Effectiveness of Problem-Based Learning to Develop Mathematical Competencies at the Postgraduate Level

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Abstract **– The objective of the article is to determine the effectiveness of PBL to develop the mathematical competencies of postgraduate students. The methodology used was quantitative with a correlational scope. The study participants were a total of 29 postgraduate students in administration. The instrument used was the questionnaire to obtain information on the effectiveness of PBL. The data were organized with the SPSS 25 statistical program that allowed us to calculate: descriptive statistics such as the mean (M) and standard deviation (SD), the Shapiro-Wilks test and Pearson correlations (r) with a level of significance (p) of 0.05. The main results are: The significant direct associations were greater satisfaction regarding the use of technology (r = 0.789, p = 0.00); with their academic performance (r = 0.854, p = 0.00); promote collaborative work (r = 0.811, p = 0.00); encourage mathematical learning (r= 0.791, p = 0.00); analyze and discuss the contents through problems (r = 0.825, p =0.00).**

Keywords **– Academic performance, effectiveness, mathematical competencies, problem-based learning, postgraduate students.**

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1. Introduction

Derived from the confinement of the COVID-19 pandemic, education implemented various changes to continue with the educational service at various levels. One of them, in the case of higher education, was to break the paradigm of face-to-face instruction in the classroom [1]. The above has implied a continuous adoption of digital tools for learning, communication, and socialization among students [2]. In addition, the teachers carried out an articulation of their academic practices through videoconferencing platforms (Zoom, Skype, Google Meet or Teams) for synchronous sessions [3].

Also, the disruptive modification from in-person to virtuality generated a reconfiguration of educational actors (managers, teachers, and students) which has allowed the implementation of changes that have made it possible to achieve the necessary competencies and thus meet educational goals [4]. One of these changes has been the implementation of active methodologies that have been positioned as an alternative that allows the gradual acquisition of competencies in students, focusing on their main role as the center of learning. These methodologies provide the opportunity to dialogue, exchange and discuss with others based on their knowledge and previous experiences with the aim of designing a solution strategy. In the post-covid era, it is relevant to continuously integrate the active methodologies that were effective during confinement because they have demonstrated their usefulness in student learning. One of these active methodologies is problem-based learning (PBL). The objective of the article is to determine the effectiveness of PBL to develop the mathematical competencies of postgraduate students.

2. Literature Review

PBL is an active teaching methodology for students to gather knowledge, skills, and attitudes to solve and find solutions or alternative solutions to problematic situations, which will allow the acquisition of other knowledge and new competencies or the strengthening of them for future professionals.

For the implementation of PBL, real-world problems are used to motivate students in order to identify and investigate the concepts and principles required to solve them. Students are organized into teams to identify and analyze information to discuss and build a solution strategy. Therefore, the problem is deliberately intended to act as a catalyst to promote the acquisition of new knowledge [5]. In this sense, Del Valle and Villa [6] indicate that the characteristics of a problem are: 1) It is resolved collaboratively; 2) The students have adequate concepts and procedures for their resolution; 3) Be organized in a structured way to be resolved; 4) Enable feedback for students to evaluate the effectiveness of their knowledge and 5) Encourage conjectures and arguments for their solution. Doing an exercise is not the same as solving a problem. In the exercise, an algorithm is applied, while in the problem, the student develops a strategy with reasoned answers, which implies responsibility during their training process [7].

PBL is a strategy that promotes learning through inquiry. It mobilizes and enhances the development of scientific and critical thinking, teamwork, and autonomy [8]. Additionally, PBL focuses on promoting individual and collective participation with the students themselves being the protagonists of their training; it is based on discovery and the study is guided by the teacher. PBL is one of the methods that favors and helps improve their skills, strengthen their capacities, acquire knowledge, and the concept and understanding of the school curriculum [9]. PBL promotes high levels of connection and social interaction with classmates and teachers, which generates higher levels of student retention and satisfaction with respect to the academic training provided by the program [10].

PBL is characterized by: 1) The students are the center of learning, they are responsible for what they need to learn and how to get the information; 2) They work in small teams, which allows them to distribute tasks and assume responsibility for achieving a common objective; 3) The problem posed serves to integrate knowledge from various disciplines; 4) There is the possibility of posing real-life problems to put knowledge into practice in authentic spaces; 5) Students acquire new information in a self-directed manner with their own strategies, prior knowledge and research and 6) Transversal skills such as socio-emotional or soft skills are developed: teamwork, assertive communication, autonomous learning, conflict management, which are necessary in any field and valued by the labor sector [11].

