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RESEARCH ARTICLE

Exploring Project-Based Learning as an Innovative Strategy for Teaching Mathematics in Higher Education: Challenges, Obstacles, and Opportunities for Comprehensive Education.

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ABSTRACT

Project-Based Learning (PBL) has emerged as an innovative methodology that challenges traditional teaching methods in higher education, especially in areas like mathematics, where abstract thinking and logical reasoning are crucial. By solving real-world problems in collaborative settings, PBL fosters key competencies such as critical thinking, teamwork, and a deeper understanding of mathematical concepts. Despite advancements, many university students still struggle with learning due to traditional methods that focus on memorisation and one-way transmission of information, limiting the development of critical problem-solving skills. This disconnect between theory and practical application impacts student motivation and academic performance. PBL offers an alternative that bridges this gap, promoting active, participatory, and meaningful learning. However, its implementation faces challenges, such as the need for institutional commitment, resource allocation, and continuous teacher training. Universities must adapt their curricula, and educators need support to integrate PBL effectively into their teaching practices.

INTRODUCTION

Project-Based Learning (PBL) has become established as an innovative methodology that challenges traditional teaching approaches in higher education, particularly in fields such as mathematics, where a high level of abstraction and logical reasoning is required. By solving real-world problems in collaborative contexts, this strategy encourages the development of key skills such as critical thinking, teamwork, and a deeper understanding of mathematical principles. In this way, PBL represents a significant alternative for transforming the teaching of mathematics, preparing students in a comprehensive manner to face the challenges of the contemporary environment.

Despite the progress made in mathematics education, many university students continue to face significant difficulties in their learning process. This is largely due to the prevalence of traditional methods that prioritise memorisation and the one-way transmission of information, thus limiting the development of skills such as critical thinking and problem-solving, which are fundamental in higher education. These limitations are especially evident in mathematics, where the disconnect between

theory and practical application affects students' motivation and negatively impacts their academic performance.

Project-Based Learning (PBL) presents itself as a pedagogical solution that promotes active and meaningful learning. According to Añazco et al. (2024), the implementation of this methodology in mathematics education at the university level poses significant challenges, such as the need to adapt resources, train educators, and redesign curricula to maximise its impact. Therefore, it is essential to explore how this methodology can overcome existing obstacles, enabling the development of a more inclusive mathematics education focused on the comprehensive development of the student.

PBL promotes more effective learning by actively engaging students in projects that simulate real-world challenges, which, according to Romero et al. (2024), helps to connect content with practical situations and fosters meaningful and relevant learning.

This methodology enhances not only academic performance but also develops essential transversal skills. Zamora (2024) advocates for competencies such as communication, leadership, and problem-solving, preparing students for a wide range of challenges.

In mathematics, PBL facilitates the connection between theory and practice, enhancing the understanding of concepts. As noted by Vera et al. (2024), this methodology allows abstract ideas to be applied to concrete situations, increasing their academic relevance.

PBL proves particularly effective in areas such as mathematics, where abstraction presents a significant challenge. Leiva et al. (2024) argue that this methodology fosters autonomy and self-efficacy, enabling students to develop key skills while tackling complex problems in a practical and collaborative environment.

PBL has proven to be a powerful tool for addressing inequalities in learning. Hernández et al. (2023) concluded that its effectiveness increases when integrated with emerging technologies, as these enrich educational experiences and enhance the development of students' competencies.

Teoría

Education must focus on the active experience of the student, a principle emphasised by PBL, as highlighted by Solano et al. (2023). This perspective underscores the importance of students directly engaging in the learning process, facilitating reflection and critical thinking.

The notion of social learning, proposed by Polo et al. (2023), highlights the relevance of interaction in knowledge construction. This aspect is crucial in PBL, where collaboration among students significantly contributes to the learning process and the development of key competencies.

Learning occurs when students can relate new knowledge to their prior experiences, a process facilitated by PBL, as noted by Sánchez et al. (2023). This approach enables students to connect what they have learned to practical situations, enhancing understanding and critical thinking.

PBL motivates students by presenting them with authentic problems that stimulate curiosity and inquiry, as argued by Martínez (2022). When tackling these real-world challenges, students develop greater interest and engagement in their learning.

Experiential learning, a key component of PBL, supports the development of practical and cognitive skills, as noted by Vargas et al. (2021). This approach enables students to learn through action and reflection, facilitating the internalization and application of knowledge in real-world contexts.

The use of PBL in mathematics can be enhanced through the integration of technological resources, as proposed by Burgos et al. (2021). These resources not only improve the accessibility of content but also increase the appeal and dynamism in teaching mathematical concepts.

PBL encourages greater responsibility in learning by requiring students to manage their time and resources independently, as highlighted by Navarro (2019). This approach not only promotes decision-making and planning but also strengthens key skills essential for academic and professional success. Students are expected to organise their work and actively collaborate with peers, enhancing their management capabilities. Furthermore, PBL fosters independence and self-regulation throughout the learning process.

