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CÁTEDRA

Problem-Based Learning and its incidence in the teaching-learning process of Chemistry

Aprendizaje basado en problemas y su incidencia en el proceso de enseñanza-aprendizaje de la Química

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Abstract

This research is based on the ongoing search for methodologies that streamline learning, with a specific focus on problem-based learning (PBL) as a key pedagogical challenge to ensure meaningful knowledge acquisition and competency development in students. The methodological strategy was integrated into microcurricular planning, organizing disciplinary knowledge so that students could identify problems relevant to their educational context. Through collaborative group discussion, they formulated conjectures, conducted independent research, and strengthened their capacity to synthesize and disseminate findings for decision-making. The main objective of this study is to analyze the



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impact of Problem-Based Learning on the Chemistry learning process. To this end, the academic performance of students who implemented PBL was compared with those who followed a traditional methodology. A quantitative approach with a quasi-experimental design was adopted, with a sample of 62 participants: 31 in the experimental group and 31 in the control group. These students were in their first year at the Ciudad de Cuenca High School during the 2023-2024 school year and were administered pre- and post-tests, as well as a satisfaction survey. The results of the control group revealed that the majority of students had good average grades, while a smaller number achieved very good average grades. In contrast, the performance of the experimental group was very good, with 100% of the 31 students achieving this grade. It is concluded that the implementation of Problem-Based Learning favors the development of disciplinary competencies with a collaborative approach, conflict resolution, and decision-making in students.

Keywords

ABPr, teaching, Chemistry, educational intervention, academic performance.

Resumen

La presente investigación se fundamenta en la búsqueda constante de metodologías que dinamicen el aprendizaje, con un enfoque específico en el aprendizaje basado en problemas (ABPr) como un desafío pedagógico clave para asegurar la adquisición significativa de conocimientos y el desarrollo de competencias en los estudiantes. La estrategia metodológica se integró en la planificación microcurricular, organizando los saberes disciplinares de manera que los estudiantes identificaran una problemática relevante para su contexto educativo. A través de la discusión grupal colaborativa, formularon conjeturas, desarrollaron investigación independiente y fortalecieron su capacidad de síntesis y difusión de hallazgos para la toma de decisiones. El objetivo principal de este estudio es analizar la incidencia del Aprendizaje Basado en Problemas en el proceso de aprendizaje de la Química. Para ello, se comparó el rendimiento académico de los estudiantes que implementaron el ABPr con aquellos que siguieron una metodología tradicional. Se adoptó un enfoque cuantitativo con un diseño cuasiexperimental, con una muestra de 62 participantes: 31 en el grupo experimental y 31 en el grupo control. Estos estudiantes cursaban el primer año en el Colegio de Bachillerato Ciudad de Cuenca durante el año lectivo 2023-2024, y se aplicaron pre y pospruebas, así como una encuesta de satisfacción. Los resultados del grupo control revelaron que la mayoría de los estudiantes se ubicó en la categoría de promedio bueno, mientras que un número menor alcanzó calificaciones de promedio muy bueno. En contraste, el desempeño del grupo experimental fue muy bueno, con el 100% de los 31 estudiantes alcanzando esta calificación. Se concluye que la implementación del Aprendizaje Basado en Problemas favorece el desarrollo de competencias disciplinares con enfoque colaborativo, resolución de conflictos y toma de decisiones en los estudiantes.

Palabras clave

ABPr, enseñanza, Química, intervención educativa, rendimiento académico.

1. Introduction

Education is a fundamental component for the comprehensive development of both individuals and society as a whole. In this context, the constant search for effective pedagogical methodologies emerges as a relevant challenge to ensure the meaningful acquisition of knowledge and skills by students. This research aims to explore the impact of



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Problem-Based Learning (PBL) on the academic performance of high school students in Chemistry. In this way, crucial questions about its impact on both academic performance and competency development are addressed.

The justification for this research on PBL is based on a theoretical review of updated scientific articles that explain the methodology for its implementation, the evaluation process, the advantages of educational intervention in the teaching and learning process of experimental sciences, among other aspects of interest to the study. The implication of the methodology modifies the way students acquire knowledge and how teachers share it. In the field of chemistry teaching, PBL has been shown to have a significant impact. A review by Bueno (2018) indicates that

the methodology has become an attractive alternative for implementing changes in educational models in higher education, particularly because its learning environment is conducive to the development of higher-order thinking skills, such as critical thinking (p. 91).

Education in the Ecuadorian educational system is undergoing transformations at all levels, with a particular focus on the Baccalaureate (high school) program. These changes seek to improve the quality of instruction students receive and achieve academic excellence. Chemistry, in particular, has applications in multiple fields of industry and scientific research, in addition to being present in many aspects of daily life. Based on a reading of the 2016 National Curriculum for Chemistry, in my personal opinion, I can say that, regarding the teaching of this subject, this level is fundamental for students to develop the foundations of their scientific and cognitive knowledge and skills. This prepares them to face new challenges, increases their self-confidence, and allows them to appreciate their own abilities. It is necessary to consider the importance of this area of experimental sciences, given that it is an element that students at the Educational Unit located in Cuenca, Ecuador, do not always want to take on. This is due to the breadth of the area of knowledge, the lack of strategies and methodologies that streamline learning, the limited ongoing training process for teachers, and the limited understanding of the purpose of their study, which involves technological, digital, and contextualization tools.

Chemistry is perceived as difficult and boring, which implies or translates into a limitation for teachers and students who fail to understand this area of knowledge. Authors such as Flores et al. (2020) state that "students who fall into rote memorization have difficulty acquiring the skills to understand chemical language, much less transfer it to their long-term memory" (p. 20). Given this, there is an urgent need to implement innovative teaching strategies that transcend and encourage participation in the teaching-learning process.

Researchers such as Varela et al., (2021) provide the guidelines in their studies to recognize the validity and relevance of including methodologies that focus on learning and that use real-world problems as a context for students to learn chemical skills in problem solving and achieve academic success. For their part, Parra et al. (2022) state that, "it is one of the most important strategies to develop students' skills in the training process, the application of which will form the basis for the necessary qualitative changes in personality" (p. 101). Likewise, Freire et al. (2021) demonstrate that, "meaningful learning helps to develop, pose, consult, solve exercises and problems, as a complement to PBL applied to the learning of



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homogeneous and heterogeneous fractions and relate them to the real context of students" (p. 498). Guamán and Espinoza (2022) indicate that, "the individual comes to learn through the experience acquired in relation to the world" (p. 126).

