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INNOVATION IN UNIVERSITY SCIENCE TEACHING THROUGH PROFESSIONAL LEARNING COMMUNITIES

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Abstract

This paper analyzes the relationship between the development of pedagogical innovation projects in experimental sciences and the establishment and evolution of Professional Learning Communities (PLC) in higher education, within an open innovation framework. To achieve this, an evaluative study employing a mixed-methods approach was conducted, involving 93 members of the academic community–including faculty, students, alumni, and administrative staff–who collaboratively designed and implemented 15 pedagogical innovation projects across various scientific disciplines. The findings indicate that projects with a clearly defined pedagogical objective foster dialogue, reflection, collaborative work, and mutual learning, thereby facilitating the formation and evolution of PLC. In conclusion, open innovation and PLC contribute to transforming a culture of individualism into one of collaboration, ultimately enhancing the quality of higher education.

Keywords **–** Professional learning communities, Open innovation, Higher education, Experimental science teaching.

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1. Introduction

The National University of Colombia (UNAL) has identified the high rate of recurring failures in experimental science courses as one of its primary challenges, significantly affecting the institution's educational quality and contributing to a high dropout rate during the initial phase of the study plan (Dirección Nacional de Programas Curriculares [DNPC], 2004; Layton-Jaramillo & Moncada, 2023; Universidad Nacional de Colombia [UNAL], 2019).

While failures in basic science courses at UNAL have been attributed to student-related factors –such as heterogeneous academic backgrounds, poor study habits, and difficulties adapting to university life

(DNPC, 2004; Layton-Jaramillo & Moncada, 2023)–, this issue is also linked to the limited pedagogical training of faculty members. According to the National Directorate of Undergraduate Programs, instructors routinely perform their duties without reflecting on their teaching practices, disregarding discussions on didactic strategies or the understanding of cognitive processes (DNPC, 2004).

Furthermore, content-centered pedagogical approaches continue to prevail (DNPC, 2004), without addressing the specific challenges of science teaching, such as integrating theory and practice or the widespread adoption of active methodologies. Additionally, some professors contend that pedagogical knowledge is not as important as disciplinary expertise (Layton-Jaramillo & Moncada, 2023).

The underestimation of the importance of representing disciplinary knowledge to students–referred to in the English-language literature as Pedagogical Content Knowledge (Shulman, 1987) and in Spain as Conocimiento Didáctico del Contenido (Didactic Content Knowledge) (CDC) (Garcia, Yot & Perera, 2016)–among science professors at UNAL is also related to the institution's incentive system. This system prioritizes faculty productivity as researchers or consultants, leading to a negative stimulus toward teaching and educational research (DNPC, 2004).

It has also been observed that when professors implement educational innovations in their classrooms, they tend to do so in an isolated and independent manner, rarely sharing their reflections, learnings, and outcomes with the broader academic community. Additionally, the university lacks a systematic record of these experiences, which undermines institutional sustainability (UNAL, 2019).

Within this framework, the National Directorate of Pedagogical Innovation (DNIA) proposed the Pedagogical Innovation Initiatives Incubator Project (I3P) to foster reflection on pedagogical challenges and explore potential solutions through the design and implementation of collaborative innovation projects.

The I3P Project aligns with the principles and strategic objectives of UNAL, where innovation is defined as "the process leading to the experience of new learning opportunities aimed at improving the education of those involved" (Layton-Jaramillo, Duarte-Velasco, Aguaded-Ramírez & Carrillo-Rosúa, 2023: page 174). According to Tejada-Fernandez (2007), educational innovation is a dynamic and multidimensional process that requires teacher reflection to seek new approaches for tackling needs and enhancing classroom reality.

To implement the I3P Project, a stage-based model was proposed (see Figure 1), based on Open Innovation (OI) as a strategy to foster the formation of Professional Learning Communities (PLC) among members of different campuses and faculties at UNAL (Layton-Jaramillo, Pulido-de-Castellanos, Aguaded-Ramírez & Duarte-Velasco, 2024).