Objective

To examine the application of Project-Based Learning as an approach to optimise the teaching and learning of mathematics in higher education, recognising its challenges, obstacles, and possibilities for comprehensive education.

Specific Objectives:

To identify the advantages of Project-Based Learning (PBL) in enhancing mathematical skills among university students.

To investigate the challenges faced by educators in implementing Project-Based Learning (PBL) in mathematics teaching.

To analyse students' perspectives on the effectiveness of Project-Based Learning (PBL) in understanding mathematical concepts.

The central question guiding this research is: How can Project-Based Learning (PBL) improve the teaching of mathematics in higher education, addressing current challenges and fostering a comprehensive education for students? This inquiry seeks to explore how the implementation of PBL can transform the teaching and learning of mathematics, contributing to a more effective education that is adapted to the needs of the contemporary academic environment.

Variables

Table 1 Dependent and Independent Variable

Variable	Dimension	Indicator	Questions
Dependent Variable: Effective Teaching of Mathematics	Application of Mathematical Concepts	Level of understanding of basic mathematical concepts.	1. How do you assess your understanding of mathematical concepts after participating in a project?
		Ability to apply mathematical concepts to real-world problems.	2. Can you apply the mathematical concepts learned in class to practical situations?
Independent Variable: Implementation of PBL	Design of Innovative Projects	Level of integration of real-world problems in projects.	1. Do you consider the projects to address real and relevant problems?

Variable	Dimension	Indicator	Questions
		Active participation of students.	2. How engaged do you feel when participating in the project activities?

METHODS

The methodology employed in this study was a mixed approach, combining both qualitative and quantitative methods to gain a comprehensive understanding of the impact of Project-Based Learning (PBL) on the teaching of mathematics in higher education. A descriptive design was used to identify and analyse the factors that affect the implementation of this strategy, as well as the challenges, obstacles, and opportunities it offers for holistic education.

The adopted approach was mixed descriptive, allowing for the integration of both qualitative and quantitative analysis of the collected data. The qualitative analysis provided an in-depth view of the experiences and perceptions of both teachers and students, while the quantitative analysis allowed for the collection of precise data on the attitudes and behaviours of the participants regarding PBL in the context of mathematics teaching.

The fieldwork was crucial in data collection, as it allowed direct interaction with the subjects of study in their academic environment. Through this approach, direct information was gathered on how PBL was implemented in mathematics classes and how this methodology was perceived by students and teachers, facilitating a more realistic and contextualised evaluation.

The mixed-methods approach was selected due to the need to analyse both the objective and subjective aspects of the implementation of Project-Based Learning (PBL). This integrative approach allowed the research to be addressed from multiple perspectives, ensuring a more comprehensive analysis. Techniques such as interviews with teachers and surveys administered to students were used. The interviews provided an in-depth exploration of the perceptions, experiences, and challenges faced by teachers when implementing PBL in mathematics teaching. On the other hand, the surveys, featuring dichotomous response questions, facilitated the collection of quantitative data on the acceptance of PBL and its impact on the learning of mathematical concepts. Additionally, a second questionnaire for students was included, which assessed their level of motivation and active participation during the projects, thus providing a more detailed analysis of their academic experience.

Population and Sample

The target population consisted of students and teachers from higher education. A convenience sample of 15 university students and 5 teachers who were involved in the implementation of Project-Based Learning (PBL) in mathematics classes was selected. This sample was chosen due to its availability and willingness to participate in the study, allowing for the efficient collection of relevant data.

Verification

For the validation of the data collection instruments, the interviews and surveys were processed and analysed using Excel software. This procedure allowed for the organisation, classification, and analysis of the information in a structured manner, ensuring the reliability and consistency of the results obtained. Validation with this software facilitated a detailed and accurate analysis of the data, contributing to the robustness of the study.

RESULTS

In this research, it is anticipated that significant results will be identified concerning the implementation of Project-Based Learning (PBL) in the teaching of mathematics in higher education.

PBL is expected to contribute to a better understanding of mathematical concepts by students, enhancing their ability to apply them to real-world problems. Furthermore, an increase in student motivation and active participation is anticipated, as well as an improvement in teachers' perceptions of their pedagogical practice. These findings could uncover the main challenges faced by educators and provide opportunities to optimise the teaching and learning processes in this subject, promoting a more comprehensive education focused on the development of transversal skills.