Based on the above, teaching and learning Chemistry is a tedious and complicated process, and achieving learning outcomes is an even more difficult process. In this sense, it is of great importance to include PBLr as a methodology that energizes students' learning and, therefore, improves their performance, satisfaction, and develops skills inherent to their disciplinary study. PBLr is a pedagogical methodology that has been developing strongly in recent years. It is characterized by the fact that "integration in medical education breaks down boundaries between different departments and leads to greater connectivity between different disciplines due to the dissolution of barriers" (Dasgupta, 2020, p. 63).

In the field of Chemistry teaching, PBLr has demonstrated a significant impact. A review by Hmelo-Silver (2004) notes that, "one of the main advantages is increasing student motivation. Since learning questions arise from the problem (in response to students' need to know), intrinsic motivation should be enhanced" (p. 259). Furthermore, more recent studies have shown that this methodology generates "the use of problems as the beginning of the learning process, collaborative work in small groups, student-centeredness, the role of tutors is guiding, and there is ample time for self-study" (Wijnia et al., 2019, p. 274).

Today's education requires students to be more active and independent in seeking information about the knowledge being taught. Here, the teacher is merely a facilitator, and the student is the focus of all learning. Learning in educational institutions has become more dynamic, particularly incorporating the PBLr methodology, which has gained increasing popularity in the educational field in recent times. This is demonstrated by the study conducted by Velázquez et al. (2021), which states that, "it encourages students to become more involved in learning, generating their own strategies to deal with real-life situations. Students remember information more easily because it is more meaningful to them" (p. 152).

Instead, it is seen as an essential part of developing self-management skills, which are essential for facing the challenges of everyday life. This perspective, as a student-centered educational approach, implies that those who embark on this method must acquire the ability to control and assume responsibility for their own learning.

PBL is a teaching strategy that promotes inquiry-based learning. It mobilizes and enhances the development of scientific and critical thinking, teamwork, and autonomy, among other aspects. Its design and implementation require consideration of the training of both teachers and students (Hernández and Moreno, 2021, p. 3).

In other words, it provides life skills so that students are able to overcome the obstacles that exist in their environment. Within this context, it is not only about acquiring academic knowledge, but also about fostering the development of fundamental competencies to face real challenges in daily life. This approach places significant emphasis on students' ability to solve practical problems, make informed decisions, and manage their own learning autonomously. Therefore, PBLr not only contributes to academic training but also prepares



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students to be more competent and self-sufficient citizens, capable of facing the challenges they face in their personal and professional environments.

This research focuses on the important findings it presents and contributes to subsequent research in secondary and university education, as it provides valuable information on the impact of PBLr on chemistry teaching. The results support pedagogical decision-making and allow for adjustments in educational practices to maximize meaningful student learning. Furthermore, the study has broader implications for society, as effective, contextualized, and quality education in the natural sciences contributes to the development of critical, competent, and active citizens in the scientific field, as microcurricular planning represents a tool that organizes and facilitates the cognitive process.

The article is structured as follows: Section 1. Introduction summarizes the aspects contained in the article; Section 2. Literature Review explains the theoretical elements and the articulation of the PBLr phases in microcurricular planning; Section 3. Methods and Instruments focuses on the methodological processes and instruments used; Section 4. Discussion and Results refers to the most relevant findings of the research; Section 5. Conclusions highlights the relevance of the article to educational intervention.

2. Theoretical reference

2.1 Problem-Based Learning

Today's education requires students to be more active and independent in their search for information about the disciplinary knowledge taught. Specifically, the teaching-learning process in educational institutions has been strengthened with the use of methodologies that streamline the way knowledge is acquired. In this sense, Problem-Based Learning (PBL) fosters elements of cognitive development involving both the teacher and the student. For their part, the teacher becomes a facilitator, and the student is the fundamental axis of this process.

The study conducted by Velázquez et al. (2021) states that Problem-Based Learning (PBL) is one of the educational methodologies that has been well accepted in higher education institutions. It is an active learning process that works by solving problems related to the interaction between students and their professional environment. This perspective as a student-centered educational approach implies that those who embark on this method must acquire the ability to control and assume responsibility for their own learning. This aspect is underscored in the research by (Hernández and Moreno, 2021, p. 3). This methodology is defined as "the development of scientific thinking based on situated and contextual problems and disciplinary integration that promotes the development of critical and proactive citizens."

Within this context, it is not only about acquiring academic knowledge but also about fostering the development of fundamental skills to face real challenges in daily life. This approach places significant emphasis on students' ability to solve practical problems, make informed decisions, and manage their own learning autonomously. Therefore, PBL not only contributes to academic training but also prepares students to be more competent and self-sufficient citizens, capable of facing the challenges they face in their personal and professional environments. Under this order of ideas, it can be said that PBLr consists of presenting students with authentic and meaningful problem situations that can facilitate their research and inquiries. Similarly, in higher education, this methodology aims to train



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professionals with diverse social skills, capable of contributing to group work and taking on challenges that provide solutions to the problems we face as a society (Coronel et al., 2023, p. 35).

2.2 Theoretical aspects that support Problem-Based Learning (PBL) in Chemistry learning

PBLr is based on a variety of theories, such as constructivism, cognitive theory, and situated learning. These theories have particular implications for chemistry learning. Constructivism is a learning theory that advocates the idea that individuals are not passive recipients of information, but rather active participants in the construction of their own knowledge. According to this perspective, learning is a process in which people interpret and give meaning to information based on their experiences and prior knowledge. When acquiring knowledge or information, students use different knowledge methodologies throughout their experience. By participating in conflict resolution in their environment and actively intervening in the real world, they improve their ability to solve different tasks and activities (Ronquillo et al., 2023, p. 259).

An essential feature of constructivism is the importance of social interaction in the learning process. It recognizes that people learn through communication, collaboration, and interaction with others. Dialogues and debates with peers and mentors play a fundamental role in the construction of meaning and the acquisition of new knowledge. Furthermore, constructivism also emphasizes the idea that learning is an active and personal process, in which each individual constructs their own unique understanding of information (Mosquera, 2024).