The steps to follow in PBL for its development are [12]:

1) Initial. It is given by the design of a problem that integrates the contents covered in a topic or subject, situations to be resolved in an interdisciplinary manner, linked to the reality of the student or professional practice. Previously learned knowledge, operations, procedures, methods, and values must be considered.
2) Orientation. The teacher proposes the problem for resolution with the use of the knowledge, skills and habits learned related to the problem. It is important that the teacher be as precise and clear as possible in the explanation, that he establishes the rules to be followed during the execution phase and provides all the necessary guidance for the search of information, but without establishing the solutions, these must be determined by the students themselves.
3) Execution. The group is divided into small work teams, made up of three or four students, for the collective reconstruction of knowledge; the proposal of possible solutions; the selection of the one that they consider most favorable and the application of the knowledge, skills, and habits to solve the problem. The students must use search, selection, recovery, and analysis strategies for the necessary and timely information that facilitates the characterization and understanding of the problem, as well as elaborate solution strategies or design their own procedures.
4) End. Once the problem has been solved, the student members of each team will make an individual and collective assessment of the results obtained, as well as the route used. The results can be shared through a presentation, a course work, or another modality that the teacher deems appropriate.

The use of PBL generates a positive effect on the academic performance and learning of students by focusing on real situations that encourage the students to recognize the usefulness of mathematics [13]. Students recognize that PBL promotes the continuous support of the teacher, and the construction of knowledge in situations that help understand the meaning and importance of the contents.

Also, PBL allows group work, which fosters skills in consulting databases to obtain information that makes it easier to address the problem with arguments based on academic sources. In addition, PBL encourages the establishment of agreements, the dialogue, the group progression towards the fulfillment of objectives, the collaboration, and the search for alternatives during the training process [14].

The evaluations made by students regarding the use of PBL highlight the usefulness of technological tools used in a collaborative work environment that have a favorable impact on the resolution of problems close to work reality [15]. PBL allows students to perceive a better mastery of their competencies; greater academic performance is obtained, as well as a positive assessment of their learning achievements. PBL encourages constant interaction between colleagues, favors self-regulation and the development of solutions to problems that influence the consolidation of arguments to defend their proposal. PBL recognizes the teacher's disposition and skills with respect to planning, implementation and feedback combined with a level of disciplinary knowledge [16].

PBL motivates students to learn the subject and promotes collaborative work among participants to achieve the goal of solving the problem. Also, support materials in digital format are effective tools to achieve better learning results [17].

PBL encourages dynamic sessions compared to the traditional method, promotes greater understanding of the contents, encourages teamwork, and contributes to strengthening the capacity for analysis and synthesis [18]. PBL provides significant benefits to students in their skills in argumentation and presentation of the solution strategy, teamwork, leadership, and use of information technologies [19]. It is necessary that PBL be adapted to the specific conditions and situations of the subject field for successful implementation. Furthermore, PBL is oriented towards creating learning opportunities through effective interactions and collaborative work [20].

PBL substantially improves the mathematics learning process in students because they strengthened their skills when faced with solving a problem. Furthermore, it encourages research and a high understanding of the knowledge acquired during the training process [21].

Mathematical competencies involve logical thinking, understanding of concepts, formulas with their procedures, as well as providing arguments to validate the strategy for solving a problem [22], [23].

The development of mathematical competencies is gradual; for this reason, it is necessary to identify their levels of development to implement training practices aimed at their consolidation in students [24]. According to Georgieva *et al.* [25] the mathematical competencies are: Mathematical thinking; mathematical reasoning; mathematical modeling; mathematical tools; skills to apply mathematics in other areas, as well as the representation and communication of results.

Also, it is important to ensure that students understand mathematics because it is a relevant tool in the real world. If the teaching of mathematics is carried out through adequate guidance that involves a permanent interaction between the teacher-student-colleagues with the purpose of exploring, classifying, abstracting, strategy argument and estimating to reach results, and being able to interpret them and communicate them to the others [26].

In the case of the postgraduate level, mathematics is an important formative axis for decision-making in the organizations in which students work. Ho *et al.* [27] emphasize that the training of graduate-level administrators is important because organizations face a growing volume of quantitative information, which is why they require their human capital to have professional preparation that allows them not only to select and organize, but also to analyze, synthesize, and evaluate information in order to design and implement actions for decision-making for the benefit of the company in which they work.

