Problem-Based Learning (PBL) as a methodology to strengthen mathematical skills —problem solving— in Basic Education

El Aprendizaje Basado en Problemas (ABP) como metodología para fortalecer la competencia matemática —resolución de problemas— en Educación Básica

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Abstract

Introduction: Problem solving is considered a cross-cutting strategy that gives meaning to the teaching-learning process and creates new environments that promote the development of mathematical skills. **Objective**: To analyze the influence of PBL in the development of mathematical problem-solving skills in middle school students. **Methodology**: A quantitative study with a quasi-experimental design involving pre-test and post-test, carried out in three phases: characterization of the problem-solving skills, experimentation based on implementation of the PBL methodology, explanation of the assessment of strengths and difficulties in acquiring the skills. **Results**: It is shown that the implementation of the PBL methodology manages to improve the skill performance levels by optimizing the processes of phase 1 (understanding of the problem) and phase 3 (execution of the plan). **Conclusions**: Mathematical problem-solving skills are enhanced through processes that combine complementary cognitive and procedural activities related to the particular context and the formal structures that comprise mathematical knowledge.

Keywords: Problem-based learning; problem solving; mathematical competence; teaching strategy; basic education

Resumen

Introducción: La resolución de problemas es considerada una estrategia transversal que da sentido al proceso de enseñanza-aprendizaje y a la configuración de nuevos ambientes que promueven el desarrollo de competencias en matemáticas. **Objetivo**: Analizar la influencia del ABP en el desarrollo de la competencia matemática resolución de problemas en estudiantes de básica secundaria. **Metodología**: Corresponde a un estudio cuantitativo de diseño cuasi-experimental con prueba pretest y postest, desarrollado en tres fases: caracterización de la competencia resolución de problemas, experimentación a partir de la implementación de la metodología ABP, explicación de la valoración de fortalezas y dificultades en la competencia. **Resultados**: Se demuestra como la implementación de la metodología ABP logra mejorar el nivel de desempeño en la competencia optimizando el proceso en la fase 1 comprensión del problema y fase 3 ejecución del plan. **Conclusiones**: La competencia matemática resolución de problemas se potencia a partir de procesos que integren de manera complementaria la actividad cognitiva y procedimental en relación con el contexto particular y las estructuras formales que configuran el conocimiento matemático.

Palabras clave: Aprendizaje basado en problemas; resolución de problemas; competencia matemática; estrategia de enseñanza; educación básica

Introduction

The development of problem solving skills is considered one of the key purposes of mathematical education (Godino et al., 2019; Juandi, 2021). According to the Colombian National Education Ministry (MEN, by its acronym in Spanish), problem solving is a process that effectively contributes to achieving major goals that promote the country's technical-scientific and social development (Martínez et al., 2020; Ministerio de Educación Nacional [MEN], 2006). In this context, the educational objectives of mathematical education in the primary and secondary cycles are aimed to developing in students capacities to reason, formulate, model, communicate and solve problems by mastering the various numeric, logical, geometric, metric, algebraic and analytical systems, thereby enabling them to develop their mathematical thinking and advance to increasingly complex competence levels, allowing them to adequately perform in different situations (Díaz and Díaz, 2018).

The development of mathematical problem-solving skills requires presenting significant situations that are of interest to students and that are related to their objectives, possibilities and socio-cultural context (Lein et al., 2020), because this creates a suitable environment for the development of mathematical thinking (Vásquez, 2021). The formulation of problem situations should arise from the students' immediate context, or distant but significant situations, and should also acknowledge and involve other disciplines (Espinoza and Triminio, 2018). Such a context encourages students to search for and use different strategies; to find, compare and interpret results, and to reason and create other problems in an assertive manner (Hudha et al., 2023). In this regard, studies such as those by Gamarra and Pujay (2021) conclude that students must develop skills of this type that enable them to better face changing, diverse and often problematic situations in their lives (Yendra et al., 2023).

Consequently, mathematical activity is considered to be useful not only in itself, but also for understanding everyday life and for structuring thought in a manner that enables the subjects to interact with their environment and create interconnected networks, which implies guiding their educational process towards this area (Instituto Colombiano para la Evaluación de la Educación [ICFES], 2018; Godino et al., 2019). In this context, problem solving is considered a cross-cutting strategy for the transformation of the students' cognitive processes by assigning meaning to the teaching and learning process, and by configuring new contexts that promote the development of mathematical skills (Herrera-Sánchez et al., 2018; Szabo et al., 2020).

The results of the PISA tests (ICFES, 2017; 2020) on mathematical problem-solving skills indicate that even though the gap compared to the best-performing countries has narrowed, only approximately 11.4% of Colombian students displayed outstanding performance, while the other participants failed to achieve the basic level, or level 2. The best results are achieved when students are able to perform, for example, basic processes involving the application of formulas, procedures with integers, the use of algorithms, and extracting relevant information from a single source to solve problems (Organization for Economic Cooperation and Development [OECD], 2019). Even though Colombia has made significant progress in this area, the results show that it remains below average compared to other participating countries.