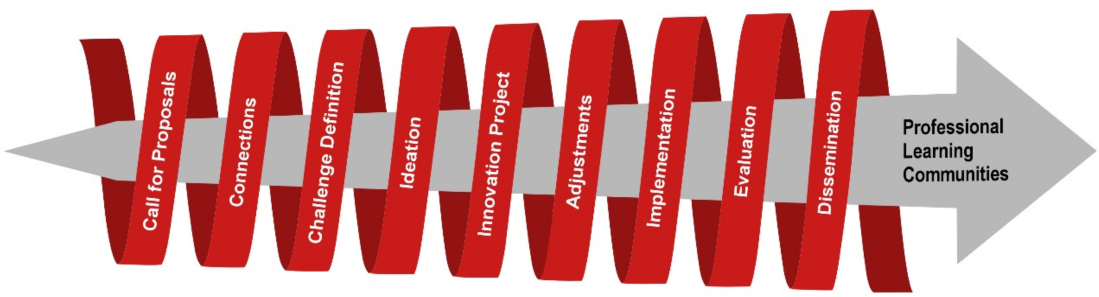

Figure 1. I3P Model (Layton-Jaramillo et al., 2024)

Open innovation is based on the free flow of both inbound and outbound knowledge to enhance traditional innovation processes (Chesbrough, 2003). Although the term originally emerged in the business sector as a strategic approach (Chesbrough, 2024), open innovation has also been successfully implemented in other types of organizations, such as universities, science parks, and technology hubs. These implementations have demonstrated that knowledge transfer in multiple directions enhances the development of capabilities in both individuals and organizations when they engage in collaborative networks and communities of practice (Bayat, Daraei & Rahimikia, 2022; Tyurikov, Kunizheva, Voevodina & Gruzina, 2022).

Additionally, I3P aligns with major educational trends that have emerged in recent decades in compulsory education to promote educational improvement. These trends focus on professional development for teachers by fostering collaborative work and distributed leadership within Professional Learning Communities (PLC) (Aparicio-Molina & Sepúlveda-López, 2018; Bolívar, 2007; Peña-Ruz, 2023).

PLC are, in themselves, an innovation and are defined as a group of teachers who share a common understanding of education, reflect on their work, and exchange their practices to improve student learning (Bolam, McMahon, Stoll, Thomas, Wallace, Greenwood et al., 2005; Bolívar, 2007). The dimensions of PLC are: shared leadership (D1), shared vision and values (D2), collective learning (D3), shared personal practice (D4), and supportive conditions (D5) (Hipp & Huffman, 2010).

In compulsory education, one common strategy to strengthen PLC is the development of projects with clear pedagogical objectives (Peña-Ruz, 2023). At the university level, this remains an emerging field of research. However, in recent years, studies have been published on the professional development of university faculty within PLC, with strong support from digital tools for virtual interaction and dialogue (Czerwonogora & Rodés, 2019; Naidoo, Gore, McKean, Mullins, Bowdle, Mack et al., 2023). According to Clark, Zhan, Dellinger and Semingson (2023), PLC serve as an effective means to enhance the sharing of didactic knowledge among university faculty and to foster the development of innovative pedagogical practices.

Given that the I3P was proposed with the explicit intention of promoting the formation of PLC through pedagogical innovation projects, the objective of this study is to analyze the relationship between the formation of PLC and the process of designing and implementing pedagogical innovation projects in science within the framework of the I3P project. To this end, four specific objectives were proposed:

1. Describe the types of connections generated among members of the UNAL community that emerged during the development of innovation projects in experimental science.
2. Compare the characteristics of PLC and the level of development they achieve when designing and implementing innovation projects in experimental science.
3. Identify the factors that contribute to and hinder the formation and consolidation of PLC during the execution of projects in experimental science.
4. Distinguish the strategies through which educational innovations in experimental science are achieved within the I3P.

2. Methodology

This study is grounded in a Program Evaluation research approach and was conducted in four phases: needs assessment, program design, intervention, and evaluation (Layton-Jaramillo et al., 2024). This document pertains to the final phase, during which the evaluation was specifically carried out for the PLC that developed pedagogical innovation projects in experimental science. A mixed-methods approach was employed, utilizing both quantitative and qualitative techniques in alignment with the specific objectives.