Dituri *et al.* [28] affirm that focusing on mathematical problems is an effective means to promote quality education that generates a better positioning of human capital. Various technological tools facilitate the development of mathematical notions in students, encourage the organization and analysis of data combined with graphical representation and calculation in efficient ways, which promotes the capacity for abstraction [29], [30]. Cano-Iglesias *et al.* [31] point out that promoting mathematical skills has a positive impact on others such as digital skills, oral and written communication, initiative, time management, and entrepreneurial spirit.

Campaign *et al.* [32] establish that it is essential to promote dynamic learning based on the experiences and contexts of the students to involve them in their educational path to promote both the development of mathematical skills and attitudes towards them in a positive way.

3. Materials and Methods

The research approach used was quantitative with a correlational scope because it focused on assessing the effectiveness of PBL during the new normal (2023-2), which corresponds to a case study of postgraduate students in administration.

A total non-probabilistic sample of 29 participated in the study (88% women and 12% men) with an average age of 29.7 years (SD=2.4). The students correspond to a postgraduate degree in administration taught by the National Polytechnic Institute in the subject of Mathematics Applied to Administration.

The PBL didactic intervention was based on four moments indicated in Figure 1.

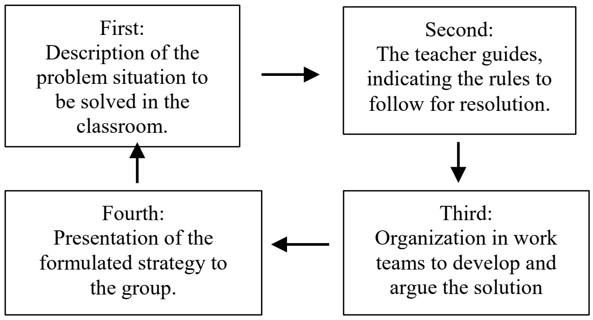

Figure 1. PBL moments used

The instrument used was the questionnaire to obtain information on the effectiveness of PBL. The dimensions of the instrument were: 1) Student assessment of the use of PBL based on a Likert scale (1 – totally disagree to 5 – totally agree) and 2) Mathematical training with a scale from 0 (not developed) to 4 (highly developed).

The application procedure was at the end of the course where the students were invited indicating the objective of the study, as well as the confidentiality and anonymity of their responses. The data were organized with the SPSS 25 statistical program, which allowed us to calculate: descriptive statistics such as the mean (M) and standard deviation (SD), the Shapiro-Wilks test and Pearson correlations (r) with a level of significance (p) of 0.05.

4. Results and Discussion

The students' highest evaluations of their training experience through PBL were: The usefulness of the contents for the business environment (M= 4.83); greater motivation for mathematical learning (M=4.82); the use of technological tools (4.81); constant and timely teaching support (M = 4.80); the development of the sessions through problems in the course (M = 4.79) and quality in training (M = 4.78). These results confirm what was stated by [14], [16], [17].

Regarding the development of mathematical competencies promoted by PBL, the results are shown in Table 1.

Table 1. Descriptive statistics

The PBL promoted the mathematical competence for	M	SD
Identify the main data of the problem to be solved	3.78	0.21
Formulate the variables of the problem in mathematical form	3.75	0.23
Use mathematical language	3.66	0.29
Build the solution strategy	3.62	0.32
Elaborate mathematical arguments	3.39	0.41
Use digital tools to develop and present the strategy	3.82	0.18
Interpret the results	3.55	0.27
Determine decision making for the administrative field	3.54	0.31
Recognize the importance of mathematical knowledge	3.83	0.14

Based on Table 1, the assessment made by the postgraduate students regarding their mathematical training found that the competencies with a high level of development are: Recognize the importance of mathematical knowledge (M = 3.83, SD = 0.14); use digital tools (M = 3.82, SD= 0.18); identify the main data of the problem (M = 3.78, SD = 0.21); mathematically formulate the variables (M= 3.75, SD= 0.23); use mathematical language (M= 3.66, SD= 0.29) and build the solution strategy (M= 3.62, SD= 0.32). These results indicate that participants recognize that PBL is effective in promoting their mathematical competencies at the postgraduate level. Therefore, what was indicated by [23], [24], [25] is confirmed.

The significant direct associations were: Greater satisfaction regarding the use of technology (r = 0.789, p = 0.00); with their academic performance (r = 0.854, p = 0.00); promote collaborative work (r = 0.811, p = 0.00); encourage mathematical learning (r= 0.791, p = 0.00); analyze and discuss the contents through problems (r = 0.825, p =0.00). These results coincide with what was pointed out by [13], [15]. Consequently, the students have acquired a consolidated mastery of these mathematical competencies that will allow them to position themselves in the organization they currently work for or have the possibility of accessing a better professional position in the short term.