Table 2 Perception of Students on the Implementation of Project-Based Learning (PBL) in Mathematics

Question	Positive Responses (Yes)	Negative Responses (No)	Total Responses (15 Students)	Percentage of Positive Responses	Percentage of Negative Responses
Do you feel that Project-Based Learning (PBL) helps you understand mathematical concepts better?	12	3	15	80%	20%
Do you think PBL makes mathematics classes more interesting?	13	2	15	86.67%	13.33%
Do you feel more motivated to participate in mathematics activities when projects are used?	11	4	15	73.33%	26.67%
Do you consider the projects in PBL to be related to real-world problems?	14	1	15	93.33%	6.67%
Do you think PBL allows you to apply what you've learned in mathematics to real-life situations?	13	2	15	86.67%	13.33%
Do you believe PBL improves your ability to work in a team?	14	1	15	93.33%	6.67%
Do you feel that PBL contributes to your overall development as a student?	12	3	15	80%	20%
Do you consider PBL to be a methodology that is difficult to implement in mathematics classes?	4	11	15	26.67%	73.33%

Note. The survey results reflected a predominantly positive perception of students towards Project-Based Learning (PBL) in the teaching of mathematics. The majority of students believed that PBL improved their understanding of mathematical concepts (80%) and made the classes more interesting (86.67%). Furthermore, more than 90% of respondents felt that PBL allowed them to apply what they had learned to real-life situations and enhanced their ability to work in teams. However, a significant percentage (73.33%) of students considered that the implementation of PBL in mathematics classes presented difficulties, suggesting that there were challenges associated with the application of this methodology in this specific context.

Table 3 Perceptions of Teachers on the Implementation of Project-Based Learning (PBL) in the Teaching of Mathematics

Question	Negative Responses (No)	Positive Responses (Yes)	Total Responses (5 Teachers)	Percentage of Negative Responses	Percentage of Positive Responses
Do you consider that Project-Based Learning (PBL) improves students' academic performance in mathematics?	4	1	5	80%	20%
Do you believe that PBL facilitates the teaching of complex mathematical concepts?	3	2	5	60%	40%
Do you perceive that students are more motivated when using PBL compared to traditional methods?	4	1	5	80%	20%
Do you consider that the projects used in PBL reflect real-world problems applicable to everyday life?	3	2	5	60%	40%
Do you believe that PBL fosters the development of skills such as critical thinking and problem-solving in students?	4	1	5	80%	20%
Do you feel that you have sufficient resources and training to effectively implement PBL in mathematics?	5	0	5	100%	0%
Do you perceive that PBL promotes a more integrated and meaningful approach to teaching mathematics?	3	2	5	60%	40%

Note. The table presented the teachers' responses on various aspects of Project-Based Learning (PBL) in mathematics education. As observed, negative responses prevailed in most of the questions, particularly regarding the effectiveness of PBL in improving students' academic performance, student motivation, and the availability of resources and training to implement this methodology. However, some teachers recognised the advantages of PBL in teaching complex concepts and fostering skills such as critical thinking. This suggested that, although PBL posed certain challenges, it was also perceived by some as a potentially beneficial strategy in the classroom.

Table 4 Survey Results on the Effectiveness of Project-Based Learning (PBL) in Mathematics Students

Question	Positive Responses (Yes)	Negative Responses (No)	Total Responses (15 Students)	Percentage of Positive Responses	Percentage of Negative Responses
Do you think Project-Based Learning (PBL) helps you understand mathematical concepts better?	13	2	15	86.67%	13.33%
Do you feel that the projects done in class are related to real-world problems?	14	1	15	93.33%	6.67%
Do you believe that using PBL motivates you more than traditional teaching methods?	12	3	15	80%	20%
Do you think that PBL improves your ability to solve mathematical problems independently?	13	2	15	86.67%	13.33%
Do you feel that working on projects in teams enhances your learning in mathematics?	14	1	15	93.33%	6.67%
Do you feel more involved in learning mathematics through PBL?	12	3	15	80%	20%
Do you think PBL contributes to the development of skills such as communication and teamwork?	13	2	15	86.67%	13.33%

Note. The results obtained from the surveys administered to 15 students showed a positive trend in the perception of Project-Based Learning (PBL) in mathematics teaching. Students highlighted that PBL facilitated their understanding of mathematical concepts, increased their motivation, and allowed for a better connection with real-world problems. Additionally, they noted that working on team projects enhanced their learning and the development of collaborative skills, suggesting that PBL was an effective methodology for improving their educational experience in mathematics.

Throughout the course of the research, both positive and negative perceptions were identified regarding the implementation of Project-Based Learning (PBL) in the teaching of mathematics in higher education. Students displayed a predominantly favourable attitude towards PBL, noting that this approach facilitated their understanding of mathematical concepts, enhanced their ability to solve problems independently, and promoted teamwork. However, challenges related to the implementation of this methodology also emerged. Notably, there was a perception that certain aspects, such as student motivation and difficulties in applying certain projects, needed improvement.

