

## ***Unlocking Critical Skills: Evaluating Problem-Based Learning in Developmental Biology Education***

### ***Desbloqueando Habilidades Críticas: Evaluación del Aprendizaje Basado en Problemas en la Educación en Biología del Desarrollo***

### ***Desbloqueando Habilidades Críticas: Avaliação da Aprendizagem Baseada em Problemas na Educação em Biologia do Desenvolvimento***

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#### **Resumen**

Este estudio evaluó la efectividad del Aprendizaje Basado en Problemas (ABP) en la mejora del conocimiento y las habilidades de estudiantes de cuarto semestre en Biología del Desarrollo. Se aplicó un programa de intervención ABP a un grupo experimental, comparando los resultados con un grupo de control mediante cuestionarios estructurados y evaluaciones de desempeño. Participaron 84 estudiantes que cursan la asignatura de Biología del desarrollo en la Facultad de Filosofía, Letras y Ciencias de la Educación de la Universidad Central del Ecuador. Utilizando un diseño cuasiexperimental con pretest y posttest y grupo control, analizado con un Modelo Lineal General de medidas repetidas, los hallazgos mostraron que el ABP mejoró significativamente el conocimiento en metodologías activas y habilidades críticas, como la explicación de fenómenos y la indagación. También se observó un fortalecimiento del pensamiento crítico y una mayor capacidad para buscar y evaluar información relevante, sugiriendo que el ABP es eficaz para un aprendizaje significativo y un desarrollo profesional robusto.

**Palabras clave:** Aprendizaje Basado en Problemas; Metodologías activas; Pensamiento crítico; Educación en Biología; Competencias científicas

#### **Abstract**

This study aimed to assess the effectiveness of Problem-Based Learning (PBL) in enhancing knowledge of active methodologies and skill development among fourth-semester students in Developmental Biology. A PBL intervention program was applied to an experimental group, and results were compared with a control group using structured questionnaires and performance evaluations. Participants were 84 students from the Faculty of Philosophy, Letters, and Education Sciences at Central University of Ecuador. This study utilized a quasi-experimental design with pretest and posttest control groups, analyzed using a General Linear Model. Findings revealed that PBL significantly improved knowledge and experience with active methodologies, as well as critical skills such as explaining phenomena and inquiry. Results also indicated a strengthening of critical thinking and an enhanced ability to seek and evaluate relevant information. These conclusions suggest that PBL is effective for meaningful learning and robust professional development.

**Key words:** Problem-Based Learning; Active methodologies; Critical thinking; Biology education; Scientific competencies

#### **Resumo**

Este estudo teve como objetivo avaliar a eficácia da Aprendizagem Baseada em Problemas (ABP) na melhoria do conhecimento de metodologias ativas e no desenvolvimento de habilidades entre os alunos do quarto semestre de Biologia do Desenvolvimento. Um programa de intervenção baseado em ABP foi aplicado a um grupo experimental e os resultados foram comparados com um grupo de controle utilizando questionários estruturados e avaliações de desempenho. Os participantes foram 84 alunos da Faculdade de Filosofia, Letras e Ciências da Educação da Universidade Central do Equador. Este estudo utilizou um design quase-experimental com grupos de controle pré-teste e pós-teste, analisado

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através de um Modelo Linear Geral. Os resultados revelaram que a ABP melhorou significativamente o conhecimento e a experiência com metodologias ativas, bem como habilidades críticas como a explicação de fenômenos e a investigação. Os resultados também indicaram um fortalecimento do pensamento crítico e uma maior capacidade de buscar e avaliar informações relevantes. Estas conclusões sugerem que a ABP é eficaz para uma aprendizagem significativa e um desenvolvimento profissional robusto.

