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Enseñanza interdisciplinaria de las Ciencias Biológicas a estudiantes no STEM mediante aprendizaje basado en proyectos

Interdisciplinary Teaching of Biological Sciences to Non-STEM Students Through Project-Based Learning

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Abstract

This paper presents an exploratory study on the implementation of Project-Based Learning (PBL) in Biological Sciences courses aimed at non-STEM students, the objective was to integrate biological concepts with other disciplines in order to foster critical and interdisciplinary thinking. Following its implementation, participants' perceptions regarding the impact of an interdisciplinary project-based learning (PBL) methodology on their learning were explored. To achieve this, five simplified stages of PBL were adapted to guide 46 students in the development of projects connecting biology with their fields of study.

The research employed a mixed-methods design, using a questionnaire and the analysis of student work as data collection instruments. The results showed a significant increase in student motivation, particularly during the practical stages of project development. Additionally, 97.2% of participants reported improvements in the integration of biological concepts when linking them to their own disciplines, demonstrating the effectiveness of PBL in interdisciplinary teaching contexts.

It was concluded that this methodology facilitates the understanding of scientific concepts and promotes critical and interdisciplinary thinking.

Keywords: interdisciplinarity, critical thinking, project-based learning, STEM, motivation, biological sciences.

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Introduction

The formation of informed citizens who are capable of understanding basic scientific concepts and are motivated to stay informed and think critically is a social necessity (Valladares, 2021; Ke et al., 2021). The growing number of people who deny relevant scientific knowledge, such as climate change, together with the proliferation of fake news and unreliable sources of information, has alerted science educators to their responsibility toward scientific literacy (Puig et al., 2021; Howell & Brossard, 2021).

In response to this situation, the United Nations Educational, Scientific and Cultural Organization (2020) presented nine major ideas to establish the foundations for post-pandemic education. Among them, the need to guarantee scientific literacy within educational curricula and to promote reflection and the redesign of these contents stands out. Applying this action to students enrolled in careers unrelated to Science, Technology, Engineering, and Mathematics (STEM) requires the adoption of methods that facilitate interdisciplinary connections and the application of scientific concepts within their respective professions. This approach enables students to identify the "anchoring elements" of meaningful learning described by David Ausubel (1968), namely prior knowledge within their cognitive structure that serves as connection points for integrating new information.

Studies such as that of Matienzo (2020) highlight that teaching without considering students' prior knowledge is ineffective, since this represents the most influential variable in the learning of new content. Furthermore, anchoring ideas have been shown to strengthen both information retention and practical application, thereby improving the capacity to achieve meaningful learning (Aliakbari et al., 2015). On the other hand, research by Drake and Burns (2004) and Semilarski et al. (2022) emphasizes that understanding central disciplinary and interdisciplinary ideas positively influences perceived self-efficacy in science learning. Likewise, Bonny Ortiz-Andrade et al. (2019) stress that the creation of products contributes significantly to interdisciplinary understanding.

Consequently, integrating knowledge related to students' own fields of study can enhance the understanding of scientific concepts, encourage critical thinking, and highlight the importance of scientific literacy in their lives and professional development. In turn, this contributes to addressing complex issues such as scientific illiteracy and misinformation among professionals outside STEM fields. These students often adopt a unidisciplinary perspective and show little motivation toward science, largely due to a lack of awareness of its relevance.

For this reason, the initiative *"Interdisciplinary Projects from the Biological Sciences"* was designed using a Project-Based Learning (PBL) approach in order to enrich the learning of Biological Sciences concepts and promote the development of critical thinking through integration with other disciplines. Subsequently, the research objective was established as exploring participants' perceptions regarding the impact of an interdisciplinary project-based methodology (PBL) on their learning, focusing on dimensions such as motivation, concept learning, critical thinking, and disciplinary integration.

To address this objective, the following sections describe the pedagogical strategies implemented during the project. Likewise, the methodology employed, based on a mixed-methods design, is explained. Finally, the results and conclusions are presented.

Theoretical Framework

Project-Based Learning (PBL) is valued for its student-centered approach, its capacity to promote interdisciplinarity, and its effectiveness in motivating students by linking content to real-world problems, thereby helping to develop key competencies such as critical thinking (Pulecio et al., 2024; Saavedra & Rapaport, 2024; Kousen & Vargas, 2021). Furthermore, PBL adapts to different educational contexts and fosters motivation, collaboration, and critical thinking among students (Chadha, 2006; Lattimer & Riordan, 2011; Medina & Tapia, 2017; Shin, 2018; Haatainen & Aksela, 2021; Pulecio et al., 2024).