This scenario gives rise to questions aimed at establishing: How does the PBL methodology influence the development of problem-solving skills in ninth grade students? How do students perform problem-solving mathematical activities? Which practices enhance and limit the development of these skills? Consequently, this study intends to assess the influence of the PBL methodology in the development of mathematical problem-solving skills in ninth-grade students. To this end, we first contextualize the framework of problem-solving skills and problem-based learning from a didactic perspective. Then we present the methodology based on a quantitative approach and a quasi-experimental design in line with the variables of the study and the phases that characterize the problem-solving skills. A description is provided of the experiment carried out involving the implementation of the PBL methodology and an assessment of the strengths and difficulties in acquiring the skills, to lastly conclude on the proposed objective.

Literature Review

Problem-solving as a mathematical skill

The research studies that have addressed the problem-solving process have taken different approaches that involve perceptions and meta-cognitive, heuristic and logical strategies, always emphasizing that students play an active role in acquiring patterns and rules that enhance knowledge of these skills (Klang et al., 2021). However, all the studies agree that the development of mathematical problem-solving skills implies not only knowledge of the concepts, skills and abilities related to procedures and argumentation, but also the student's good disposition and attitude to understand and act in a responsible manner in the mathematical activity, individually or as part of a group (Jäder et al., 2020; García-Moya et al., 2020). Therefore, the problem-solving process should allow the student to experiment directly in the development of his/her own mathematical knowledge and in putting it into practice in his/her surrounding environment (Nurkaeti, 2018; Rosero-Calderón and Ardila-Muñoz, 2022; Nantha et al., 2022).

Problem-solving methods emphasize the activities that each subject must carry out, following a series of steps or phases, which include the processes of understanding, planning, execution and supervision. Such methods include those proposed by Schoenfeld (1985), Dunlap and McKnight (1980), Gagné (1985), Brandsford and Stein (1984) and Mayer (1983), among others. However, the most renown method is the one proposed by Polya (2004), because it is the model followed by the other methods to improve the problem-solving process. This method presents the following four-phase heuristic process:

1. *Understand the problem*: Identify the information, such as data, symbols or words presented in the problem, and transform its enunciation into a more understandable form, which may include tables, graphs or drawings.
2. *Develop a plan*: Review similar problems, or involve known procedures, or divide it into sub-problems.

3. *Execute the plan*: Implement strategies until the problem is fully solved, verifying and demonstrating the accuracy of the procedure.
4. *Verification of the solution*: Confirm the result and assess the procedure used to achieve the goal.

These processes or phases are proposed as guidance to enable the student to apply the knowledge and skills acquired previously to advance his/her own development of problem-solving skills, and are not presented as a means to obtain correct results.

In view of the consistent and understandable structure set out by the Polya method (2004) for the characterization of problem-solving skills and its direct relationship with the curricular guidelines (MEN, 1998), and mathematical skills standards (MEN, 2006), as foundations for the development of mathematical thinking, this study follows this approach.

Characterization of Problem-based Learning

The Problem-based Learning –PBL– methodology enables linking the pedagogical principles with the student's learning context, in order to propose an educational alternative that promotes the students' active participation in developing their own knowledge and a comprehensive education (Hendriana et al., 2018; Maskur et al., 2020). In this manner, PBL promotes the development of skills focused on the identification of real solutions, comparisons and information analysis, the formulation of strategic actions, teamwork, monitoring of the process and all the activities involved in problem solving. At the same time, it promotes among students the acquisition of specific knowledge about the discipline, and strengthens the specific skills of the area (Ortiz & Vega, 2020). It is based on the constructivist principles set out by Piaget (1964), Vygotsky (1973) and the principles of significant learnings proposed by Ausbel et al. (1989), among others. According to these principles, learning is a process that the subject directly decides to undertake, associated with his/her interaction and communication with his/her physical and social environment. In this case, the student and teacher take on specific roles in order to achieve significant learning through problem solving.

PBL conceives learning as an ongoing and active process of discovery in which the need to solve a problem leads the student to establish relationships between previously learned cognitive structures and the new arrangements to obtain a solution to the proposed problem (Da Silva et al., 2018). By proposing targeted problems, the teacher guides the class while maintaining control over the theory and algorithms required to find the solution (Padilla and Flórez, 2022; Tapia-Vélez et al., 2020). On their part, the students carry out discussion activities, identify difficulties and missing information, share ideas and define strategies to advance their understanding and solve the problem.

During this process the student maintains an attitude of engagement, commitment, autonomy, participation, responsibility for his/her own education and his/her role in the group to successfully complete the assigned task. Meanwhile, the teacher takes on the role of guide, coach and mediator between the knowledge and the procedures carried out by the students, proposing targeted activities that promote the acquisition of knowledge through substantial relationships (non-arbitrary) and acknowledging the student's significant context in order to advance his/her development level (Vera et al., 2021).