**Palavras-chave:** Aprendizagem Baseada em Problemas; Metodologias ativas; Pensamento crítico; Educação em Biologia; Competências científicas

## **Introduction**

The rapid evolution of educational methodologies necessitates innovative approaches to enhance knowledge acquisition and skill development. Problem-Based Learning (PBL) is recognized for encouraging active participation and critical thinking among students. Recent studies highlight PBL's effectiveness in higher education (da Silva & de Resende, 2020; Y. F. Liu et al., 2020; Nurkhin et al., 2020). However, its application in pedagogical training, specifically in Developmental Biology courses, remains underexplored.

This research addresses this gap by evaluating the effectiveness of PBL in the fourth semester of the Pedagogy of Experimental Sciences, Chemistry, and Biology program at Central University of Ecuador. Originally successful in health sciences, PBL's application in Developmental Biology—a key subject in medical sciences—remains largely uncharted in pedagogy.

The study examines PBL's implementation in the Developmental Biology course to enhance metacognitive abilities, critical thinking, and collaboration skills. By integrating PBL, we aim to provide future educators with pedagogical strategies that go beyond rote memorization, promoting deep understanding and reflective learning (Darhim et al., 2020; Hursen, 2021; Mustofa & Hidayah, 2020; Surur et al., 2020). This aligns with the goal of equipping students for effective professional performance.

The study also seeks to bridge the gap between traditional teaching methods and the contemporary needs of education. The classical educational paradigm often emphasizes rote learning, neglecting the cultivation of independent, critical thinking skills (Burke et al., 2020; De Walt & Barker, 2020; X. Liu et al., 2020; Pawlak et al., 2020). This limitation is particularly evident in the Developmental Biology course, which demands a deeper, more analytical approach.

Integrating PBL into the curriculum represents a significant shift towards a student-centered educational model. PBL encourages active engagement, self-directed learning, and the development of essential skills like problem-solving, critical thinking, and collaboration (Alt & Raichel, 2022; Thahim, 2020; Ulazia & Ibarra-Berastegi, 2020). These skills are crucial for future educators responsible for shaping the minds of the next generation.

The global educational landscape is evolving, with a growing emphasis on sustainability and new technologies. Sustainable education meets present needs without compromising future generations' ability to meet their own. By embracing innovative approaches like PBL, educators can ensure their methods remain relevant and effective in a rapidly changing world (Bijsmans & Versluis, 2020; Deep et al., 2020; Hung & Tsai, 2020). PBL not only fosters critical thinking and independent learning but also aligns with sustainable education goals, preparing students for an ever-evolving global society (Alves et al., 2020; Fernandes & da Silva, 2020).

PBL not only fosters critical thinking and independent learning but also aligns with sustainable education goals by equipping students with skills for an evolving global society (Alves et al., 2020; Fernandes & da Silva, 2020; Urrutia-Heinz et al., 2020). Applying PBL in the Developmental Biology course at Central University of Ecuador is a forward-thinking initiative aimed at preparing students for modern complexities.

The shift from teacher-centered to student-centered learning mirrors global pedagogical transformations. In this new model, students actively engage and construct their own knowledge, fostering deeper understanding and critical life skills (Caires-Hurley et al., 2020; Fadiawati et al., 2020; Urrutia-Heinz et al., 2020). This approach is crucial for comprehensive subject mastery and skill development.

Implementing PBL in the Developmental Biology course seeks to maximize the benefits of this approach, offering a rich, engaging learning experience beyond traditional methods. By addressing real-world problems and encouraging collaborative solutions, PBL enhances academic performance and prepares students for future roles as educators and leaders (Herrmann, 2020; Noordzij & Wijnia, 2020; Thorndahl & Stentoft, 2020).

The main objective of this study is to analyze the impact of Problem-Based Learning (PBL) on the performance of fourth-semester students in the Developmental Biology course, focusing on the comprehensive use of scientific knowledge, explanation of phenomena, and inquiry. The specific objectives are: 1) To assess students' knowledge and experience with active methodologies, particularly PBL. 2) To develop a didactic proposal guiding instructors in applying PBL to enhance students' skills in scientific comprehension, explanation, and inquiry. 3) To determine the effects of PBL on student performance in the course.