Another central concept in constructivism is problem-based learning, which promotes integrated learning methods and highlights the need to align study time in medical education with global needs (Dasgupta, 2020, p. 62).

Thus, constructivism is a learning theory that emphasizes the importance of actively constructing knowledge through interaction with the environment and social collaboration. This pedagogical approach has become a pillar of modern education, promoting critical thinking, problem-solving, and the development of deep understanding in students.

Cognitive Learning Theory (CLT), which focuses on how students process information and how higher-order thinking skills develop (Morinigo & Fenner, 2021, p. 1), addresses how individuals construct knowledge, taking into account cognitive development. Information processing theory is also used to understand how problems are solved using analogies and metaphors. Essentially, this theory views learning as a cognitive process, meaning it involves mental activities such as perception, memory, thinking, and problem-solving. Furthermore, one of the key aspects of the theory is the idea that people are not passive recipients of information, but rather actively participate in the construction of their knowledge. Likewise, students develop a cognitive process so that they are inquisitive and demonstrate skills in research and problem-solving; so that they think critically and creatively; and are reflective in order to act with integrity, honesty, and ethics (Veliz and Rangel, 2022, p. 1454).

Furthermore, CAT places a strong emphasis on problem-solving as a means of learning. Individuals learn by addressing challenges and applying cognitive strategies to find solutions. It also promotes meaningful learning, where acquired knowledge connects with prior knowledge and can be applied in real-life contexts. Metacognition, or the ability to be



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aware of and control thought processes, is another essential aspect of this theory. "Students learn to self-regulate their learning, identify effective strategies, and evaluate their own knowledge, leading to more autonomous and effective learning" (Cuenca et al., 2021, p. 12). In short, CAT underscores the importance of the mind and cognition in the educational process, which has significantly influenced pedagogy and the creation of teaching strategies that focus on the development of critical thinking, problem-solving, and deep understanding of information.

Situated learning is most effective when it takes place in a context that is relevant and meaningful to the student. Problem-solving from a STEM perspective as a central strategy for achieving these contextualized learning approaches is promising for promoting thinking skills and inquiry in chemistry education (Primera, 2022). This educational approach is based on the idea that learning is most effective when it takes place in contexts and situations that are relevant and meaningful to students. Rather than focusing solely on the acquisition of abstract knowledge, it focuses on the practical application of that knowledge in real-life situations. A distinctive feature is that it takes place in the environment or context in which students are expected to apply their skills and knowledge.

This approach is also related to the theory of constructivism, as it improves academic performance and the development of interpersonal and social skills. It is based on student action, which responds to the need for self-learning proposed by constructivism (Castillo, 2021, p. 2479). Finally, constructivism emphasizes the active construction of knowledge by students, drawing on previous and new experiences, emphasizing the importance of social interaction and *Vygotsky's zone of proximal development*. Cognitive Learning Theory focuses on information processing and the development of cognitive skills, emphasizing metacognition as a key element. Finally, Situated Learning emphasizes the relevance and meaning of learning in practical contexts, promoting intrinsic motivation and active interaction with the environment. Each theory offers unique perspectives on how students acquire knowledge and skills, complementing each other.

2.3 Articulation of the phases of Problem-Based Learning in microcurricular planning

Articulating the phases of PBLr in microcurricular planning is an essential process for effectively implementing this pedagogical strategy. These include problem identification, hypothesis formulation, independent research, knowledge synthesis, and evaluation, and each should have a designated space within the teaching process.

It is important for educators to design learning experiences that allow students to move through these stages systematically and coherently. The activities and resources assigned should support the development of the problem-solving and critical thinking skills required at each stage, such as: evaluating information sources, questioning the validity and relevance of data, and seeking connections to their problem. Likewise, assessment should be integrated into all phases to monitor student progress and provide timely feedback. In general, "for the use of PBL in education, it must be configured by the teacher in their curriculum planning resource, the microcurriculum" (Manobanda et al., 2022, p. 174).

The articulation of the PBL phases in microcurricular planning is essential for designing an effective and coherent educational process. "Greater participation in curriculum discussions and planning is needed." (Dasgupta, 2020, p. 65). A proposal is presented below:



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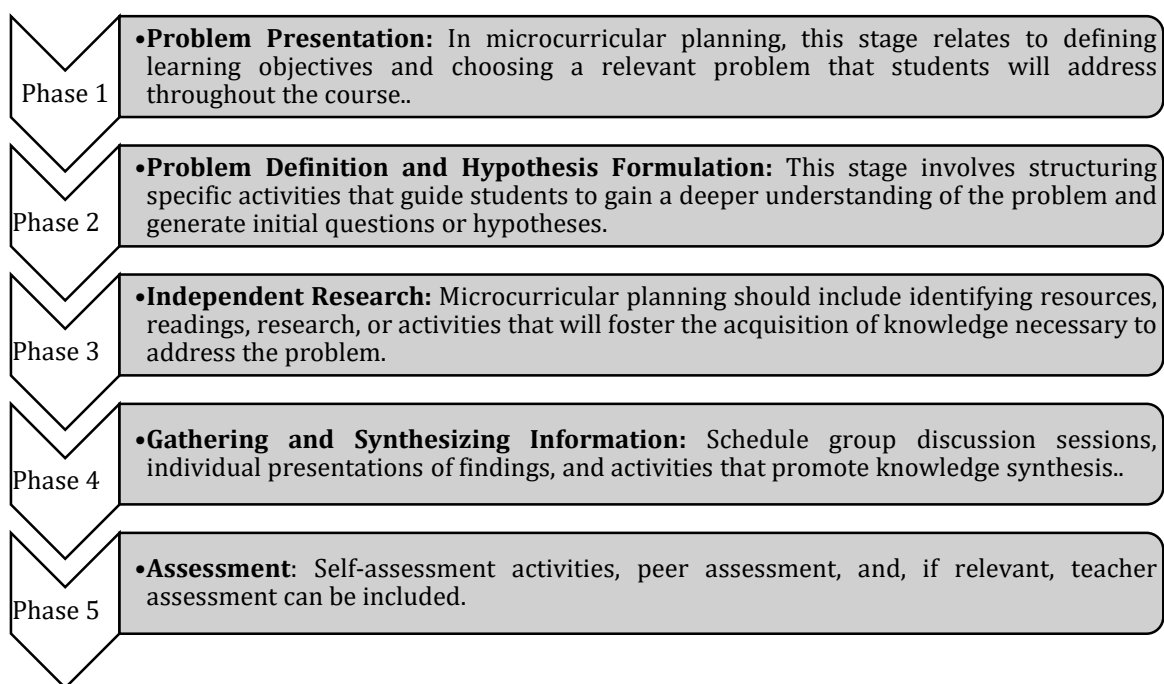


Figure 1. PBL phases in microcurricular planning. Source: Prepared by the authors.