In this context, the problem-solving process using the PBL methodology is described as an activity with applications in educational mathematics, because it is not simply about developing procedures, but about bringing into action thinking skills, creativity and logical-mathematical reasoning to develop significant learning that can be applied to different daily situations both in real life and the educational context.

Methodology

Research approach

This study uses a quantitative approach of the quasi-experimental type, which enables taking measurements, in this case of the dependent variable (*Vd* = problem-solving skills), in response to the stimulus or the independent variable (*Vi* = Problem-based Learning) (Hernández-Sampieri and Mendoza, 2018). This methodological approach allows monitoring the performance of the studied group through the relationship between the variables (*Vd* – *Vi*), to finally asset the influence of PBL in the development of these mathematical skills.

Research design

The study uses a pretest and posttest design with a single group (Hernández-Sampieri and Mendoza, 2018). This design allows maintaining the same group members intact, in this case, the students of grade 9A, a group created according to institutional criteria since the beginning of the school year (before the experiment), who take the tests in order to observe the effects of the independent variable on the dependent variable.

Systematization of the variables

Table 1 shows the systematization of the variables, identified as:

*G*1 = Intervention group;

*P*1 = Pretest - diagnosis;

X = Stimulus – treatment through application of the didactic unit;

*P*2 = Posttest.

Table 1. *Systematization of the variables.*

	Vd: Problem-solving skills			
*G*1	P1: Application of the pretest, diagnosis	*X*: Application of PBL - didactic unit	*P*2: Application of the posttest	*G*1: Hypothesis verification results
	Pretest Measurement 1	Stimulus or treatment	Posttest Measurement 2	
	Vi: Problem-based Learning			

Source: Prepared by the authors.

Table 1 shows that the intervention group – $G1$ takes a pretest – $P1$ to assess their problem-solving skills = *Vd*. Then the stimulus/ treatment – X is applied using Problem-based Learning = *Vi*. Lastly, the posttest – P2 is applied to once again to assess the *Vd* and to verify the hypothesis. The hypotheses of the study are expressed as:

- *General hypothesis* (*HG*): The implementation of the didactic unit using the problem-based learning methodology develops mathematical problem-solving skills.
- *Research hypothesis* (*HI*): The measurement of the posttest result is greater than the pretest result.
- *Null hypothesis* ($H0$): The measurement of the posttest is not greater than the pretest results, or there is no significant difference between the results of the two measurements.

Sample population

This study was carried out with students of a municipal high school in the city of Cúcuta, in the department of Norte de Santander (Colombia). It is a government educational institution that offers formal education academic programs and study plans approved by the MEN to issue certificates and titles to academic and technical high school graduates. The student population is identified as coming from socioeconomic levels 1, 2 and 3, mainly from lower socioeconomic levels. Ninth grade students are in the age range of between 14 and 18 years old. Table 2 describes the studied population.

TABLE 2. *Study population.*

Ninth grade	Shift	No. of students
A	Morning	36
B	Morning	33
C	Morning	32
Total	101	

Source: Prepared by the authors.

The sample is made up of the students in grade 9A, which is the last grade of basic education that takes the Saber tests.[1] Group A was selected because it met the criteria of willingness of the teacher and all the students to take the tests, compatibility of schedules according to the school hours established by the institution, signing and authorization of the informed consent by all the students in the class.

[1] The Saber Tests are periodic assessments made to basic and middle education students in Colombia. The Saber tests are taken by basic education students in grades 3, 5, and 9, and their purpose is to monitor and control the development of basic skills in a manner that fulfills the educational and quality objectives of the Colombian educational system.