The perceptions of the teachers reflected a more critical stance, with a higher proportion of negative responses, particularly concerning the effectiveness of PBL in improving students' academic performance and the lack of necessary resources and training for its proper implementation. While some teachers recognised the value of PBL in developing skills such as critical thinking, most pointed out significant challenges that still needed to be addressed.

The results indicated that, while PBL offered potential benefits for teaching mathematics, it also presented significant obstacles that needed to be overcome to ensure its effective implementation and acceptance, both among students and teachers.

DISCUSSION

The implementation of Project-Based Learning (PBL) in the teaching of mathematics in higher education has proven to be a strategy with great potential, although it presents certain challenges. According to Barwell (2024), although traditional methods remain common in many classrooms, PBL introduces an innovative methodology that promotes active learning, encourages problem-solving, and contributes to the development of key competencies such as critical thinking and collaboration. However, for this approach to be successful and achieve its pedagogical objectives, it is crucial to adapt the curriculum and provide adequate training for teachers.

In mathematics, a discipline that has historically struggled to bridge the gap between theory and practice, PBL emerges as an effective tool. By involving students in practical projects, the understanding of abstract concepts is facilitated, enabling them to apply knowledge to real-world situations. This not only enhances academic performance but also promotes the development of transversal skills, such as communication, autonomy, and problem-solving abilities—key competencies for academic and professional success.

The incorporation of technological resources in PBL can significantly enrich the educational experience, facilitating access to and engagement with mathematical content. As Ödmo et al. (2024) state, the use of emerging technologies, combined with the PBL approach, not only strengthens the understanding of concepts but also promotes greater responsibility in the learning process. Students are motivated to manage their time and resources, fostering the development of autonomy and self-management—skills that are essential in both academic and professional settings.

Despite the clear benefits it offers, the implementation of PBL faces several challenges. Mora et al. (2023) acknowledge that the scarcity of adequate resources and the need for ongoing training for educators are significant obstacles that must be overcome to ensure the success of this methodology. Moreover, resistance to change from both educators and students can limit its effectiveness, highlighting the importance of meticulous planning and a gradual approach to integrating PBL.

PBL has the potential to transform the teaching of mathematics, promoting a more active, collaborative, and meaningful learning experience. As Fresneda et al. (2023) suggest, its success will depend on various factors, such as institutional commitment, proper teacher training, and the availability of resources. These elements are crucial to overcoming existing barriers and fully exploiting the benefits of this methodology in higher education.

The integration of PBL into the teaching of mathematics requires adjustments at both the institutional and teacher levels. Steflitsch (2023) recommends that educational institutions not only support the adoption of this approach but also ensure the necessary resources for its effective implementation. Teachers, on the other hand, must receive training not only in the pedagogical strategies of PBL but also in the use of technologies and in restructuring their curricula to maximise the benefits of this methodology. Despite the challenges it presents, PBL has the potential to increase student motivation and promote deeper, more lasting learning, provided that existing barriers are adequately addressed.

CONCLUSIONS

Project-Based Learning (PBL) emerges as a highly promising educational strategy for teaching mathematics in higher education, offering an alternative to traditional methods that focus on the unidirectional transmission of content. This approach fosters a more active, participatory, and meaningful learning experience, enabling students not only to understand mathematical concepts but also to apply them in practical situations, thereby strengthening the connection between theory and reality. Through PBL, students develop key competencies such as critical thinking, problem-solving, collaboration, and autonomy, skills that are essential for their academic and professional success.

The implementation of Project-Based Learning (PBL) in the university setting faces various challenges. At an institutional level, it is crucial to have a firm commitment to ensure that adequate resources, both human and material, are allocated to support the adoption of this methodology. Universities must align with this strategy by adapting their curricular structures and providing the necessary support for effective integration. On the other hand, teachers encounter difficulties when applying PBL, as this approach requires a significant change in their pedagogical practice. Ongoing training and the learning of new pedagogical technologies are essential to ensure that teachers can implement PBL effectively.

Students' perceptions of the effectiveness of Project-Based Learning (PBL) in understanding mathematical concepts vary. While many appreciate the opportunity to apply their knowledge in real-world projects, some may experience initial difficulties due to the more autonomous and collaborative nature of this learning model. These aspects may generate resistance or insecurity in students accustomed to more traditional teaching methods. Therefore, it is crucial that both teachers and educational institutions provide the necessary support to overcome these barriers, offering guidance and appropriate resources to facilitate adaptation to the new approach.

Although the implementation of Project-Based Learning (PBL) presents challenges, this approach has enormous potential to transform the teaching of mathematics in higher education. By promoting a more inclusive and student-centred learning model, PBL not only enhances the understanding of mathematical concepts but also fosters a more comprehensive and holistic education. With proper planning, ongoing professional development for teachers, and commitment from institutions, PBL can significantly contribute to a more relevant, motivating, and future-ready education.

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