Microcurricular planning should be detailed and sequential, ensuring that each phase of PBL is clearly articulated in the teaching moments of a lesson. It is important to consider how activities from one phase will be connected to the next, and how students' autonomy and critical thinking will be fostered. Furthermore, formative assessment should be incorporated throughout the process, which will help teachers measure students' progress and make adjustments as needed. Effectively articulating the PBL phases in microcurricular planning ensures a coherent and meaningful learning experience for students.

3. Methods and instruments

The research approach of this article is quantitative. Ortega-Sánchez points out that this approach allows for the representation of first-year high school students' satisfaction with the application of Problem-Based Learning (Ortega-Sánchez, 2023). Furthermore, a descriptive and inferential statistical analysis was applied to the collected data to determine whether rPBL improves the teaching-learning process in Chemistry.

"The design is quasi-experimental and transactional; the scope of the research was descriptive-explanatory with a hypothetical-deductive method" (Hernández et al., 2018, p. 150). This type of design is used in research involving two groups: one experimental and one control, with the aim of determining whether "the pedagogical intervention with the experimental group is effective when compared to the control group" (Galindo-Domínguez, 2020, p. 24), as shown in Table 1. The analysis focused on a single period. The question to be answered was: How does Problem-Based Learning (PBL) as a methodology impact and improve the teaching-learning process of Chemistry in first-year high school students?

To define the context of the research, a population comprised of the first years of the Cuenca High School was established during the 2023-2024 academic year. The research focuses on the use of rPBL as a methodological strategy for learning chemistry through the



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implementation of its phases in microcurricular planning. This research aims to modify the traditional practice of teachers in the classroom and, in this way, place greater emphasis on the role of the student in their learning process, with their involvement in each phase of the methodology. Furthermore, the institution was accessible for the application of the instruments and the collaboration of the institutional authorities was ensured to carry out the study.

“The selection of participants was carried out through non-probabilistic, purposive sampling; the expert establishes the criteria” (González, 2021, p. 2). Therefore, the entire population was selected, as each of the students and teachers are essential for obtaining data. Therefore, they are the subjects from whom all the necessary non-probabilistic, census-type data with criteria will be obtained. The sample consisted of a total of 62 students who made up the A and B parallel groups of the educational institution: 31 from the experimental group (EG) and 31 from the control group (CG). The research design is presented below.

Groups	Methodology	Sample: First-year high school students	Intervention in the learning of Chemistry	Post-test
Control Group (CG)	Traditional	31 students	5 traditional lessons	
Experimental Group (EG)	Problem-Based Learning	31 students	5 lessons with PBLr in didactic sequences	X

Table 1. Quasi-experimental design

Table 1 shows some relevant elements of the quasi-experimental design. Five micro-curricular plans were developed in response to Performance-Based Skill (PCS) CN.Q.5.1.6. Relate the electronic structure of atoms to their position in the periodic table to deduce the chemical properties of the elements. In each class, the learning objective was modified, and the PBLr phases were incorporated into the teaching moments. Learning experiences were proposed that focused on the development of the methodology's phases and achievement indicators. The plans were approved by the academic vice-rector of the educational institution.

For data collection, and based on the premise that the PBL intervention impacts the teaching-learning process of chemistry, standardized tests (post-tests) were used to collect data on academic performance by assessing the understanding of disciplinary knowledge focused on: the classification of the periodic table, the location of the chemical elements according to the current periodic table, the identification of representative chemical elements, knowledge of the physical and chemical properties of metals, and the physical and chemical properties of non-metals. This process was carried out at the end of each pedagogical intervention and involved structured lessons on disciplinary knowledge with value scales that were able to assess the impact of the methodology on learning.

Likewise, at the end of the didactic mediation, a survey was administered on the perception of PBL in the teaching-learning of chemistry. This survey was structured with questions focused on eliciting students' opinions regarding: collaborative pedagogical activities; presentation and definition of the problem; hypothesis formulation; independent research; Data collection and synthesis; Methodology evaluation. Response options were organized



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into frequency scales. It is important to mention that the instrument was adapted from a similar study by the author (Santiago, 2016). The contribution regarding the questions in the evaluation instrument allowed us to identify the study's relevance to competency development, enabling students to achieve an objective perspective, critical thinking, and self-directed learning throughout their lives, not just during school. These competencies are reinforced by applying the methodology to the teaching sequence.

4. Discussion and results

4.1 Analysis of academic performance using PBLr

The analysis of the grades of the 62 students is presented in the following table, since it is relevant to evaluate the effectiveness of the intervention with the Problem-Based Learning methodology; in the first instance, the performance of the control group.

Control Group Activity Ratings					
		Frequency	Percentage	Valid percentage	Cumulative percentage
Valid	Average Good	19	61,3	61,3	61,3
	Average Very Good	12	38,7	38,7	100,0
	Total	31	100,0	100,0	

Table 2. Ratings of the Control Group's activities

Table 2 presents the ratings for the control group's activities, which are distributed across two performance categories: average-good and average-very-good. The table shows the distribution of ratings in terms of frequency, percentage, valid percentage, and cumulative percentage.

4.1.1 Distribution of grades

El grupo control estuvo compuesto por 31 estudiantes, todos con calificaciones válidas. La distribución de las calificaciones es la siguiente: Promedio bueno: 19 estudiantes (61,3%) recibieron esta calificación. Esto indica que una mayoría significativa del grupo control se ubicó en este nivel de rendimiento. Promedio muy bueno: 12 estudiantes (38,7%) obtuvieron esta calificación, lo que representa el resto del grupo. El porcentaje acumulado refleja que, al sumar ambas categorías, se llega al 100%, lo que confirma que todas las calificaciones del grupo se distribuyen entre estos dos niveles.