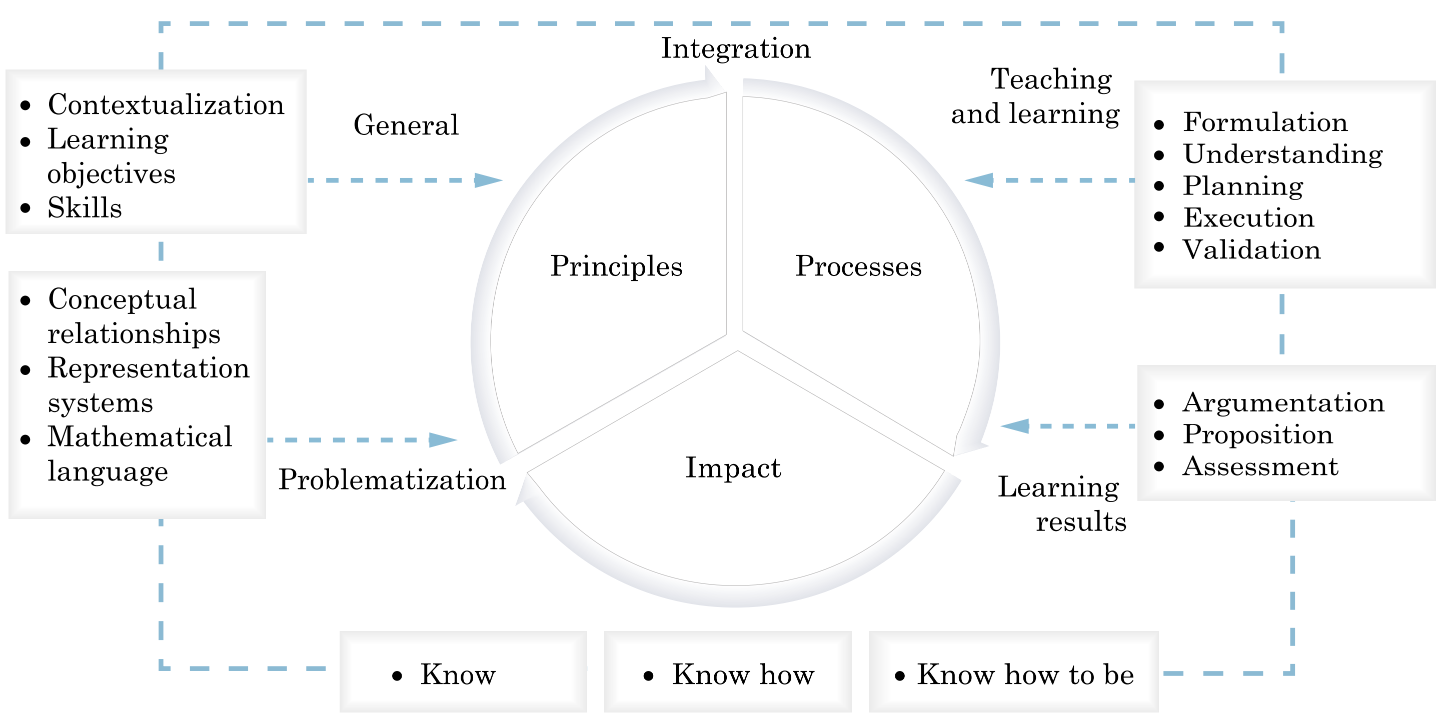
Information gathering technique and instruments

The information was gathered using the survey technique, using as instruments the pretest-posttest questionnaires and the didactic unit. The pretest and posttest questionnaire consisted of four problems addressing the contents of the solids area —geometric figures and basic arithmetic operations. These problem situations were proposed and adapted in accordance with the curricular guidelines, mathematical skills standards and the conceptualized problems contained in the Saber 9 Tests, with a total of 15 multiple-choice questions with single answers in accordance with the Saber Tests (MEN, 2022).

The questionnaire assessment dimensions were based on the four phases involved in the problem solving process (Polya, 2004): understand the problem, conceive a plan, execute the plan and review the obtained response. The scale used to assess the problem solving performance level was obtained from score ranges similar to those used by the Saber Tests (MEN, 2022): from 1.0 (lowest score) to 5.0 (highest score). The description assigned to each indicator of the four performance levels was: insufficient (1 point – 2.3 points), minimum (2.4 points – 3.4 points), satisfactory (3.5 points – 4.5 points) and advanced (above 4.6 points).

The didactic unit is the stimulus/treatment, whose purpose is to strengthen problem-solving skills through the PBL methodology. The didactic unit was designed to incorporate the phases of the PBL methodology (Moust et al., 2007; Pérez, 2018), and problem solving (Polya, 2004). The outcome was the structure of the didactic unit (Figure 1):

Figure 1. *Integration of the didactic unit - PBL methodology.*



Source: Prepared by the authors.

Figure 1 presents the structural parts of the didactic unit: principles, processes, impact. The principles consist of communicating the general aspects and pedagogical-didactic orientations for their development. It addresses the theoretical constructs that refer to the conceptual elements that support the mathematical procedures to be carried out. The processes refer to performance of the teaching-learning process and the learning results. The impact describes the assessment of the mathematical skills achieved in connection with the application of the PBL methodology and the didactic unit (Flórez-Nisperuza and González-Rivas, 2021).

In this case, it includes skills related to Knowing: reasoning, argumentation and formulation of mathematical procedures, algorithms and representations used to solve problem situations. Doing: in diverse contexts with complex situations that involve command of the concepts and procedures for solving problem situations. *Being*: promote an attitude of persistence and critical reflection in decision-making and solving problem situations in the classroom and with others, as a learning context.

Instrument validation technique

The questionnaires and the didactic unit were reviewed and submitted to validation based on the opinion of experts in the area of mathematical education and research. The expert researchers offered comments and contributions on how to convert certain ICFES-type multiple-choice questions into open questions that would enable obtaining a thorough understanding of whether the students completed each step of the problem-solving process and allowing them to propose alternative responses.

After making the adjustments, a pilot run of the test was made with a group of 12 students (6 men and 6 women) of class 9C-morning shift at campus two. Four students at the top of the list, four in the middle of the list and the last four on the list were selected, ranked according to their academic grade point average in the second school period. As a result of the test, the obtained Cronbach Alpha value was $\alpha = 8$, which implies that the instrument to be used is reliable.