Despite its advantages, students may face challenges during the implementation of PBL, such as difficulties in becoming fully engaged (Dauletova, 2014), problems with time management, lack of follow-up, and insufficient facilities (Aldabbus, 2018). Nevertheless, this approach continues to stand out as a valuable strategy for fostering interdisciplinarity in higher education teaching (MacLeod & Van der Veen, 2020). It also increases student participation by stimulating the exchange and discussion of knowledge and information (Almulla, 2020).

PBL is based on real-life situations that motivate students to investigate, create solutions, and develop tangible products, culminating in a public presentation that celebrates the achievements attained (Colley, 2008). Projects designed under this approach focus on real challenges that are clear and relevant to learning objectives, thereby promoting deep immersion in the topic and encouraging independent learning. The research required to solve such challenges drives students to explore solutions, acquire knowledge, and critically evaluate information.

Additionally, group work allows students to analyze advantages and disadvantages, predict outcomes, and make informed decisions, facilitating the effective resolution of the challenge. Finally, this approach includes the creation of prototypes or models as part of the solution, along with the presentation of results (Colley, 2008; Steuer, 2022).

Planning the Interdisciplinary PBL Approach

To ensure that students enrolled in Biological Sciences courses establish connections among different disciplines, it is necessary to create guiding pathways that both educators and students can follow in an organized manner, thereby avoiding confusion (Holgaard et al., 2020; Steuer, 2022; Van den Beemt et al., 2020; Ke et al., 2021). Several studies have shown that these projects not only improve conceptual understanding, but also motivate students by demonstrating the applicability of their learning in real-world scenarios (Lavado-Anguera et al., 2024; Chadha, 2006; Domènech-Casal, 2018; Saavedra & Rapaport, 2024). Furthermore, this methodology promotes collaborative work and creativity among students (Hutchison, 2016; Haatainen & Aksela, 2021).

The depth of disciplinary integration is framed within the three levels of interdisciplinarity defined by Jean Piaget (1975): multidisciplinarity, interdisciplinarity, and transdisciplinarity. Multidisciplinarity represents the basic level, in which various disciplines contribute information to address a common problem; although they collaborate in parallel, their boundaries remain clear, enriching each discipline without significantly altering its methods or approaches. Interdisciplinarity, by contrast, involves deeper cooperation, with interactions that lead to exchange and mutual conceptual enrichment. At this level, disciplines support one another by combining methods and knowledge to provide integrated solutions. Finally, transdisciplinarity constitutes the most advanced level of integration, where disciplinary boundaries disappear entirely, creating a cohesive system of relationships. This approach addresses problems from a holistic perspective that transcends the capacities of a single discipline (Piaget, 1975).

In this study, the PBL steps proposed by Colley (2008) and Steuer (2022) were adapted into five simplified stages with the aim of enabling non-STEM students to integrate Biological Sciences in a meaningful way and better understand the importance of its concepts according to their needs and interests. In addition, the process seeks to ensure that the evaluation of student progress considers not only technical knowledge, but also key skills and competencies such as critical thinking and the ability to integrate different disciplines (Freeman et al., 2014; Lavado-Anguera et al., 2024).

Methodology

This study adopted a mixed-methods approach that combined quantitative and qualitative data to analyze students' perceptions and experiences. As a research design, a case study with a single unit of analysis was employed (Creswell, 2019), allowing for a more comprehensive understanding of the impact of interdisciplinary Project-Based Learning within the framework of the initiative *Interdisciplinary Projects from the Biological Sciences* (PICBio).

The participants were 46 students enrolled in Biological Sciences (CIBI) courses, specifically courses coded 3016 and 3026, at the Faculty of General Studies of the University of Puerto Rico. These interdisciplinary courses typically attract students from different faculties, resulting in a diverse and representative sample. Of the 46 students, 28 were women (61%) and 18 were men (39%). Most participants came from the faculties of Social Sciences and Business Administration, each represented by 10 students. Other represented faculties included Communication and Information (6 students), Education (6), Architecture (4), Humanities (4), and General Studies (2).

Regarding year of study, 5 students were in their first year, 21 in their second year, 15 in their third year, and 5 in their fourth year. In terms of majors, there was broad representation from areas such as Political Science (10 students), Marketing (10), Audiovisual Communication (6), Art (6), among others. This disciplinary diversity enabled a wide range of perspectives and approaches in the creation of interdisciplinary products, enriching both the learning process and the integration of biological concepts with participants' fields of study.