4.1.2 Interpretation of the results

The distribution of scores in the control group shows that the majority of students fell into the good average category, while a smaller number achieved very good average scores. This suggests that, overall, the control group's performance was solid, but with a greater concentration in the intermediate performance range.

Experimental Group Activity Ratings					
		Frequency	Percentage	Valid percentage	Cumulative percentage
Valid	Average Very Good	31	100,0	100,0	100,0

Table 3. Ratings of the Experimental Group's activities

In this analysis, the experimental group's activity grades are presented. The data show an even distribution within a single performance category: very good, with all students in this group receiving this grade. The table summarizes the frequency, percentage, valid



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percentage, and cumulative percentage. The experimental group consists of 31 students, all with valid grades.

4.1.3 Distribution of grades

Very good average: 31 students (100%) achieved this grade. This means that every student in the experimental group demonstrated high and uniform academic performance. The cumulative percentage is 100%, indicating that there are no other grade categories within this group.

4.1.4 Interpretation of Results

The results of the experimental group are notable for their homogeneity in performance, as all students obtained a very good average grade. This finding indicates that the students in this group showed a consistently high level of performance in their activities. The uniformity in grades may indicate the effectiveness of problem-based learning applied to this group. However, the lack of variability in grades may also limit the ability to assess individual differences in performance, and it may be relevant to further investigate the reasons behind this homogeneous result. Compared to the control group, where grades showed greater diversity, the experimental group stands out for its uniformly high level of performance, which implies the success of the implemented strategies.

4.2 Analysis of competencies using PBLr

Learning assessment is an important indicator for determining the effectiveness of problem-based learning versus traditional teaching, as PBLr allows for more meaningful learning because it involves active student participation.

To implement the PBLr methodology, a sample of 31 first-year high school chemistry students was considered. These students were organized into groups of four and five students. Five learning activities were presented to each group, each focusing on analysis, interpretation, and scientific research. As part of this process, a detailed synthesis of the information was presented in the form of infographics, graphic organizers, summaries, and other materials.

The results of the competencies assessed through learning experiences are presented as follows: Activity **one** focuses on evaluating collaborative teamwork. With traditional teaching, the average performance is 7.61 points, while with PBLr it is 8.74 points, demonstrating that the methodology improves student performance. In Activity **two**, the development of problem-solving skills is more evident since the methodology is more familiar to the students; therefore, the result is evident in the grades for PBLr: 9.00 and the traditional methodology: 8.00 points. For Activity **three**, PBLr continues to be effective, with an arithmetic mean of 9.11 versus 7.94. It is important to highlight that, in both groups, motivation is essential to achieving favorable results. In activity **four**, the average score for traditional teaching is 7.98 and for PBLr, 9.05. Active participation is assessed here. This activity strengthens learning interactions because each student has the right and opportunity to influence and collaborate in the actions to be carried out. In activity five, the PBLr average was 9.11 compared to traditional teaching, which scored 7.89. Constant feedback in the research process and in the development of activities is essential.

These results support the successful application of Problem-Based Learning because it fosters the development of competencies over time and is also characterized by strengthening students' ability to search, use, and critically evaluate information, an essential factor for solving complex problems. These results suggest that this aspect is being



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satisfactorily addressed in the current educational environment, according to España and Viguera (2021). In today's society, it is essential to consider the educational use of methodologies that seek to develop problem-solving skills using information resulting from individual and group research.

To explore the impact of problem-based learning on the development of cognitive skills and the retention of knowledge acquired in chemistry, the normality test table is analyzed. First, the null (H_0) and alternative (H_a) hypotheses are defined:

1. Null hypothesis (H_0): The activity ratings in both groups follow a normal distribution.
2. Alternative hypothesis (H_a): The activity ratings in at least one of the groups do not follow a normal distribution. The results of the normality tests are then evaluated.:

Control group:

- Kolmogorov-Smirnov: Statistic = 0.107, p-value = 0.200
- Shapiro-Wilk: Statistic = 0.933, p-value = 0.055

Experimental group:

- Kolmogorov-Smirnov: Statistic = 0.112, p-value = 0.200
- Shapiro-Wilk: Statistic = 0.951, p-value = 0.172

Since the p-values are greater than the commonly used significance level (such as 0.05), there is not enough evidence to reject the null hypothesis in either group. Therefore:

- • Control Group: H_0 cannot be rejected. The activity ratings in the control group follow a normal distribution.
- • Experimental Group: H_0 cannot be rejected. The activity ratings in the experimental group also follow a normal distribution.

After confirming the normal distribution of grades in both groups of 31 students, as evidenced by the Shapiro-Wilk normality test, the means of each group were compared using the independent samples t-test. This comparison allowed us to assess whether there were significant differences in academic performance between the experimental group (using rPBL) and the control group (using traditional methodology).

The results obtained from the t-test highlight the significant difference in grades between the two groups. This test was essential to validate the study hypothesis, as it revealed that the pedagogical intervention using rPBL had a statistically significant impact on student performance. The detailed test values and their interpretation are presented below.



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Independent samples t-test										
		Levene's test for equality of variances		t-test for equality of means						
		<i>F</i>	<i>Sig.</i>	<i>T</i>	<i>gl</i>	<i>Sig.</i>	Diferencia de medias	Stand error difference	95% de intervalo de confianza	
									Inf.	Sup.
GC and GE Ratings	Equal variances are assumed	.023	.88	-14.95	60	.00	-5.59	.37	-6.33	-4.84
	Equal variances are not assumed			-14.95	59.97	.00	-5.59	.37	-6.33	-4.84

Table 4. Independent samples t-test

Table 4 provides the results of an **independent samples t-test** comparing scores between two groups: the **Control Group (CG)** and the **Experimental Group (EG)**. The results are analyzed below.:

1. Levene's Test for Equality of Variances:
 - The F-value is 0.023, and the p-value is 0.88
 - Since the p-value is greater than 0.05, there is insufficient evidence to reject the null hypothesis of equality of variances.
2. t-Test for Equality of Means:
 - Equal variances are assumed:
 - The t-value is -14.95 with 60 degrees of freedom (df).
 - The p-value is 0.000 (significant at the 0.05 level).
 - The difference in means between groups is -5.59.
 - The 95% confidence interval for the difference in means is between -6.33 and -4.84

Conclusion:

- Since the p-value is significant (less than 0.05) in both cases, the null hypothesis of equal means is rejected.
- The difference in means suggests that the scores in the Experimental Group are significantly higher than those in the Control Group.
- The confidence interval does not include zero, which supports this conclusion.