Systematization of the Procedure

Based on the proposed objective, the methodology was developed in three stages, as follows: 1) Determine the current state of the problem-solving skills. 2) Implement the PBL methodology in order to strengthen problem-solving skills. 3) Compare the problem-solving skill level achieved by the students by means of the pretest and posttest (Páez, 2017). The methodological process of each phase is described below:

Phase 1. *Characterization of the problem-solving skills.* It begins with applying the pretest questionnaire, which was filled out individually. For this test, the students were only allowed to use a pen, pencil, eraser and pencil sharpener. The duration of the test was one hour and a half, during the math class scheduled hours normally attended by all the participating students.

Phase 2. *Experimentation following implementation of the PBL methodology.* It consisted in implementing the problem-based learning methodology through the didactic unit. Seven sessions were held, of one hour and a half each, for two weeks, during the math class hours scheduled by the school. During each session they worked on the activities included in the didactic unit, working in groups, and each student performed the assigned tasks in the assigned group.

Phase 3. *Explanation of the assessment of strengths and difficulties in applying the skills.* Upon completion of the phase 2 sessions, the posttest questionnaire was applied, which was the same one applied in the pretest, with adjustments made to certain question items that were found to contain certain ambiguities and terms that were unknown to the students. The posttest was taken with the same duration and contextual circumstances as the pretest. During this phase, the results from these two questionnaires enabled assessing the strengths and difficulties related to the problem-solving skills of the participating students.

Information processing and analysis techniques

The descriptive statistical analysis of the results from comparing the scores of the pretest and posttest for each problem-solving phase was performed with the support of the SPSS (v.21.0) statistical package. The comparative analysis of before and after applying PBL offers a description of the skills displayed by the students to understand the problem, conceive a plan, execute the plan and review the obtained solution.

Initially the Shapiro-Wilk test was applied to assess the normality of the data set, in this case a sample of less than 50 students. As a result, data parameters were obtained, followed by performance of the Student T test, which is suitable for assessing the existence of significant differences between the scores of the pretest-posttest for each phase, before and after applying the PBL methodology. Lastly, a comparison of problem-solving skills performance is provided.

Results

The results are presented for each of the three phases defined in the systematization of the procedure:

Phase 1. Characterization of the problem-solving skills

We first present the descriptive statistics of the pretest diagnosis, which assess the students' performance in terms of problem-solving skills.

Table 3 shows a "minimum" performance level in the pretest results of the first three phases of the problem solving process. It also displays an "insufficient" performance level for phase 4 "review the obtained solution". All phases have at least one item in which the students' performance is "insufficient", such as: phase 1 - item 4, phase 2 - item 8, phase 3 - item 12, phase 4 - item 16.

TABLE 3. *Descriptions of each phase of the skill - Pretest.*

Phases	Item	Performance				Total
		Insuf	Min	Satisf	Adv	
Understand the problem	Identify the main parts of the problem: the unknowns, data, condition.	5.56%	36.11%	50%	8.33%	100%
	Graphically represent the problem.	11.11%	13.89%	27.78%	47.22%	100%
	Determine whether the condition is sufficient to find the solution.	44.44%	-	-	55.56%	100%
	Detect the existence of unnecessary data.	0%	19.44%	27.78%	2.78%	100%
Conceive a plan	Organize the steps of a strategy to solve the problem.	5.56%	25%	38.89%	30.56%	100%
	Make rough estimates of a problem's result.	13.89%	-	-	86.11%	100%
	Assess the suitability of the problem-solving strategy.	22.22%	63.89%	-	13.89%	100%
	Develop a plan to solve a given problem.	44.44%	33.33%	8.34%	13.89%	100%
Execute the plan	Correctly substitute data in formulas.	27.78%	27.78%	8.33%	36.11%	100%
	Correctly create statements based on the operations.	8.33%	30.56%	44.44%	16.67%	100%
	Recognize procedural errors in the operations.	36.11%	-	-	63.89%	100%
	Accurately perform the calculation procedures.	47.22%	30.56%	-	22.22%	100%
Review the obtained solution	Verify that the obtained result answers the question.	30.56%	44.44%	19.44%	5.56%	100%
	Identify cases in which the same reasoning could be used.	13.89%	52.77%	5.56%	27.78%	100%
	Identify the appropriate answer for a given problem.	13.89%	44.44%	38.89%	2.78%	100%
	Select the answer found from among several statements.	72.22%	-	-	27.78%	100%

Source: Prepared by the authors.

Phase 2. Experimentation through implementation of the PBL methodology

The significant differences between the skill levels of each phase are displayed in Table 4, based on the pretest – posttest results.

Table 4 shows that in phase 1 "*Understand the problem*" there is a positive difference of 0.74 points between the average results and of 0.09 in the standard deviations, which indicates a significant difference in this phase. In phase 2 "*Conceive a plan*" there is a positive difference of 0.60 points between the averages and a 0.06 negative difference in the standard deviations. In phase 3 "*Execute the plan*" there is a significant positive difference of 0.73 points between arithmetic means and of 0.07 in the standard deviations.