The study's hypotheses are:

H1: Fourth-semester students will improve their knowledge and experience with Problem-Based Learning (PBL) and active methodologies.

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H2: A didactic proposal can effectively guide instructors in using PBL to enhance students' skills.

H3: PBL positively impacts performance in the comprehensive use of scientific knowledge, explaining phenomena, and inquiry.

H4: PBL significantly enhances conceptual performance in the Developmental Biology course (theoretical knowledge of Developmental Biology).

In conclusion, this research on PBL in the Developmental Biology course at Central University of Ecuador represents a significant step in advancing the educational process. Integrating PBL creates a more interactive and effective learning environment, essential for developing critical thinking, analytical, and problem-solving skills. This initiative bridges the gap between traditional and modern educational demands, preparing students to meet future challenges effectively.

## **Materiales y métodos**

### ***Participants***

The "Application of Problem-Based Learning in the Developmental Biology Course" was conducted at the Central University of Ecuador, in the Faculty of Philosophy, Letters, and Educational Sciences, specifically within the Department of Experimental Sciences Education, Chemistry, and Biology, in Quito. The program targeted fourth-semester students during the May to September 2022 academic period, focusing on the "Embryonic Development of Human Systems" unit.

The study involved two sections: a morning session (PCEQB4-001) as the experimental group (Group A) with 49 students, and an afternoon session (PCEQB4-002) as the control group (Group B) with 35 students. Students were regular, first-time fourth-semester attendees who had not transferred or previously studied Developmental Biology.

Participants were randomly assigned to groups in the presence of the Biology Department director. The experimental group (Group A) consisted of 11 males and 38 females, while the control group (Group B) had 9 males and 26 females. The overall population included 20 males and 64 females, aged 19 to 32, with an average age of 21.62 years.

The balanced division between the control (41.7%) and experimental (58.3%) groups allowed for a thorough assessment of Problem-Based Learning's impact on student performance in the Developmental Biology course.

### ***Measures***

This section outlines the research instruments used to address the study's objectives and hypotheses. The following instruments were employed to collect data:

Questionnaire on Knowledge and Experiences with Active Learning Methodologies and Problem-Based Learning (PBL) (López et al., 2013): This tool assesses students' familiarity and experiences with Active Learning Methodologies (ALM) and PBL. It includes an informed consent section and demographic details such as age, gender, session, and group. The questionnaire comprises 39 questions in two blocks (A and B), evaluating knowledge and experience, with a total score of 80 points. Developed according to the National Institute for Educational Assessment (INEVAL) guidelines, it was validated by three faculty members from the Faculty of Philosophy, Letters, and Educational Sciences at Central University of Ecuador.

Knowledge Test: This test was administered to both control and experimental groups to evaluate their prior theoretical knowledge of Developmental Biology (pre-test). Scores were compared with the final semester grades, including a post-test to assess final theoretical understanding. The tests featured structured multiple-choice questions, crafted per INEVAL's directives and validated by three faculty members.

Knowledge and Skills Tests for Unit Four: These tests specifically evaluated students' knowledge and skills related to Unit Four of the Developmental Biology course. Three separate instruments were designed: one pre-test and two post-tests to evaluate outcomes after studying the unit's content. Each test covered scientific knowledge use, explanation of phenomena, and student inquiry, with 45 items each. Evaluation tools used a rubric with a scale from 1 to 4, where 1 signifies minimal achievement and 4 signifies optimal achievement, reflecting the expected outcomes post-PBL application.

The variables assessed were:

- **Comprehensive Use of Scientific Knowledge:** Evaluates students' ability to understand and apply scientific concepts in problem-solving and relate acquired knowledge to phenomena.
- **Explanation of Phenomena:** Assesses students' capacity to construct explanations, understand arguments or models related to phenomena, and evaluate the validity of claims about scientific problems.
- **Student Inquiry:** Measures students' understanding of how research leads to explanations about the natural world, including methodologies used to generate and address new questions.