Throughout the project, students were provided with a guide that was progressively adjusted as they advanced through the project phases. Over the course of 14 weeks, 30 minutes of each class session were allocated weekly for students to work on the project, share ideas, make adjustments, and receive feedback. For the implementation of PBL, the phases described by Colley (2008) and Steuer (2022) were adapted and simplified into five fundamental stages:

1. **Introduction and topic selection.** In this stage, the project is introduced, the main objectives are defined, and a challenge is assigned. Students identify a real-world problem connecting Biological Sciences with their disciplines, guiding the project's development. They also begin conceptualizing a product that reflects this integration.
2. **Initial research.** Students begin searching for relevant information related to the selected topic. This process allows them to deepen the interdisciplinary connection and advance the conceptual development of the product.
3. **Product design and development.** Using the information collected, students design the product by defining the necessary materials and techniques. During this phase, they continue exploring the disciplines involved in order to enrich the project.
4. **Presentation development.** This stage is based on the developed product, the integrated disciplines, and the project's social impact. Students receive a guiding template and continuous feedback throughout the process, including prior rehearsals to refine their presentations.
5. **Presentation of results, celebration of achievements, and reflection.** Students present their results at a project fair attended by peers, family members, and community guests. During this same stage, students engage in reflection to evaluate their learning, identifying how the project strengthened their understanding of biological concepts and their relationship with their disciplines.

This student-centered model positioned participants as active protagonists throughout each of the five stages, promoting self-directed learning. During the development of the project, formative assessment instruments were implemented at every stage to guide progress and address difficulties. Examples included graphic organizers, concept maps, and partial presentations that facilitated continuous feedback from both the instructor and classmates.

As a data collection instrument, a final questionnaire was designed and reviewed by a panel of experts consisting of three science educators. Their review ensured the relevance and clarity of the questions in relation to the study's objective: integrating students' non-STEM disciplines for the learning of biological concepts and the development of critical and interdisciplinary thinking. The questionnaire was administered at the end of the project and focused on two thematic axes: motivation and learning perspectives mediated through disciplinary integration. Specifically, students' levels of motivation throughout the project were measured, along with their perceptions regarding learning outcomes, their ability to integrate

biological concepts with their disciplinary areas, and the development of specific critical-thinking processes.

In addition, open-ended questions were included so that students could express their experiences and the challenges they encountered during the process. These responses provided a more comprehensive view of the project's influence on their motivation, learning, and skill development. To achieve a holistic perspective, questionnaire results were analyzed through both quantitative and qualitative approaches.

Quantitative data were evaluated using descriptive statistical methods, allowing the identification of key patterns and trends. Likewise, to determine significant differences between initial and final motivation levels, an independent samples t-test was conducted. Prior to performing the test, assumptions of normality and homogeneity of variances were verified. Initial and final motivation values were grouped into two independent sets, and the t-test was carried out at a significance level of 0.05 using the programming language Python to ensure precision in the calculations.

On the other hand, qualitative data were examined through manual coding, following a thematic approach based on the study categories. To ensure objectivity and consistency in the analysis, clear coding criteria were established and review processes were conducted to validate emerging categories.

Likewise, the student-developed product prototypes were analyzed according to the levels of integration described by Jean Piaget (1975). Prototypes in which disciplines contributed information to the product while maintaining clearly defined boundaries were classified as multidisciplinary. Those demonstrating interaction among disciplines, with less clearly defined boundaries, were considered interdisciplinary. Finally, products characterized by deep interaction among disciplines, blurred boundaries, and such profound connections that the absence of one discipline would compromise the existence of the product, were categorized as transdisciplinary.