As can be seen, the methodology has a student-centered didactic approach, serving as an appropriate medium for real-world learning. In relation to the application of PBLr, teachers



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play multiple roles in the teaching process, such as facilitators, supervisory guides, and referees, rather than providers who emphasized the explanation of topics and the transfer of knowledge. In PBLr, it is important to:

Maintaining student motivation while guiding them toward inquiry into core areas of the profession. The problems presented must be real, complex, and challenging; it is a teaching strategy that helps students develop adaptable knowledge and skills, such as problem-solving, communication, self-directed learning, and teamwork (Coronel et al., 2021, p. 38).

“It is a student-centered pedagogical method in which students learn by solving open-ended problems as part of a team” (Freund et al., 2022, p. 3). (Lee and Jo, 2023) notes that, “students propose solutions based on individual and cooperative learning, and focus on realistic and authentic problems” (p. 4). Finally, “teachers must design problems that are not aimed at predictive answers, but rather can trigger an in-depth inquiry into multifaceted topics” (Okolie et al., 2021, p. 96)).

4.3 Perception of PBLr in the Teaching and Learning of Chemistry

To assess students' perceptions of the use of PBL in the teaching and learning of chemistry, a survey was conducted at the end of the course. In this way, the participants' expression of their general opinion on the methodology can be counted on.

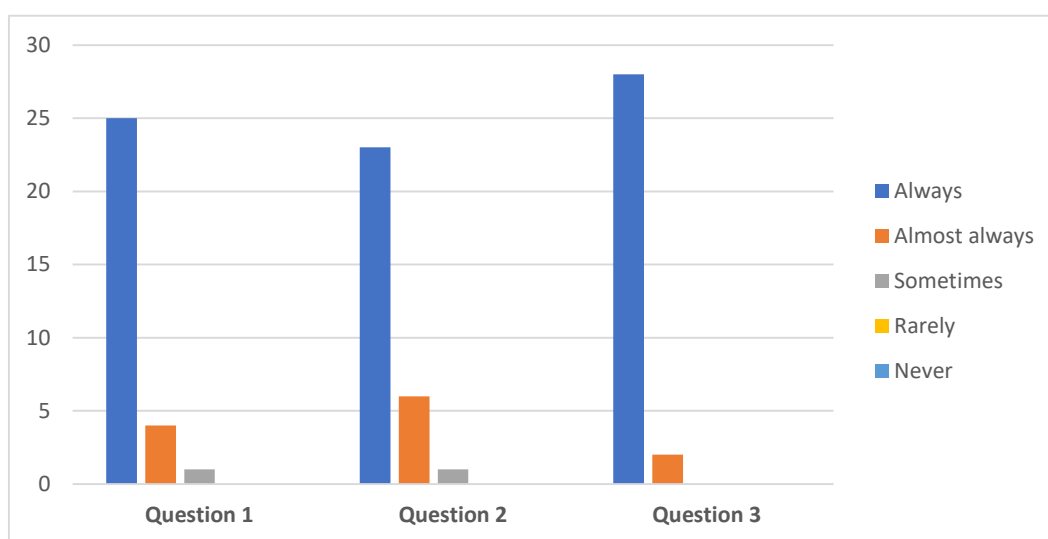


Figure 2. Pedagogical activities with a collaborative approach

In general terms, from the survey applied to 31 students, 25 indicate that the pedagogical activities used by the teacher allowed them to actively participate in the teaching-learning process of chemistry; significantly evidencing that the application of the PBLr methodology is subject to the current needs of knowledge development and construction. The teacher encourages collaborative work, as mentioned by 23 students, and 28 indicate that the education professional provides the necessary guidance for the development of work in the formed teams. This work environment, Benoit points out, is a strategy that promotes the active role of the student and favors their cognitive and metacognitive development, allows them to respond to activities that take into account their individual abilities, creates



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purposeful work environments for the development of individual and group competencies (Benoit, 2021). "Improvement of analytical reasoning, problem solving and collaborative learning" (Liu and Pasztor, 2022, p. 3).

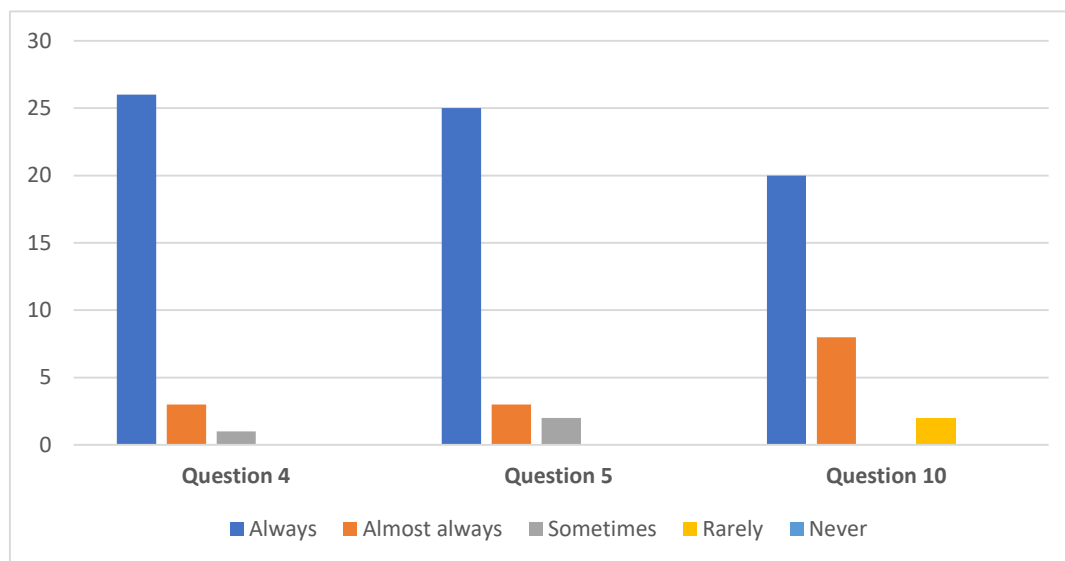


Figure 3. Presentation and definition of the problem

The results of the fourth question indicate that approximately 25 students demonstrate a high level of responsibility in carrying out the activities assigned to their work groups. Overall, the results suggest a solid foundation for group learning activities. The fifth question shows that 25 teachers effectively integrate theory with practical activities, thus providing students with a more comprehensive and contextualized learning experience.