The Problem-Based Learning (PBL) Intervention Program aimed to enhance student performance by developing skills in the comprehensive use of scientific knowledge, explanation of phenomena, and

student inquiry. Implementing PBL, an Active Learning Methodology proposed by Howard Barrows in 1996 (Barrows, 1996) and initially executed at McMaster University's Faculty of Health Sciences in Canada, aimed to improve performance in Unit Four of the Developmental Biology course.

Specifically, the intervention program focused on addressing the complexities of the fourth unit by improving students' abilities in scientific knowledge use, explaining phenomena, and fostering inquiry through PBL. This approach provided a structured and effective method to engage students actively in the learning process and develop essential skills for their future roles as educators.

Students started by identifying the central problem: the challenging nature of teaching the fourth unit of the Developmental Biology syllabus. To tackle this, they developed a micro-curricular plan designed to teach the unit's content effectively in secondary education settings, where they will soon begin their teaching careers. This required a deep understanding of psychological principles, curriculum design, and the scientific content of the subject.

The intervention spanned eight weeks, following PBL guidelines. Students worked in small groups, each focusing on a different human body system. They followed a structured approach to solve the problem, which involved clarifying concepts, defining the problem, and analyzing specific challenges.

During the problem definition phase, groups collaborated with public educational institutions and formulated specific questions about teaching the embryonic development of different body systems. They considered factors such as the educational level of their audience, content depth, and student characteristics.

To support their objectives, students conducted thorough research on curricular, methodological, and scientific aspects. They investigated the psychological profiles of secondary students and explored effective teaching strategies. Each team developed a detailed plan based on this research, including a Gantt chart to manage tasks and timelines.

The final phase involved preparing a comprehensive report that included meeting records, teaching plans, and assessment tools. This report was evaluated through self-assessment, peer assessment, and tutor assessment to ensure a well-rounded evaluation. Assessment criteria focused on scientific knowledge use, explaining phenomena, and student inquiry.

By integrating these elements, the program aimed to improve students' understanding of complex biological concepts and their ability to apply effective teaching methodologies in their future roles as educators.

### ***Procedure***

The intervention program aimed to analyze the impact of Problem-Based Learning (PBL) as an active learning methodology on the performance in the fourth unit of the Developmental Biology course. Specifically, it focused on improving the comprehensive use of scientific knowledge, explaining phenomena, and fostering student inquiry among fourth-semester students in the Pedagogy of Experimental Sciences, Chemistry, and Biology program. The program was conducted in coordination with the program director, and the study was implemented during the 2022 semester with ethical approval from the University of Alicante.

Students were informed that a quasi-experimental study would be conducted, involving one experimental group and one control group. All participants were required to sign informed consent forms, ensuring voluntary participation and ethical compliance. The selection of the experimental group was done randomly in the presence of the Biology program director. As a result, the morning cohort (PCEQB4-001, Fourth A) was chosen as the experimental group, while the evening cohort (PCEQB4-002, Fourth B) served as the control group.

To conclude, the instruments were administered at the beginning of the semester during the pretest phase, and then again at the end of the semester during the posttest phase.

### ***Design and Data Analysis***

To evaluate the effectiveness of the Problem-Based Learning (PBL) methodology in student learning, a quasi-experimental design with pre-test and post-test assessments and a control group was utilized. The data analysis was conducted using the General Linear Model (GLM) for repeated measures.

The statistical software SPSS v.29, licensed to the University of Alicante, was employed for data analysis. The following sections present the results of the analysis, highlighting the intervention program's impact on the various study variables. Through this rigorous methodological approach, the study aimed to provide robust evidence of PBL's effectiveness in enhancing student performance and competency in developmental biology.

### **Results and Discussion**

The results indicate that the intervention effectively enhanced the studied variables. The experimental group showed significant improvements in their knowledge of Problem-Based Learning (PBL). Their experience with PBL also improved notably, reflecting a deeper understanding of its principles. Additionally, substantial gains were observed in the explanation of phenomena, and inquiry skills. These outcomes align with broader research findings on the impact of such programs (Fitriani et al.,

2020; Günter, 2020; Jdaitawi, 2020; Palupi et al., 2020; Suhirman et al., 2020; Wondie et al., 2020; Zhao et al., 2020). Detailed data supporting these findings can be found in Table 1.