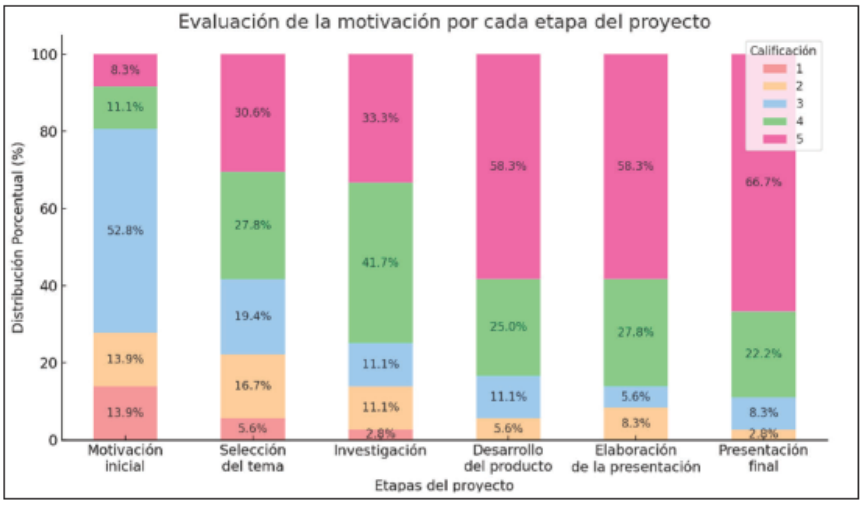
Results

The following section presents the results obtained from the data collected through the questionnaire, which was completed by 36 participants.

Thematic Axis 1: Motivation Throughout the Project

The means and standard deviations of the ratings on a scale from 1 to 5 were calculated for each stage, including the initial motivation and the final motivation during the presentation stage.

Figure 1. *Percentage distribution of student motivation ratings across the different stages of the project.*



Nota. La figura muestra cómo los estudiantes evaluaron su motivación a lo largo de las etapas del proyecto ABPr. Los datos representan el porcentaje de estudiantes que calificaron su motivación en una escala de 1 a 5, desde el inicio del proyecto hasta su culminación con la presentación final, y evidencian el aumento progresivo de la misma.

The percentage distribution graph of the ratings shows a clear trend of increasing student motivation as participants progressed through the different stages of the project (Figure 1). Initial motivation was moderate, with most students (52%) assigning a rating of 3. However, by the end of the project, during the final presentation stage, 66% of the students rated their motivation as 5, reflecting a significant increase.

Intermediate stages, such as presentation development and product design, also received high ratings, with 58% and 56% of students assigning a rating of 5, respectively. Furthermore, the results of the t-test confirmed this trend, indicating a significant difference between initial and final motivation levels, with a p-value of < 0.001 (1.19×10^{-10}).

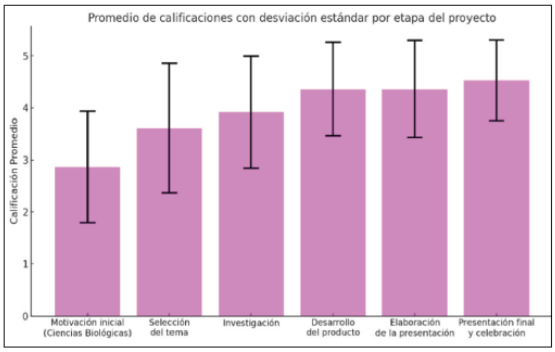
To conduct this analysis, the motivation ratings reported by students at the beginning of the project were compared with those reported during the final stage, corresponding to the public presentation of the product. The results reflect a significant increase in average motivation, supporting the effectiveness of the PBL approach in fostering student participation and engagement.

The p-value of < 0.001 (1.19×10^{-10}) represents an extremely high level of statistical significance, indicating that the probability of the observed differences occurring by chance is practically nonexistent.

In practical terms, these results reinforce the validity of the observations and demonstrate that the implementation of PBL had a consistent impact on increasing student motivation. Although the standard deviation at each project stage shows some variability in individual responses, the analysis of means reveals a significant increase in motivation, rising from 2.86 (SD = 1.07) at the beginning to 4.53 (SD = 0.77) at the end of the project. This suggests

that, despite the dispersion in individual ratings, student motivation increased consistently as participants progressed through the different stages of the project.

Figure 2. *Means and standard deviations of student motivation across the different stages of the project.*



Nota. La figura presenta la evolución de la motivación estudiantil mediante promedios y desviaciones estándar calculadas para cada etapa del proyecto. Los resultados destacan un aumento significativo en la motivación, especialmente durante las etapas prácticas y la presentación final.

The qualitative analysis of the elements students considered motivating in completing the project revealed a diversity of factors. The main themes identified included: connecting science with their academic fields and careers (12 responses), interest in understanding new concepts that would be useful in their lives (6 responses), group work (6 responses), the satisfaction derived from producing a tangible and innovative result (4 responses), and presenting in an amphitheater setting (4 responses).

These findings suggest that the project offered multiple pathways for motivation; however, the connection between science and students' own disciplines clearly emerged as the distinguishing factor.

Thematic Axis 2: Perception of Learning

Most students (97.2%), who assigned ratings of 4 or 5, were able to integrate concepts from different areas into the creation of a product. Likewise, 94.3% of participants, with ratings of 4 or 5, stated that the project helped them establish interdisciplinary connections. Only 5.7% assigned a rating of 3, suggesting that very few students had a less favorable experience.