Lastly, in phase 4 "*review the obtained solution*" there is a significant positive difference of 0.66 points between averages and of 0.02 in the standard deviations between the results of this phase.

Table 4. *Descriptors of each phase of the skills Pretest – Posttest*

Phases	Test	$\bar{x}$	*S*	*SE*
Phase 1	Pretest	3.336	0.891	0.148
	Posttest	4.080	0.801	0.133
Phase 2	Pretest	3.407	0.768	0.128
	Posttest	4.016	0.832	0.138
Phase 3	Pretest	3.226	0.983	0.164
	Posttest	3.958	0.906	0.151
Phase 4	Pretest	2.801	0.811	0.135
	Posttest	3.463	0.791	0.131

Note. $\bar{x}$ = Mean; *S* = Standard deviation; *SE* = Standard error of the mean.
Source: Prepared by the authors.

Table 5 shows that the students' responses improved in the posttest in each of the four phases. The Student T significance test indicates a significance level of less than 0.05 in all the phases, which implies that the differences between the arithmetic means of the pretest and posttest phases are significant, and we can therefore say that the PBL methodology had a favorable influence on the performance of the ninth grade students' problem-solving skills.

Table 5. *Paired differences between Pretest – Posttest in each phase*

		$\bar{x}$	*S*	SE Lower	95% confidence interval of the difference		*t*	*gl*	Sig.
					Upper	Superior			
Pair 1	PHASE 1 Pretest - Posttest	–0.743	0.995	0.165	–1.080	–0.406	–4.483	35	.000
Pair 2	PHASE 2 Pretest - Posttest	–0.608	0.763	0.127	–0.867	–0.350	–4.782	35	.000
Pair 3	PHASE 3 Pretest - Posttest	–0.732	1.108	0.184	–1.107	–0.357	–3.966	35	.000
Pair 4	PHASE 4 Pretest - Posttest	–0.662	1.129	0.188	–1.044	–0.279	–3.517	35	.001

Note. $\bar{x}$ = Mean; *S* = Standard deviation; *SE* = Standard error of the mean.
Source: Prepared by the authors.

Table 6 shows that the Shapiro-Wilk normality test indicates that the significance of the pretest data is greater than 0.05 in every phase, i.e., it is greater than the error, and consequently we can say that the data fit within normality parameters. However, the significance level of the data obtained in each phase of the posttest is less than 0.05, and consequently they are not parametric.

Table 6. *Normality test*

Phase/test	Phase 1		Phase 2		Phase 3		Phase 4	
	Stat.	Sig.	Stat.	Sig.	Stat.	Sig.	Stat.	Sig.
Pretest	.979	.707	.983	.855	.974	.557	.920	.053
Posttest	.838	.000	.859	.000	.873	.001	.815	.009

Source: Prepared by the authors.

Phase 3.
Explanation of the assessment of strengths and weaknesses in acquiring the skills

A comparative analysis is performed of the average pretest and posttest scores to identify the problem-solving processes that require most attention and to highlight the phases in which the students obtain the highest scores.

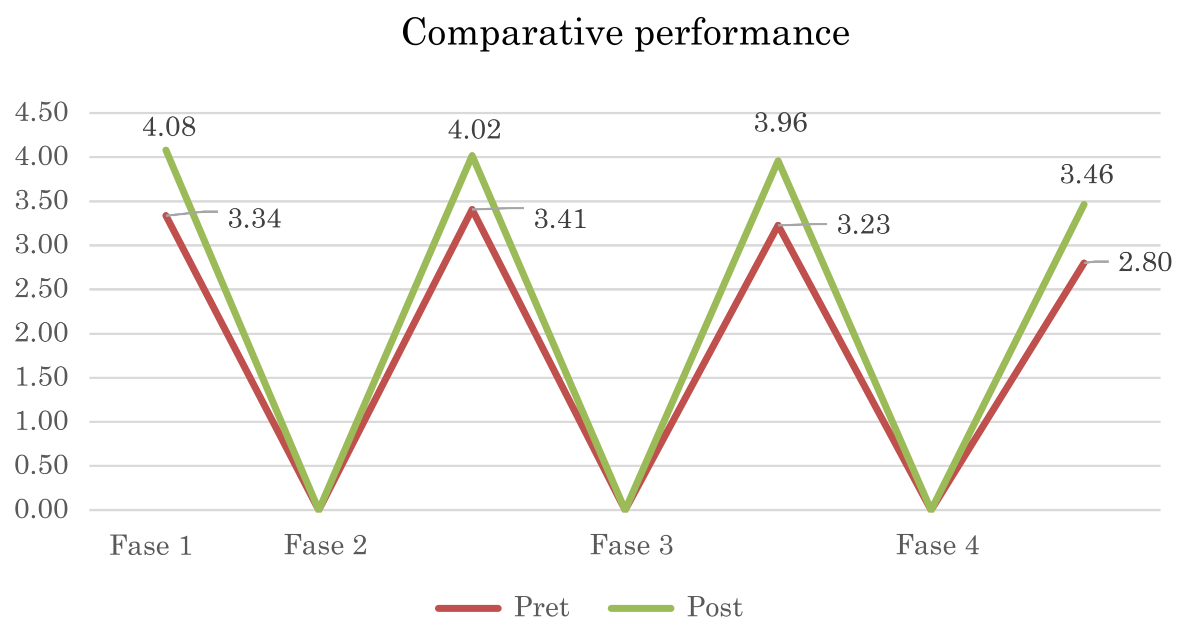
Table 7. *Comparative analysis of pretest and posttest average scores*