5. Conclusion

The research carried out is important because it is oriented towards mathematical training at the postgraduate level based on an active methodology such as PBL. This study is useful because it provides results on the effectiveness of PBL based on the use of digital tools, which promotes collaborative work and mathematical learning, so the objective was met.

The results found indicate the relevance and usefulness of PBL because it generates training spaces in combination with digital materials that influence both the participation and motivation of students. In addition, PBL promotes collaborative work and communication with students. Also, PBL allows the teacher to be a guide in each session and for the activities to focus on solving problems based on professional practice.

Furthermore, the research is useful because it was oriented towards student assessment as a relevant component of the quality with which an educational program is taught at the postgraduate level. In this sense, the student assessments indicate the transfer and usefulness to the workplace, which implies quality in the training received.

Therefore, the findings determine a high effectiveness of PBL in the mathematical training of postgraduate students, which generates an educational quality that makes its continuous incorporation as an active methodology that favors the development of mathematical competencies relevant.

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References:

[1]. Pérez-Escolar, M., & Navazo, P. (2019). Activismo y narrativas gamificadas: estudio comparativo de entornos ciberdemocráticos de empoderamiento ciudadano. *CIC. Cuadernos de Información y Comunicación, 24*, 31–46. Doi: 10.5209/ciyc.64842

[2]. Vuorikari, R., Velicu, A., Chaudron, S., Cachia, R., & Di Gioia, R. (2020). *How Families Handled Emergency Remote Schooling During the Covid-19 Lockdown in Spring 2020.* European Commission: JRC Science for Policy Report. European Commission. Doi: 10.2760/31977

[3]. Sánchez, C., Santiago, R., & Sánchez, M. (2021). Teacher digital literacy: the indisputable challenge after Covid-19. *Sustainability 13*(4), 1858. Doi: 10.3390/su13041858

[4]. Vilela, P., Sánchez, J., & Chau, C. (2021). Desafíos de la educación superior en el Perú durante la pandemia por la COVID-19. *Desde el Sur, 13*(2), 1-11. Doi: 10.21142/des-1302-2021-0016

[5]. Hansen, J. (2006) Using Problem-Based Learning in Accounting. *Journal of Education for Business, 81*(4), 221-224. Doi: 10.3200/JOEB.81.4.221-224

[6]. Del Valle, A. & Villa, N. (2021). Aprendizaje Basado en Problemas: Una propuesta metodológica con futuro. In Escribano & Del Valle (Eds.). *El Aprendizaje Basado en Problemas (ABP): Una propuesta metodológica en Educación Superior*. Alfaomega Editores.

[7]. Cristancho, D. & Cristancho, L. (2018). Aprendizaje basado en problemas en matemáticas: el concepto de fracción. *Educación y Ciencia*, (21), 45-58.

[8]. Rubinsten, B., & Moreno S. (2021) El aprendizaje basado en problemas: una propuesta de cualificación docente. *Praxis & Saber*, *12*(31), 36-51. Doi: 10.19053/22160159.v12.n31.2021.11174

[9]. Bermúdez, J. (2021). El aprendizaje basado en problemas para mejorar el pensamiento crítico: revisión sistemática. *Innova Research Journal, 6*(2), 77-89. Doi: 10.33890/innova.v6.n2.2021.1681

[10]. La Barbera, R. (2013). The relationship between students' perceived sense of connectedness to the instructor and satisfaction in online courses. *Quarterly Review of Distance Education, 14*(4), 209–220.

[11]. Santos-Ellakuria, I. (2019). Fundamentos para el aprendizaje significativo de la biodiversidad basados en el constructivismo y las metodologías activas. *Revista de Innovación y Buenas Prácticas Docentes, 8*(2), 90- 101.

[12]. Espinoza, E. (2021). El aprendizaje basado en problemas, un reto a la enseñanza superior. *Conrado*, *17*(80), 295-303.

[13]. Quinzo, J., Zamora, A., Paredes, G., Trujillo, E., & Muriel , O. (2023). Incidencia del ABP en el Aprendizaje de las Matemáticas en alumnos de tercero de Bachillerato de la Unidad Educativa Santa Rosa. *Ciencia Latina Revista Científica Multidisciplinar*, *7*(5), 112-139. Doi: 10.37811/cl_rcm.v7i5.7616

[14]. León, R. (2023). El aprendizaje basado en Problemas (ABP) en una asignatura teórica sobre el estudio de las ideas y la producción de conocimiento en Trabajo Sociail: Estudio de una experiencia pedagógica. *Revista de Trabajo Social*, (98), 56-74. Doi: 10.7764/rts.98.56-74

[15]. Quintanal, F. (2023) Aprendizaje basado en problemas para Física y Químicade Bachillerato. Estudio de caso. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias 20*(2), 2201.

