previously described results in [38]. However, students perceive that this methodology is more appropriate for a face-to-face environment than an online mode, especially when there is alternation between a master class and the workshops applied in the methodology.

In relation to the competencies developed by the students who follow the PBL methodology, it is interesting to note that although their performance in the individual

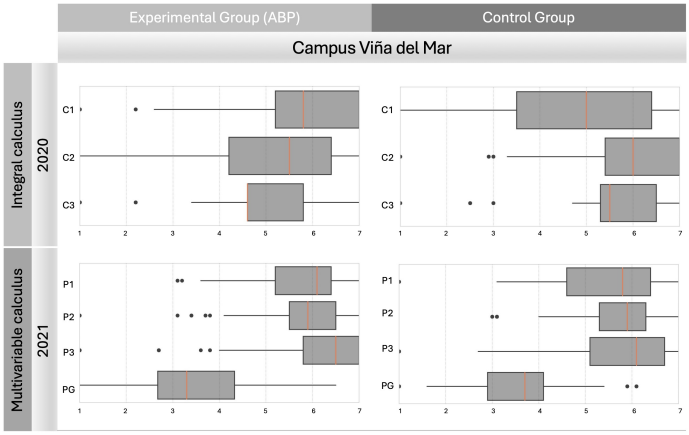

Fig. 5. Bloxplot of student performance according to the experimental and control groups applied to the topics Integral Calculus and Multivariable Calculus at the Viña de Mar' campus. C1, C2, C3 Intermediate written assessments. P1, P2, P3. Intermediate presentations of projects with ABP methodology; PG: general written test.

written evaluations is slightly below the performance of the students in the control group in Integral Calculus, the situation is reversed in the following course: Multivariable Calculus, as evidenced in the overall test. This highlights the importance of aligning learning objectives, methodologies and evaluation instruments, that John Biggs proposed as constructive alignment [**?**]

We can infer that individual written evaluations fail to quantify the skills, abilities, and attitudes that students develop in relation to the PBL experience, such as responsibility for and self-regulation of their learning, development of critical thinking, development of interpersonal skills, contact and work relationships, innovation, and creativity. These competencies can be evaluated in the long term as they correspond to transversal competencies rather than specific ones.

- ***To quantify whether there is a significant difference in the application of PBL methodology in Integral Calculus subjects for cohort 2020 and its impact on students' academic performance in Multivariate Calculus.*** In the first year of application of the PBL methodology, statistically significant differences were observed in the C1, C2, C3 partial evaluations in 2020. This is because the teaching teams at both sites did not have enough time or maturity in the use of the methodology to align the focus of the evaluation; results previously reported in literature [39]. In the following years, the teaching team was able to align assessment strategies at both campuses. Thus, the results were more consistent even though the students and campuses were different.

  Students who had previously experienced the PBL methodology obtained equivalent or slightly higher performance than those who had not used it. This result allows us to conclude that the competencies developed by the students in this methodology have a long-term effect, and that previous experience is not a determining factor in achieving the same level of performance in the short term.

V. Conclusion

This research presents an extensive review of the Project-Based Learning (PBL) methodology applied in the Integral Calculus and Multivariate Calculus courses in Santiago and Viña del Mar campuses of Universidad Adolfo Ibáñez (Chile) during 2020 and 2021, respectively. The analysis was conducted in two phases. First, we analyzed student performance using different assessment instruments to determine whether there were significant differences between instruments according to campus and year and two type of groups (Experimental and Control). Second, we evaluated the impact of previous experiences with PBL methodology in a later course of the curriculum.

Regarding the evaluation, the main differences occurred in the evaluation instruments of 2020, precisely the period in which all the activities were carried out in maximum confinement and under strong pressure from the teaching team, which had to face methodological changes in learning and evaluation in a short time. The results indicate that in the experimental group (where the PBL methodology was applied), the performance in written evaluations with problem solving was relatively lower than that of the control group. This is due to the fact that the evaluation instrument was not appropriate for the experimental group, focused on analysis and collaborative work. However, in the next subject of the curriculum (Multivariable Calculus, 2021), this phenomenon was reversed in favor of the experimental group. Although the differences between the two groups are very slight, it is interesting to note that this phenomenon is observed at two geographically distant sites and with groups of students from different parts of the country. This leads us to conclude three aspects:1) the evaluation instruments should be aligned with the study methodologies; 2) the PBL methodology has a slightly positive effect on students who have used this methodology in a previous subject; and 3) over time, the teaching team became aligned with the learning strategy, and the results were more similar between campuses.

It is relevant to understand the long-term effects of learning developed during the pandemic period on students. For this reason, future work should analyze the specific competencies of the 2020 cohort in relevant engineering subjects.

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