Phases	Test	Insuf	Min	Satisf	Adv	$\bar{x}$	S	SE
Understand the problem	Pret	11.1	41.7	38.9	8.3	3.34	0.8911	0.1485
	Post	2.8	8.3	44.4	44.4	4.08	0.8018	0.1336
Conceive a plan	Pret	11.1	38.9	44.4	5.6	3.41	0.7682	0.1280
	Post	2.8	16.7	55.6	25	4.02	0.8323	0.1387
Execute the plan	Pret	16.7	44.4	30.6	8.3	3.23	0.9837	0.1640
	Post	2.8	19.4	38.9	38.9	3.96	0.9068	0.1511
Review the obtained solution	Pret	72.2	0	0	27.8	2.80	0.8119	0.1353
	Post	2.8	52.8	30.6	13.9	3.46	0.7912	0.1319

Note. $\bar{x}$ = Mean; S = Standard deviation; SE = Standard error of the mean.
Source: Prepared by the authors.

Table 7 shows how in general the dispersion level of the scores decreased considerably, which is noteworthy because of the difference between the averages and standard deviations between the two tests. Figure 2 displays a comparison of the performance levels obtained in each of the phases involved in this skill.

Figure 2. *Overall comparison of problem-solving skills performance.*



Source: Prepared by the authors.

Discussion

Regarding phase 1, *understand the problem*, the pretest results indicate that students experience certain difficulties in processes such as the identification of the parts of the problem and the appropriate analysis of reasons and consequences in terms of detecting necessary and unnecessary data for finding a solution. The students displayed greater skill in terms of graphic representation, even though they were not clear on the conditions for finding the solution. In this regard, authors such as Maulyda et al. (2019) and Maher et al. (2018) point out that a didactic and contextualized approach towards the process of building knowledge improves students' performance in mathematical activities.

The traditional approach towards mathematics practice creates strong resistance from students and disinterest in participating in problem-solving activities (Dele-Ajayi et al., 2019). For this same phase, the posttest shows how the PBL didactic sequence strengthens the process of understanding the problem in two dimensions: (1) clarification of the concepts and terms of the problem statement that they find difficult through activities such as discussion, communication of meanings and contextual examples, and (2) identification of the problem's data through reading comprehension, which enables understanding the questions that was asked. These dimensions are considered key processes to promote critical reflection on the application of mathematical knowledge in educational practice and everyday life (Montero and Mahecha, 2021).

In phase 2, *conceive a plan*, the students performed well in processes such as organizing the steps of a strategy to solve the problem; making rough estimates of the results; assess the relevance of a strategy to find a solution, and create a strategy to solve the given problem. However, they displayed little interest in creating or designing the strategy that would lead to obtaining an accurate solution to the problem. Some authors identify these as irreflexive strategies that students often adopt in the absence of plan, which usually result in errors, which should give rise to inquiring on mathematical reasoning styles to offer new practices (Barham, 2020; García-García, 2019). The posttest indicates significantly positive changes in processes such as the formulation of propositions that contribute to solving the problem, the articulation of plausible connections and making a summarized description containing the expressed ideas and explanations. They also generate a greater number of ideas about the problem, greater systematization and organization of the results, selecting the most relevant ones, highlighting the existing relationships between them and making a sketch representing and concluding on the solution para to favor the interpretation and argumentation processes that are typical of these mathematical skills. Some authors attribute these achievements to the students' participation and motivation through learning by doing in math class, guided by significant and contextualized objectives (Hernández-Morales et al., 2019; Salazar-Arbeláez et al., 2020).

In Phase 3, *execute the plan*, the pretest shows that the indicators in which the students display low performance levels are those related to the correct substitution of data in mathematical formulas and the development of statements based on the operations for solving the problem. This situation usually arises due to the failure to communicate and provide argumentation on the work performed with other students and the teacher (Meneses and Peñaloza, 2019).

The posttest displays the strengthening of the skills that enable understanding the purpose of the problem in order to decide on the aspects that must be reviewed more carefully, as well as the additional and missing information required to understand and correctly solve the proposed situation. In this regard, authors such as Gutiérrez-Rodríguez (2018), Jiménez-Espinosa and Sánchez-Bareño (2019) point out the importance of identifying and differentiating the essential information from superficial information in the problem's contents, highlighting their differences, in order to make sure they obtain successful solution strategies and results in the problem-solving process.