Perception of Learning Mediated Through Disciplinary Connections

The majority of students (63.89%) perceived that their learning was greatly facilitated by the connections established between Biological Sciences and their own disciplines, assigning the highest rating (5). A smaller percentage of students (22.22%) also gave a high evaluation to their learning experience (4), while 13.89% assigned a rating of 3.

Concepts Learned

The qualitative analysis of the biological concepts explored by students through the project revealed broad thematic diversity, encompassing areas such as ecology, health, genetics,

evolution, and bioart. Topics included current issues such as climate change, eco-anxiety, and assisted reproductive technologies, while also reinforcing essential foundational concepts such as evolution and DNA.

Figure 3. *Relationship between the stages of the project and the establishment of interdisciplinary connections.*



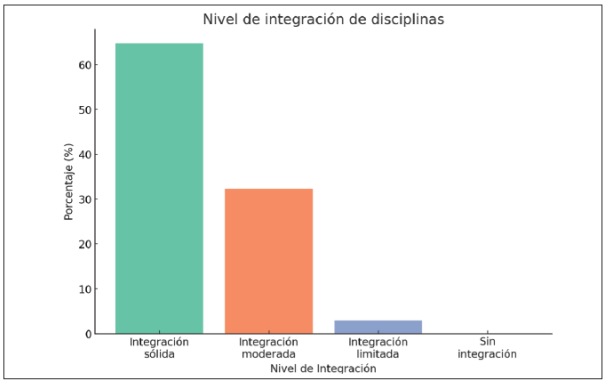
Nota. La figura representa la percepción de los estudiantes sobre el nivel de conexión interdisciplinaria logrado en cada etapa del proyecto ABPr. Las etapas más prácticas, como investigación y el desarrollo del producto, fueron identificadas como las más efectivas para visualizar la interacción entre disciplinas en el contexto de los proyectos realizados.

Project Stages and Disciplinary Connections

Participants stated that the stage in which they were best able to understand the connections between disciplines was the product development stage (Figure 3). Although the overall perception of the interdisciplinary connections achieved was high, students considered that these connections became particularly visible during the more practical and exploratory phases of the project: the research and product creation stages.

According to these findings, these stages were the most effective in helping students visualize how different disciplines interact within the applied context of their projects.

Figure 4. *Perception of the level of disciplinary integration.*



Nota. La figura muestra cómo los estudiantes percibieron el nivel de integración logrado a lo largo del proyecto, clasificándolos como multidisciplinario (limitado), interdisciplinario (moderado) y transdisciplinario (sólido).

Perception of the Level of Disciplinary Integration

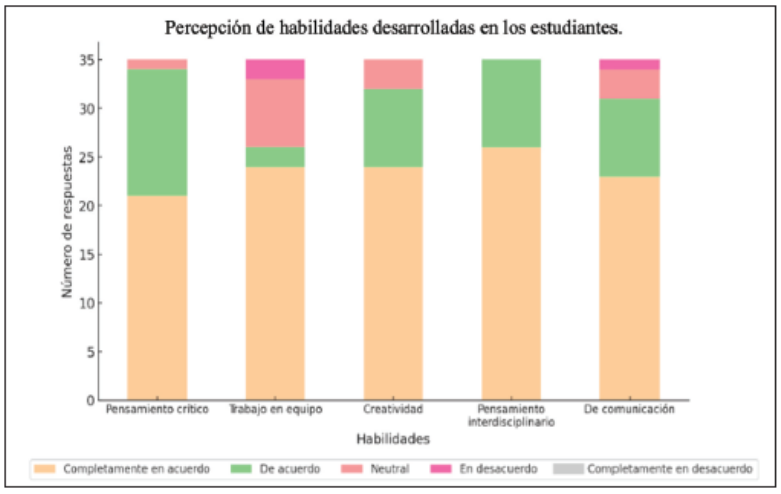
Responses regarding the level of integration among disciplines showed that most students perceived a strong level of integration (21 responses). A considerable number also described it as moderate (14 responses), indicating that although the interdisciplinary relationship was effective, it was not always perceived as equally strong by all participants. Only one student reported limited integration, and no cases were reported in which students perceived no integration at all (Figure 4).

The analysis of the developed products confirmed this diversity in integration levels, highlighting creations such as ecological school designs and models inspired by evolution (deep integration), infographics about the relevance of Biological Sciences in their university education (moderate integration), and analogies between biological evolution and the evolution of advertising (limited integration).