Meanwhile, 20 students believe that objectives and time management are clear, as these can be crucial factors for understanding, analyzing, and synthesizing knowledge in the Chemistry subject. These results support the idea that planning and goal setting are key components of the teaching methodology, which is consistent with the principles of Problem-Based Learning (PBL). Therefore, this process should be included in microcurricular planning; it becomes an educational practice that has always required innovation in all areas of life, as it provides a new opportunity for active participation and learning. improves critical thinking and problem solving (España and Viguera, 2021; Márquez et al., 2023).



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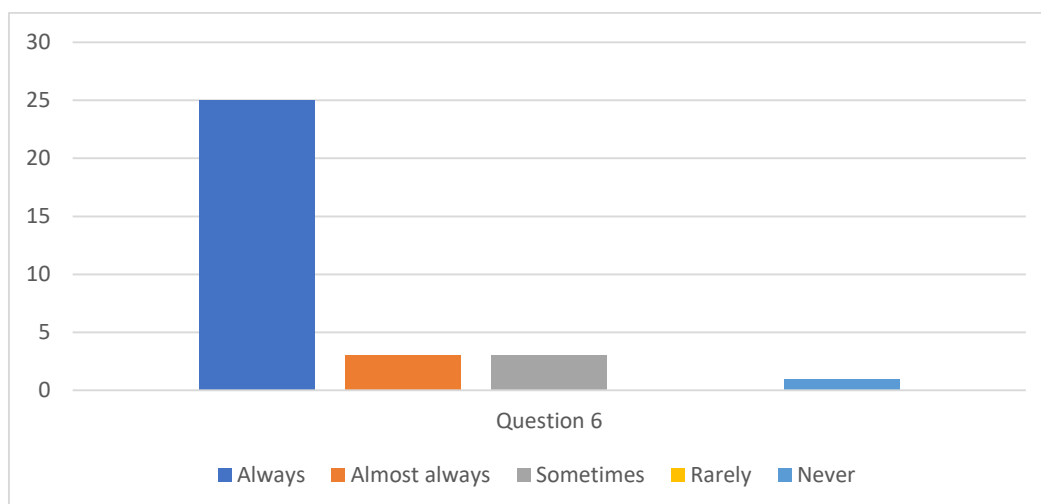


Figure 4. Hypothesis formulation

These results support the idea that students regularly experience challenges and problem-solving situations in their learning, which is consistent with the philosophy of PBLr. The ability to actively and autonomously confront and solve problems is essential for the development of research skills, which can positively contribute to activities of this type in chemistry. (Mosquera, 2021; Barbieri et al., 2020; Puello, 2023) The preliminary inquiry reveals that students had weaknesses when conducting argumentative analysis. It develops research potential, the integration of theory and practice, and viable problem-solving skills for structured problems for which the existing and desired states are identified. Finally, it fosters conscious thinking and learning processes; it promotes critical thinking.

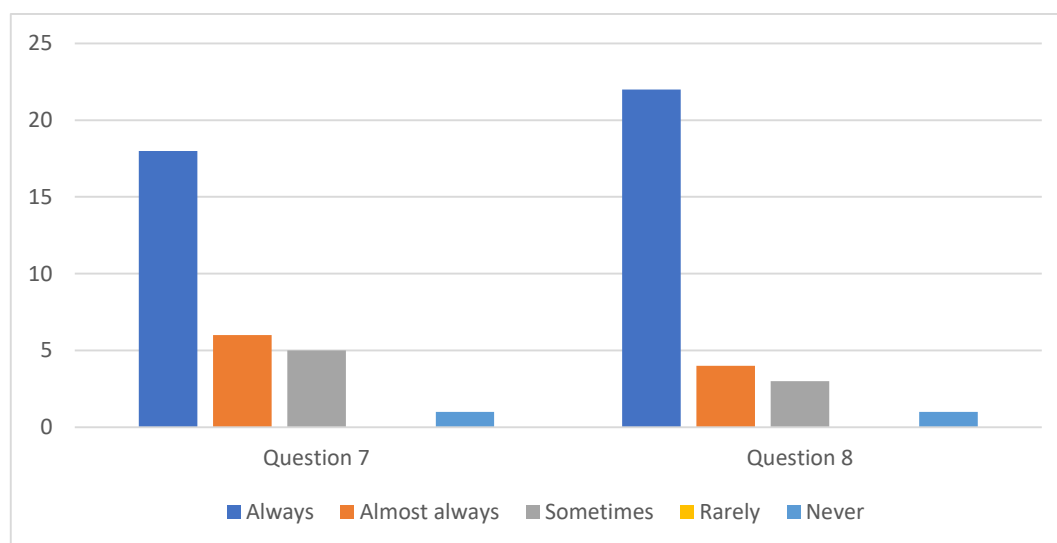


Figure 5. Independent research

In questions seven and eight of the survey, it is determined that the results support the successful application of Problem-Based Learning (PBLr), since students determine and value the contextualization of problems in real life and this in turn significantly increases the motivation and relevance of learning. The connection with everyday situations enhances students' ability to apply their knowledge in practical contexts, thus strengthening their research skills. (Meriño et al., 2024) point out that there is "the



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development of research competence in students; it is the expression of the appropriation of the knowledge of the subjects that make up the disciplines of the study plan" (p. 197). Therefore, the results support the idea that students are engaged in the reflection and practical manipulation of concepts.