In phase 4, *review the obtained solution*, the pretest indicates a general difficulty in verifying the results obtained compared to the question that was asked, and in identifying cases in which the same reasoning could be used in selecting the statement with the correct answer. However, the students display better performance in developing procedures that lead to the answer to the given problem. Some authors such as Harangus (2019) mention that it is important to carry out a process of reading comprehension to improve the process of reviewing, preparing and assessing problem-solving strategies.

In turn, the posttest indicates the strengthening of aspects such as the development of skills to summarize information, prepare reports that demonstrate the knowledge that was acquired, propose reflective and critical discussions on the results, value the information contributed by other team members, and argue about the relevant solutions to the problem. In this regard, some studies agree that when the PBL didactic sequence is applied, skills, abilities and good attitudes increase, while at the same time displaying a favorable change in the skills for solving mathematical problems (Cadena-Zambrano and Nuñez-Naranjo, 2020; Masitoh & Fitriyani, 2018).

Lastly, it was found, based on the p-value obtained in the Student T test, that there are statistically significant differences in every one of the four phases of the skills, based on the pretest and posttest results (Figure 2). It is therefore concluded that the implementation of the PBL methodology considerably improves the defined phases for problem solving in mathematics.

Conclusions

In terms of the proposed objective, it was found that the PBL methodology has a positive influence in developing mathematical skills —problem solving— when the cognitive-conceptual processes are assessed in combination with procedural activities. To this end, it is necessary to integrate the knowledge previously acquired by the students in connection with the practices (planning, contexts, interests, motivations, resources, strategies and interaction) with the formal structure of mathematical knowledge (conceptual networks, symbols, representation systems and mathematical language) established in the goals of mathematical education. The coordinated performance of these processes drives both knowing and doing in a well-proportioned manner in order to become competent in mathematics.

Regarding the question: How do students perform problem-solving mathematical activities? first it is necessary to identify the teacher's mediation role in the students' learning of mathematical knowledge and its application in particular aspects of the context and curriculum, to strengthen decision-making processes, logical reasoning, posing of questions and search for solutions. In addition to incorporating social, emotional and cultural aspects in mathematical activity, it strengthens the development of skills in the area and reduces learning focused on contents.

Use of the PBL methodology significantly improves the students' problem-solving skills, in terms of the processes of understanding the problem and executing a plan. In terms of understanding the problem, it specially strengthens the skills related to the identification of the main parts of the problem, making graphic representations, argumentation of the sufficient conditions to find the solution, and identification of the required data. In terms of executing the plan, it reinforces skills related to correctly substituting data in formulas, proposing statements based on the operations, recognizing errors in operation procedures, and accurate execution of the calculation procedures.

The mathematical processes that display the greatest difficulties are related to the phases of conceiving a plan and assessing the obtained solution. In order to strengthen these processes, it is recommended to carry out activities that promote logical reasoning, abstraction, accuracy, verification of results, careful review of the procedures that were executed and the formulation of statements that are appropriate for the given answer.

Regarding the question "Which practices enhance and limit the development of these skills?" it was found that the PBL methodology promotes a didactive approach towards teaching and learning mathematics, that includes processes such as formulating, setting out and solving problems as an opportunity to achieve significant learning. These activities should be implemented in levels that cover the theoretical rationale – learning, planning – execution of methods and assessment – impact of the mathematical activity to be carried out.

Mathematical practices guided through this approach promote the students' acquisition of new skills and good attitudes that enhance their commitment to learning, building their knowledge and the development of capabilities that will enable them to make good decisions and successfully perform in their personal and academic lives and in the application of mathematics. The difficulty lies in that practices are often limited to posing arbitrary problems outside of any context and executed with a strictly algorithmic approach.

Lastly, it was found that promoting these guidelines in the implementation of PBL also promotes cross-disciplinary work, because it allows incorporating situations from the context of other disciplines, and particularly posing problems based on daily life and classroom experiences. This encourages and motivates students and teachers to develop mathematical practices from a didactic perspective to enhance problem solving skills, as well as learning mathematical knowledge. This enhances the education of people who are capable of addressing any type of situation, enabling achieving the proposed goals through the acquisition of skills and abilities that enable students to successfully perform any task they decide to engage in.

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There are no conflicts of interest in this study between the authors, with the journal or the publishing entity.

Author´s Contribution

Mayra-Alejandra Arévalo-Duarte: Theoretical conceptualization, obtain personal funds to perform the study, construction and development of the methodology, formal analysis with software, project management, definition of physical resources, writing of the original version of the document, validation and visualization of the information, write, review and final editing.

Miguel-Ángel García-García: Theoretical conceptualization, obtain personal funds to perform the study, construction and development of the methodology, writing of the original version of the document, validation and visualization of the information, write, review and final editing.
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