Perception of Skill Development

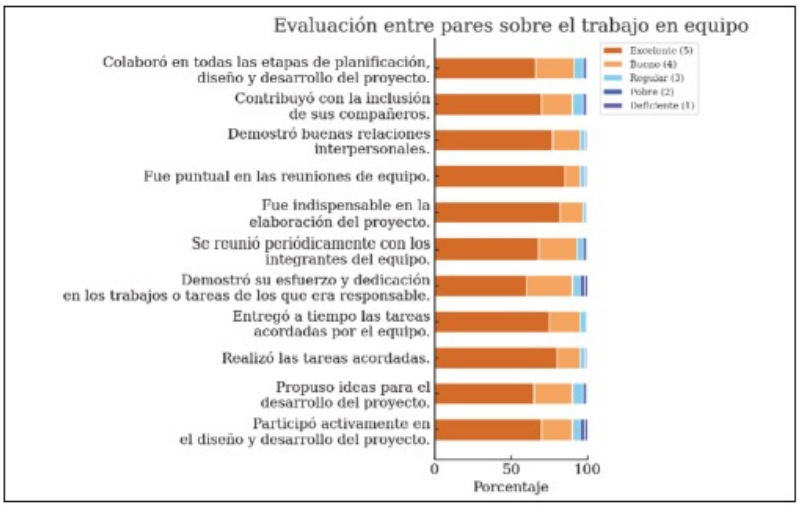
Figure 5 shows that, overall, students perceived their skill development positively. One of the most highly valued skills was interdisciplinary thinking. However, it was also observed that a small group of students expressed disagreement regarding the development of teamwork skills facilitated by the project. For this reason, peer evaluations were reviewed, revealing that this disagreement could be related to difficulties in collaboration and communication among team members (Figure 6).

Figure 5. *Students' perception of skill development.*



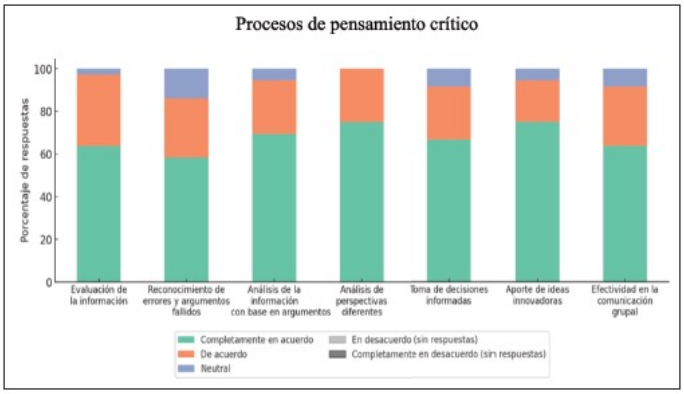
Nota. La figura ilustra las valoraciones de los estudiantes sobre las habilidades desarrolladas durante el proyecto, destacándose el pensamiento interdisciplinario como una de las competencias más valoradas.

Figure 6. *Results of the peer evaluation of teamwork.*



Nota. Los datos reflejan variaciones en la percepción de efectividad grupal, destacando tanto fortalezas como áreas donde algunos estudiantes enfrentaron desafíos en la colaboración y comunicación dentro de sus equipos.

Figure 7. *Critical thinking processes carried out by students during the development of the project.*



The questionnaire further explored several critical thinking processes, such as information evaluation, error recognition, information analysis based on arguments, perspective analysis, informed decision-making, the contribution of innovative ideas, and effectiveness in group communication. Most students perceived the evaluated processes positively (Figure 7). However, some responses were neutral, suggesting opportunities for improvement in the implementation of strategies, particularly in aspects such as error recognition, informed decision-making, and effectiveness in group communication.

Resources Used by Students

The questionnaire also investigated the technological resources used by students, revealing a wide variety of tools represented in Table 1. These resources were also reflected in the students' final products and presentations.