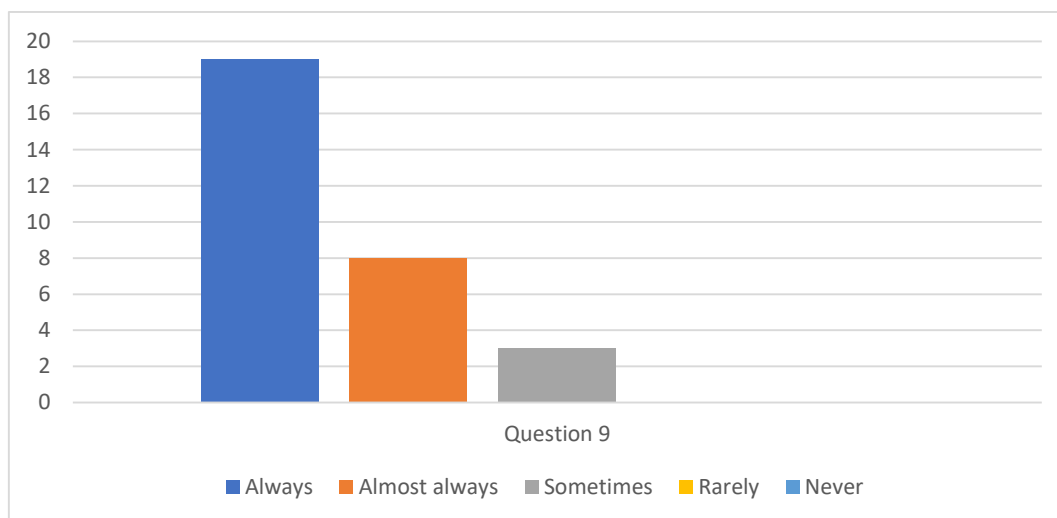


Figure 6. Gathering and synthesizing information

Students' reflection is framed in that, the application of PBLr in addressing real-world problems, learning becomes a participatory and interactive experience, where students are encouraged to ask questions and seek answers, promoting the analysis, evaluation and synthesis of information, through cognitive processes that include perception, attention, language, memory, learning, motivation, thinking and problem solving. (Pazos-Yerovi and Aguilar-Gordón, 2024). In addition, giving meaning to learning from different contexts, developing a critical and participatory sense of students, establishing relationships between teaching and technical-professional aspects (Carneiro, 2023).



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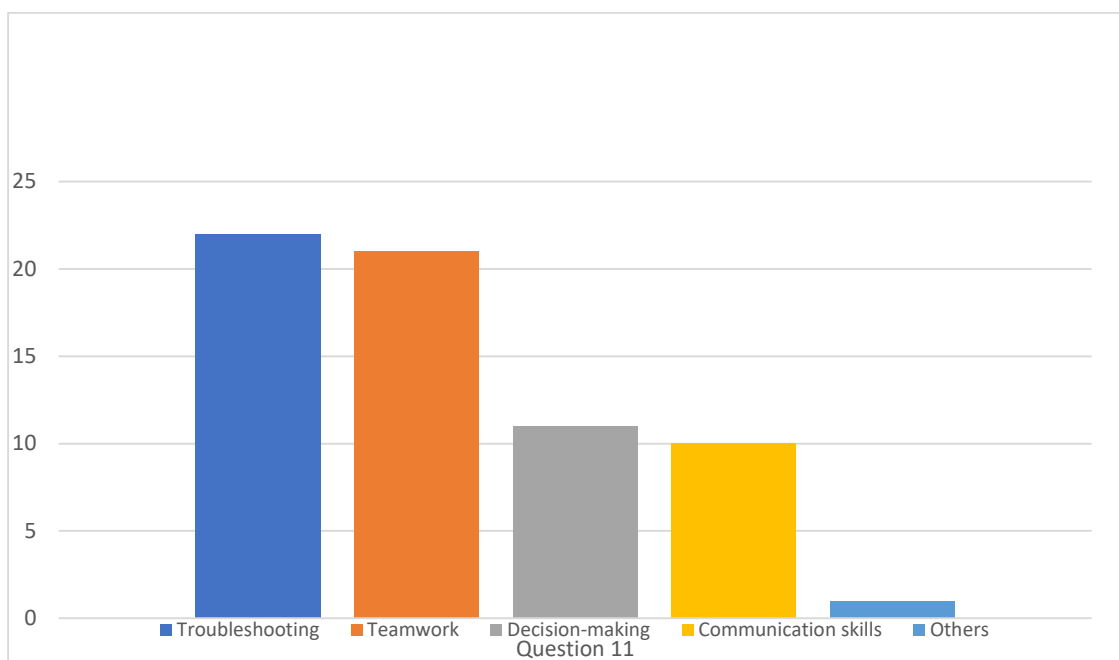


Figure 7. Evaluation

The information in Figure 7 is compiled from the responses of 22 students who mention that the skill they develop most is problem-solving, 21 of them consider it to be teamwork, 11 that this learning methodology allows them to prepare for decision-making; and 10 students emphasize communication skills. In this regard, Cornejo-Sanabria and Carpio-Quesada (2023) point out that, “pedagogical mediation where students can fit into the educational environment and be inclusive in the teaching-learning process” (p. 79) consequently, the role of the teacher represents a fundamental element to innovate in the teaching-learning process. “Recognition and respect for disabilities is the skill in which students reach the highest levels of performance after using PBL” (Fernández-Jiménez et al., 2014, p. 339).

5. Conclusions

The data indicate that the application of PBLr impacted the learning process of students in the control group compared to those who followed the traditional methodology; the academic performance of students in the experimental group was higher. This implies that the methodology favors the development of cognitive skills and, consequently, increases academic performance. In the teaching and learning of chemistry, the development of disciplinary skills goes hand in hand with the development of competencies specific to the methodology. This process is evidenced in the research, as it enhances teamwork in the classroom, promotes engagement, provides solutions to problems in the context presented, promotes constant feedback, and fosters a high level of student motivation.

It is necessary to propose new forms of microcurricular planning in educational institutions, one that articulates the phases of Problem-Based Learning in chemistry teaching, since it has proven to be an effective methodological tactic that modifies the learning process. By focusing on microplanning and problem-solving, students not only actively participate in their own learning process but also acquire fundamental skills such as independent research and the ability to synthesize. Group discussion fosters a collaborative environment that enhances the teaching process. Findings from the comparative analysis of academic



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performance show a notable improvement after the intervention with active methodologies, as opposed to conventional strategies. Therefore, PBLr emerges as a valuable option for promoting meaningful learning in the field of chemistry..

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Declaration of Authorship-CRediT

VÍCTOR CASTILLO-GAONA: State of the art, related concepts, methodology, validation, data analysis, writing - first draft.

GRETHY QUEZADA-LOZANO: State of the art, related concepts, data analysis, organization and integration of collected data, project management, conclusions, final writing and editing.



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