2.1. Population and Sample

The population consists of 93 members of the UNAL educational community who participated in the I3P with pedagogical innovation projects in experimental science.

The sampling design was multi-stage. The first stage relates to objectives 1, 3, and 4. In this stage, the sample included 100% of the population. The second stage corresponds to objective 2, and the sampling method was non-probabilistic, specifically incidental sampling, with the sample consisting of individuals who voluntarily completed a questionnaire on the characteristics of pedagogical innovation in I3P.

Table 1 summarizes the characteristics of the population and sample according to the role and UNAL campus.

	Population and Sample Stage 1		**Sample Stage 2**	
	N	**%[a]**	**n**	**%[b]**
According to role				
Professors	21	22.8	17	80.1
Graduate students	39	42.4	24	61.5
Postgraduate students	24	26.1	17	70.8
Alumni	5	5.4	1	20.0
Administrative staff	3	3.3	3	100.0
Total	**92**	**100.0**	**61**	**66.3**
According to UNAL campus				
Amazonía	3	3.3	2	66.7
Bogotá	52	56.5	32	61.5
La Paz	1	1.1	1	100.0
Manizales	6	6.5	3	50.0
Medellín	4	4.3	1	25.0
Palmira	25	27.2	21	84.0
Orinoquía	1	1.1	1	100.0
Total	**92**	**100.0**	**61**	**66.3**

[a] % stage 1/ population; [b] % stage 2/stage 1.

Table 1. Population and sample

2.2. Instruments

The instruments used in the study were as follows:

2.2.1. I3P Project Databases

Systematized by the I3P leadership team, containing information on each group and its projects. These databases include details on team members, such as college, campus, and role, as well as information related to team monitoring. Additionally, selected information from project reports is included, such as learning objectives, challenges, achievements, and results. The database contains both quantitative and qualitative data and was used for objectives 1, 3, and 4.

2.2.2. I3P Questionnaire

Designed and validated by 12 experts in educational innovation and/or education, who assessed content clarity, wording clarity, the number of questions, and the relevance of the requested data. Aiken's V index was calculated for each question with a 95% confidence interval, obtaining values of $V > 0.70$ for all questions, indicating their adequacy (Merino & Livia, 2009). Expert recommendations were applied to improve certain questions. This instrument is associated with objective 2.

The questionnaire was structured into blocks. The first block included sociodemographic questions. The second block consisted of 33 Likert-scale questions (1: Strongly disagree; 2: Partially disagree; 3: Partially agree; and 4: Strongly agree) regarding the characteristics of the I3P Model. The third block included an open-ended question about aspects to improve.

For this study, in addition to sociodemographic data, only five questions from the second block were considered, specifically those related to the dimensions of PLC, adapted from Bolívar (2017):

D1: Teamwork was developed through shared leadership: all members actively participated in decision-making.

D2: I share values and principles with my team members, which guided the development of our innovation initiative.

D3: Team members shared information and worked together to solve problems and develop new skills or strategies.

D4: The team developed strategies to support each other and share practices aimed at improving participants' learning.

D5: During the implementation of the initiative, we had systems and resources to promote the continuous learning of teachers and students.

Cronbach's Alpha for these five questions was 0.86. These questions aimed to assess the degree of evolution of the teams as PLCs, according to the following scale (Bolívar, 2017):

1. Not initiated: The team has not yet started functioning as a PLC and, therefore, does not exhibit its defining attributes.
2. Initiated: Efforts have been made to start functioning as a PLC, but most of the team has not yet been affected.
3. Implemented: The team is operating as a PLC and has begun focusing curricular and organizational decisions on enhancing student learning.
4. Institutionalized: A PLC becomes institutionalized when it becomes a standard part of the school's culture.

2.2.3. Written Reports by the Groups

Each team submitted interim reports and a final report in accordance with the DNIA requirements. A content analysis was conducted on these reports to address objectives 3 and 4.

For objective 3, an inductive analysis was performed, from which the following categories emerged:

Factors contributing to the formation of PLC in the I3P: Common interests, communication systems, mutual learning, collaborative work, and UNAL values.