**Table 2.** Summary of intra-inter subject univariate analysis of variance

	Source	Type III	df	F	Sig.	$\eta^2$ partial	Ob. Power
Knowledge of PBL	Intra	12.975	1	2.380	.127	.029	.332
	Intra*Entre	89.077	1	16.339	.000**	.170	.979
	Error intra	436.154	80				
	Inter	27.102.203	1	1.599.676	.000**	.952	1.000
	Condition	1.732.552	1	102.262	.000**	.561	1.000
	Error inter	1.355.385	80				
Experience with active learning methodologies	Intra	1.712.832	1	67.877	.000**	.459	1.000
	Intra*Entre	65.449	1	2.594	.111	.031	.356
	Error Intra	2018.755	80				
	Inter	19.410.431	1	532.659	.000**	.869	1.000
	Condition	172.685	1	4.739	.032*	.056	.576
	Error inter	2.915.251	80				
Experience with PBL	Intra	203.493	1	21.992	.000**	.216	.996
	Intra*Entre	177.883	1	19.224	.000**	.194	.991
	Error Intra	740.257	80				
	Inter	12.348.682	1	942.406	.000**	.922	1.000
	Condition	1.163.926	1	88.827	.000**	.526	1.000
	Error inter	1.048.269	80				
Overall Performance (theoretical knowledge of Developmental Biology)	Intra						
		2.073.390	1	704.842	.000**	.897	1.000
	Intra*Entre	.533	1	.181	.671	.002	.071
	Error Intra	238.273	81				
	Inter	21132.974	1	5.579.758	.000**	.986	1.000
	Condition	14.274	1	3.769	.056	.044	.483
Comprehensive Use of Scientific Knowledge	Error inter	306.782	81				
	Intra	8.303.943	1	2.384.394	.000**	0.968	1
	Intra*Entre	10.057	1	2.888	0.093	0.035	0.389
	Error Intra	278.61	80				
	Inter	20.896.413	1	5.794.758	.000**	0.986	1.000
	Condition	173.363	1	48.075	.000**	0.375	1.000
Phenomenon Explanation	Error inter	288.487	80				
	Intra	8.503.740	1	2.584.549	.000**	.970	1.000
	Intra*Entre	25.466	1	7.740	.007*	.088	.785
	Error Intra	263.218	80				
	Inter	16.234.108	1	4.618.297	.000**	.983	1.000
	Condition	150.071	1	42.692	.000**	.348	1.000
Scientific Inquiry	Error inter	281.214	80				
	Intra	8.336.790	1	2.204.905	.000**	.965	1.000
	Intra*Entre	19.273	1	5.097	.027*	.060	.607
	Error Intra	302.482	80.000				
	Inter	13.294.137	1	6.488.287	.000**	.988	1.000
	Condition	123.312	1	60.183	.000**	.429	1.000
	Error inter	163.916	80				

\* $p < .05$ , \*\* $p < .01$ .

The findings from this study demonstrate that the implementation of Problem-Based Learning (PBL) led to significant improvements in specific key areas, notably in students' Knowledge of PBL, Experience with PBL, Explanation of Phenomena, and Scientific Inquiry.

These positive outcomes partially confirm the first hypothesis (H1), underscoring the effectiveness of the intervention in enhancing students' understanding and practical application of PBL as an educational strategy. These results are consistent with broader research that supports the impact of such programs on fostering deep learning and engagement (Fitriani et al., 2020; Günter, 2020; Jdaitawi, 2020; Palupi et al., 2020; Suhirman et al., 2020; Wondie et al., 2020; Zhao et al., 2020).