[16]. Araya, P. (2023). El Aprendizaje Basado en Problemas como estrategia de seguimiento de las competencias del perfil de egreso. Una experiencia en Ingeniería Civil en la Universidad de Valparaíso. *Educatio Siglo XXI, 41*(2), 11-38.

[17]. Gómez-del Río, T. (2022). Aplicación de una metodología de PBL y clase inversa a un curso de laboratorio en Ingeniería Mecánica. *RELATEC, Revista Latinoamericana de Tecnología Educativa, 22*(1), 191-206. Doi: 10.17398/1695-288X.22.1.191

[18]. Rodríguez, R., Angulo, L., & Leitón, N. (2020). Desarrollo de la metodología de aprendizaje basado en problemas en un curso de ingeniería. *Revista Educación en Ingeniería*, *15*(30), 26-33.

[19]. Borah, N. Paudel, S. & Stivers, A. (2023): Comparing the effectiveness of case-based learning and problem-based learning in a core finance class. *Journal of Education for Business*, *99*(2), 113-124. Doi: 10.1080/08832323.2023.2277272

[20]. Yusof, K., Tasir, Z., Harun J. & Helmi, S. (2005). Promoting Problem-Based Learning (PBL) in Engineering Courses at the University Technology Malaysia. *Global Journal of Engineering Education, 9*(2), 175-184.

[21]. Hidalgo, H., Mera, E., López, J. & Patiño, L. (2015). Aprendizaje basado en problemas como potencializador del pensamiento matemático. *Plumilla Educativa, 15*(1), 299-312. Doi: 10.30554/plumillaedu.15.845.2015

[22]. Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In Griffin, P., McGaw, B., Care, E. (Eds). *Assessment and Teaching of 21st Century Skills*, 17-66. Springer. Doi: 10.1007/978-94-007-2324-5_2

[23]. Niss, M. (2015). Mathematical Competencies and PISA. In Stacey K. (ed.), *Assessing Mathematical Literacy: The PISA Experience*, 35-56. Springer.

[24]. Griffin, P., & Care, E. (Eds.). (2014). Assessment and teaching of 21st century skills: Methods and approach. Springer. Doi: 10.1007/978-94-007-2324-5

[25]. Georgieva, D., & Georgieva-Trifonova, T. (2023). Developing mathematical competencies through makeblock mBot Programming in Computer Modelling Education. *TEM Journal, 12*(4), 2437-2447. Doi: 10.18421/TEM124-56

[26]. Vélez Córdova, J. del R., & Arteaga Pita, I. G. (2022). Aprendizaje Basado en Problemas en el aprendizaje significativo de la asignatura de Matemáticas. *Revista Cognosis*, *7*(3), 41–54. Doi: 10.33936/cognosis.v7i3.5114

[27]. Ho, G., Lam, C. & Law, R. (2023). Conceptual framework of strategic leadership and organizational resilience for the hospitality and tourism industry for coping with environmental uncertainty. *Journal of Hospitality and Tourism Insights, 6*(2), 835-852. Doi: 10.1108/JHTI-09-2021-0242

[28]. Dituri, P., Davidson, A., & Marley-Payne, J. (2019). Combining financial education with mathematics coursework: Findings from a pilot study. *Journal of Financial Counseling and Planning, 30*(2), 313–322. Doi: 10.1891/1052-3073.30.2.313

[29]. Fernández, I., Riveros, V. & Montiel, G. (2017). Software educativo y las funciones matemáticas. Una estrategia de apropiación. *Omnia, 23*(1), 9-19.

[30]. García, E. (2015). La evaluación del aprendizaje: de la retroalimentación a la autorregulación. El papel de las tecnologías. *Relieve: Revista Electrónica de Investigación y Evaluación Educativa, 21*(2), 1-24. Doi: 10.7203/relieve.21.2.7546

[31]. Cano-Iglesias, M., Franco-Mariscal, A. & Blanco-López, A. (2021). *Secuencia de actividades de argumentación para estudiantes de ingenierías industriales*. Graó.

[32]. Campaña, R., Gallego, M. & Muñoz, F. (2019). Estrategias de enseñanza para la adquisición de competencias en formación profesional: perfiles de estudiantes. *Educar, 55*(1), 203-229. Doi: 10.5565/rev/educar.876