Factors hindering the formation of PLC in the I3P: Administrative management, project scheduling, and personal non-compliance.

Regarding objective 4, a deductive analysis was conducted based on the classification of educational innovations by Tejada-Fernández (2022).

2.3. Data Analysis

Graphs were created using Excel. Quantitative data analysis was conducted using SPSS V. 28. The reliability of the questionnaire was measured using Cronbach's Alpha. Descriptive analysis was performed using measures of central tendency and dispersion for categorical variables, and Inferential analysis was conducted using non-parametric statistics, as the sample sizes were too small to ensure population normality, making parametric statistics unreliable for obtaining valid results. Mann-Whitney U tests were performed, considering statistical significance at $p<0.05$ with a 95% confidence interval (Phillips, Wykoff, Thabane, Bhandari & Chaudhary, 2022). Additionally, effect size (ES) was calculated to assess the practical significance of differences between the groups being compared (Sullivan & Feinn, 2012), using Cohen's d, calculated with the Campbell online calculator (Wilson, 2023) with a 95% confidence interval. Results were analyzed according to the following scale: 0.21 to 0.49, small effect; 0.50 to 0.79, moderate effect; and, greater than 0.8, large effect (Cohen, 1998).

Qualitative data were analyzed using Nvivo 1.7.1 software, following an inductive process to identify the factors that contributed to and those that hindered the formation and consolidation of PLC.

3. Results

This section presents the results according to the specific objectives of the study.

3.1. Types of Connections Generated Among Members of the UNAL Community During the Development of Innovation Projects in Experimental Science

Initially, the I3P was designed to establish connections among teachers facing similar pedagogical concerns and challenges. However, the dynamic nature of open innovation–which permits the incorporation of new members throughout the project–coupled with the state of emergency caused by the COVID-19 pandemic, resulted in the formation of four distinct types of PLCs. These were categorized by the role of their originators: Type D (teachers), Type E (students), Type A (administrative staff), and Type G (alumni) (Layton-Jaramillo et al., 2024). (The letters D, E, A and G correspond to the Spanish language names).

Team members connected in three different ways, forming three types of PLCs: Type 1 (Members did not know each other beforehand), Type 2 (Members knew each other beforehand but had not worked together as a team), and Type 3 (Members applied to the I3P as established teams with prior collaboration (Layton-Jaramillo et al., 2024).

During the execution of the I3P project, 15 PLCs were formed, developing innovation projects in science. Their characteristics are summarized in Table 2.

Team	Type according to role	Type according to connections	Members					
			Professors	Graduate students	Postgraduate students	Alumni	Administrative staff	Total
PBLScience	D	1	3	1	1			5
Biology	D	1	2	2		1		5
BiochemicalAids	E	2	1	4	3			8
Science+	E	1	2	4		1		7
ScienceForAll	E	2			5			5
WithActiveScience	E	3	1		3			4
Eukarya	D	3	2	8	4	1	1	16
Microbiology	A	3	1				2	3
REDAScience	E	3		5				5
Parasitology	D	2	4	2				6
PhysicSounds	E	1			5			5
Chemistry	D	1	5	3	1	1		10
STEM	E	3		4		1	1	6
Biodiversity	E	3		1	2			3
ZoociedadUNAL	E	3		5				5

Table 2. Characteristics of the PLCs that developed projects in experimental science

No PLC were initiated by alumni; however, they were initiated by professors, students, and administrative staff, with participation from other roles. In this regard, only three groups established connections within a single role category (ScienceForAll, REDASciences, and ZoociedadUNAL). Other groups established connections across different roles, with Eukarya being the group that achieved the highest number of connections, as it included teachers, students, alumni, and administrative staff.

Table 3 presents the types of PLCs formed in experimental science, categorized by the initiating role and the type of connections established.

	Type D	Type E	Type A	Total
Type 1	3	2	0	5
Type 2	1	2	0	3
Type 3	1	5	1	7
Total	**5**	**9**	**1**	**15**

Table 3. Number of PLCs according to the role of the promoter and the type of connections

Most innovation initiatives in science were led by students, with a total of nine initiatives–five of which were classified as Type 3. This is likely due to UNAL's emphasis on forming student work groups, which has resulted in significant student engagement. In contrast, Type D PLCs were predominantly Type 1, with the I3P team effectively connecting faculty members who, despite having similar innovation initiatives, had never previously collaborated. The sole Type A PLC consisted of a team with an established collaborative track record (Type 3).