Table 1. *Resources mentioned by students in the questionnaire.*

Aplicación o herramienta tecnológica	Proceso
Google Scholar Bing Google YouTube Sitios web y aplicaciones de arquitectura (Ej. ArchDaily) y para mercadeo (Ej. www.marketing.com) Bases de datos UPR Periódicos digitales	Búsqueda de información
Goodnotes	Diseño de productos: visualización
Capcut	Diseño de productos: edición de videos
Procrearte	Diseño de productos: diseño de obras de arte
Libros de anatomía	Búsqueda de información: inspiración para el diseño de bioarte
ChatGPT / Copylot / Otras	Búsqueda de información y generación de ideas
WhatsApp	Compartir y organizar información
Microsoft Word	Compartir y organizar información
Google Docs	Compartir y organizar información
Google Slides	Compartir, organizar y presentar información
PowerPoint	Presentar información
Canva	Organizar, compartir y presentar la información, Desarrollo de productos como imágenes de campañas publicitarias, infografías, edición de videos, analogías, entre otras

Finally, the qualitative analysis of students' suggestions and comments regarding the PICBio project highlighted key areas for improvement, including increasing classroom interaction to facilitate group coordination, improving the management of time allocated for the different project stages, and optimizing oral presentations through more dynamic and interactive approaches.

Discussion

The results indicate that student participation in the project was effective in connecting knowledge from their disciplines, learning biological concepts, and developing both interdisciplinary and critical thinking. This finding reinforces the proposal by Medina and Tapia (2017), who emphasize that PBL allows for the integration of diverse areas of knowledge while fostering critical skills in students. In this context, two key thematic axes were identified: motivation and perception of learning. Both were positively impacted by the implementation of PBL, suggesting its effectiveness in promoting meaningful and contextualized learning.

The following discussion analyzes how these aspects contributed to the development of critical and interdisciplinary skills, as well as the implications of these findings for future educational contexts.

Motivation

In this study, the connection between science and students' non-STEM careers was identified as a key factor in motivation. This result aligns with the theory proposed by David Ausubel (1968), who states that prior knowledge functions as anchoring ideas, facilitating the integration of new concepts and promoting interdisciplinary connections. According to Matienzo (2020), this increase in motivation may be explained by the fact that students found a clear purpose that encouraged them to acquire new concepts in a meaningful way.

In addition to acting as facilitators of learning, students' academic disciplines served as anchoring ideas that helped connect biological concepts with their professional contexts. This integration enabled participants to visualize the practical relevance of the content, thereby strengthening both motivation and self-efficacy. Likewise, interdisciplinarity amplified the impact of these anchoring ideas by promoting deeper connections among disciplines and fostering meaningful, contextualized learning.

The increase in motivation throughout the different stages of the project may be explained by the fact that, although interdisciplinary connections initially represented a challenge, students gradually achieved greater fluency as they advanced and understood the purpose of these interrelationships. In response to the question, *"What elements of the project contributed to your motivation to complete it?"*, students highlighted key aspects such as collaborative work and the relevance of interdisciplinary connections. This finding is consistent with the research of Botella and Ramos (2019), who emphasize that teamwork and the exchange of perspectives strengthen both motivation and engagement in educational settings.

For example, Student 1 (St. 1) stated: *"The most important element was that everyone in my group was able to find something that united us. Once we found that, we became motivated and started working hard."* In addition, some participants emphasized the importance of understanding how Biological Sciences connect with their academic majors and highlighted the relevance of interdisciplinary connections: *"It was mainly trying to understand how Biological Sciences connect with our majors"* (St. 2).

The creation of a tangible product also emerged as a motivating factor, consistent with previous studies emphasizing the importance of practical tasks in interdisciplinary learning (Saavedra et al., 2021). As Student 7 (St. 7) explained: *"I think the product our group worked on was one of the motivations for completing the project. This contributed greatly to our motivation."*

These findings, in addition to complementing the quantitative results, align with recent research highlighting how PBL fosters motivation by actively involving students in practical and creative processes, allowing them to become protagonists of their own learning (Lattimer & Riordan, 2011; Medina & Tapia, 2017; Shin, 2018; Pulecio et al., 2024). Furthermore, the use of interdisciplinary activities and the connection of academic content with real-world contexts reinforce the arguments presented by Domènech-Casal (2018) and Saavedra and Rapaport (2024), who emphasize that these strategies increase motivation by making learning relevant to students' future professional and personal lives.

The results from the Motivation thematic axis highlight the importance of interdisciplinary connections and the practical relevance of academic content in student motivation. The integration of biological concepts with the professional contexts of non-STEM students acted as a catalyst for meaningful learning, increasing both motivation and self-efficacy. In addition, collaborative work and the creation of tangible products were identified as key factors that encouraged students to engage with and complete the project.

These results are consistent with previous research demonstrating how project-based learning and interdisciplinarity can foster greater engagement in educational environments. Finally, the findings provide valuable evidence regarding how educational strategies that promote connections among disciplines and the practical application of knowledge can enrich the learning experience and motivate students to achieve their academic and professional goals.