However, the study also revealed that the intervention did not lead to significant improvements in certain areas, specifically in students' Experience with Active Learning Methodologies, Overall Performance, and Comprehensive Use of Scientific Knowledge. These findings suggest that while PBL is highly effective in developing particular critical skills, the evaluation of the program's effectiveness in this study does not indicate improvement across all educational dimensions. To address these gaps, future iterations of the intervention could incorporate a more integrated approach, combining PBL with other active learning methodologies to ensure a more comprehensive enhancement of students' skills across all areas. Additionally, more tailored support and scaffolding could be provided to students who may struggle with adapting to PBL, potentially leading to more consistent improvements across various performance metrics.

Moreover, the study partially confirms the second hypothesis (H2) by demonstrating that a well-structured didactic proposal can effectively guide instructors in using PBL to enhance students' skills, particularly in the explanation of phenomena, and inquiry. This finding underscores the critical role of PBL in promoting essential skills such as critical thinking, problem-solving, and the ability to seek and assess relevant information—all of which are crucial for meaningful learning and robust professional development.

The third hypothesis (H3) was also partially confirmed, as the intervention had a significant positive impact in explaining scientific knowledge and in developing critical inquiry skills. The experimental group exhibited substantial improvements compared to the control group, reinforcing the view that PBL is a powerful tool for enhancing educational outcomes. These findings align with established literature (De Araújo et al., 2020; Gu & Yang, 2020; C. X. Liu et al., 2020; Perusso & Baaken, 2020; Tang et al., 2020), further affirming the effectiveness of integrating PBL into curricula to foster student engagement, deeper comprehension, and improved overall performance.

Finally, the fourth hypothesis (H4) was not confirmed, as there was no significant improvement in the theoretical knowledge of developmental biology in the experimental group compared to the control group. The study agrees with Gorbaneff (2010) that problem-based learning (PBL) does not contribute to the accumulation and recall of information required in traditional assessments. Additionally, Martínez (2015) emphasizes that PBL necessitates a shift in evaluation methods to focus on developing mental competencies and real-world application.

## **Conclusions**

Based on the findings, the intervention program has effectively advanced students' understanding of active learning methodologies and their experience with Problem-Based Learning (PBL). These results are consistent with the growing body of research that highlights the positive impact of these learning strategies on educational outcomes (Fadiawati et al., 2020; Fitriani et al., 2020; Mustofa & Hidayah, 2020; Urrutia-Heinz et al., 2020). The significant progress observed in the experimental group underscores the importance of integrating these methodologies into educational practices.

Looking ahead, future interventions should focus on addressing two key areas for improvement. Firstly, while the content was communicated effectively, the specialization of each team in different scientific areas may have limited their overall understanding of the broader material. To enhance comprehension, future programs should allocate additional time for cross-team knowledge sharing, fostering a more integrated understanding of the content. Secondly, the study did not include a tool to assess the broader professional strengths and scientific knowledge that students acquired and shared. Developing such an assessment tool could provide a more comprehensive evaluation of students' knowledge and its impact on their professional development.

In summary, the study's findings affirm the substantial benefits of incorporating active learning methodologies and PBL into educational curricula. The observed enhancements in students' skills and their enriched learning experiences highlight the transformative potential of these approaches. By continuously refining and expanding these strategies, educators can further improve student engagement, deepen understanding, and better prepare students for future academic and professional challenges. This progress not only contributes to individual student success but also elevates the overall quality and effectiveness of educational practices, paving the way for more dynamic and impactful learning environments.

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**Conflicto de intereses**

Los autores declaran que no existe conflicto de intereses

**Declaración de contribución de autoría**

Elizabeth Yolanda Pérez Alarcón: Conceptualización, Investigación, Metodología, Administración del proyecto, Validación, Redacción de original.

María Verónica Maila Álvarez: Investigación, Curación de datos, Análisis formal, Supervisión, Redacción y edición.

Teresa Pozo-Rico: Investigación, Curación de datos, Análisis formal, Supervisión, Redacción y edición.

Raquel Gilar-Corbí: Curación de datos, Adquisición de fondos, Recursos, Visualización