Perception of Learning Mediated Through Connections Between Disciplines

For the second thematic axis, most students perceived a strong integration among disciplines, followed by a moderate level of integration, with only one student mentioning limited integration. These results reflect the model proposed by Jean Piaget (1975), which describes the levels of multidisciplinarity, interdisciplinarity, and transdisciplinarity as scales for evaluating the connections between areas of knowledge.

Interdisciplinary connections were most evident during the practical stages of the project, such as product development and the research phase, reinforcing the importance of hands-on approaches in consolidating meaningful learning (Domènech-Casal, 2018). This high degree of cohesion among disciplines aligns with research highlighting the effectiveness of PBL in promoting deep connections between areas of knowledge, particularly through creative and collaborative activities (Ortiz-Andrade et al., 2019; Medina & Tapia, 2017).

The product prototypes created by students reflected different levels of integration. For example, a model inspired by whale evolution was categorized as transdisciplinary because

it merged concepts from biology and art without clearly defined boundaries, enabling a deep synthesis. This result is consistent with studies emphasizing that the integration of art and science strengthens interdisciplinary understanding and promotes meaningful learning (Drake & Burns, 2004; Ortiz-Andrade et al., 2019; Saavedra et al., 2021).

In contrast, a product establishing an analogy between biological evolution and the evolution of advertising showed clearer disciplinary boundaries, reflecting a lower level of integration. Nevertheless, both cases demonstrated that students achieved significant mastery of biological concepts, suggesting that the level of disciplinary integration did not negatively affect conceptual learning. This finding highlights the need for additional research exploring the relationship between levels of disciplinary integration and long-term learning outcomes.

Recent studies further reinforce the effectiveness of PBL in developing critical competencies. For example, Medina and Tapia (2017) and Domènech-Casal (2018) emphasize that this approach connects different areas of knowledge.

Conclusions

Project-Based Learning (PBL) proved to be an effective strategy for connecting knowledge from Biological Sciences with other disciplines, enabling students to understand concepts while developing both critical and interdisciplinary thinking. In this study, linking biological content with the participants' diverse academic fields was a key factor that motivated and facilitated their learning. Furthermore, practical and exploratory tasks, particularly during the product development and creation stages, enabled students to better visualize interdisciplinary connections and contributed to consolidating their understanding and strengthening their self-efficacy.

The concepts inherent to the different disciplines represented within the study population played a fundamental role as anchoring ideas, serving as starting points for integrating biological concepts into non-STEM contexts. The contribution of these disciplines facilitated integration and promoted meaningful learning that strengthened both motivation and critical thinking. Likewise, it allowed students not only to understand biological concepts, but also to apply them in practical situations relevant to their professions and communities. These findings highlight the importance of designing projects that use anchoring ideas and interdisciplinary connections as central axes of learning.

Alongside these positive results, several areas for improvement were also identified. One limitation observed, to a lesser extent, was variability in student participation, especially regarding group communication skills. Although PBL encourages teamwork, some groups experienced difficulties in establishing effective communication, underscoring the need to implement activities that reinforce these competencies.

Additionally, the lack of specific instruments capable of objectively measuring levels of interdisciplinary integration represents another limitation of the study. Therefore, the following recommendations are proposed for educators, curriculum designers, and researchers interested in interdisciplinary and project-based teaching:

1. **Strengthen group communication skills:** Design workshops and specific activities aimed at improving communication and collaborative work among students in order to foster cohesion and the exchange of ideas.
2. **Develop interdisciplinary assessment instruments:** Create standardized tools capable of measuring levels of interdisciplinary integration and their impact on learning in a more precise and reliable manner.
3. **Explore the application of PBL in broader contexts:** Extend this methodology to other disciplines and student populations in order to evaluate its effectiveness across different academic scenarios.
4. **Conduct longitudinal studies:** Investigate the long-term impact of PBL on students' professional development and their ability to apply interdisciplinary connections within their careers.

In conclusion, the findings of this study highlight the potential of Project-Based Learning (PBL) as a pedagogical tool that connects scientific concepts with non-STEM disciplines, thereby promoting critical thinking, interdisciplinarity, and meaningful learning. The integration of disciplinary areas enabled students to visualize the practical relevance of biological concepts within their academic and professional contexts, while also strengthening their motivation and active participation.

Moreover, this approach underscores the need to continue developing innovative methodologies that foster interdisciplinary connections, which are essential for addressing educational challenges and preparing students for an increasingly complex and interconnected world.

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