Additionally, the I3P also aimed to connect people from different campuses to collaborate on a common project. Table 4 presents the composition of the 15 teams according to the campus affiliation of their members.

Team	Campus								
	Amazonía	Bogotá	La Paz	Manizales	Medellín	Palmira	Orinoquía	Tumaco	Total
PBLScience		4		1					5
Biology	3	2							5
BiochemicalAids		8							8
Science+		5			2				7
ScienceForAll		5							5
WithActiveScience		4							4
Eukarya						15		1	16
Microbiology						3			3
REDAScience						5			5
Parasitology		5				1			6
PhysicSounds		5							5
Chemistry		6	1		2		1		10
STEM				6					6
Biodiversity		3							3
ZoociedadUNAL		5							5

Table 4. Characteristics of the PLCs that developed experimental science projects

Campus participation reflects the composition of UNAL: the highest participation was from Bogotá, where 57.7 % of the students are enrolled, while the lowest participation occurred in the national presence campuses (Amazonía, La Paz, Orinoquía, and Tumaco), which, together with the Caribbean campus, represent only 3.9 % of the student population (UNAL, 2023).

According to Table 4, connections between different campuses were not as extensive as intended. A total of 60.0 % of the teams were formed by individuals from the same campus, 33.3 % by individuals from two campuses, and only one team (6.7 %) included members from four campuses.

3.2. Characteristics of PLCs and Level of Development

Table 5 presents the general objective of each innovation project developed by the 15 Science teams, organized according to the three I3P calls for proposals. Each call had a specific focus that was mandatory to follow. First Call (I3P-1): Professors were invited to propose projects aimed at solving problems related to specific fields of knowledge. Second Call (I3P-2): Coinciding with the onset of the COVID-19 state of emergency, students were invited to present projects aimed at supporting other students facing academic vulnerability and remote learning challenges. Third Call (I3P-3): The academic community as a whole was invited to propose projects to promote intercultural dialogue as a means of support during this prolonged confinement (Layton-Jaramillo et al., 2024).

Team	Objective
Biology I3P-1	Promote autonomous learning among students of General Biology at the Amazonia Campus and Molecular Biology at the Bogotá Campus to enhance their critical and contextual thinking.
Parasitology I3P-1	Facilitate meaningful and comprehensive learning for students enrolled in Parasitology courses offered in Medicine, Veterinary Medicine, and Animal Science programs through augmented reality and/or virtual reality tools.
Chemistry I3P-1	Improve autonomous and meaningful learning among students in selected basic Chemistry courses at UN campuses to encourage the critical and contextual appropriation of knowledge while leveraging the diversity of campuses.
BiochemicalAids I3P-2	Encourage the creation of educational resources by undergraduate and graduate students in vulnerable conditions from the Colleges of Sciences and Veterinary Medicine and Animal Science, to be utilized as learning tools in Basic Biochemistry classes.
Science+ I3P-2	Support the learning process of students with no prior experience in remote teaching through the management of a Learning Management System (LMS), disciplinary workshops, and the "Ciencia+ en Casa" competition, to enable them to become co-creators and co-constructors of knowledge.
ScienceForAll I3P-2	Develop a pilot plan for a pedagogical methodology for students of Fundamentals of Mechanics that allows them to manage their knowledge, create experiments, and apply theory.
WithActivScience I3P-2	Mitigate the impact of virtual classes on the development of the experimental component of the course Teaching of Electromagnetism and Waves, offered during the 2020-3 term to students of the master's program in Science Teaching.
REDAScience I3P-2	Contribute with Open Educational Didactic Resources (REDA) to the Alejandría-D platform on the subjects of Heat Transfer, Wastewater, Environmental Chemistry, and Mass and Energy Balance.
STEM I3P-2	Promote each student's interest in the creation and innovation of ideas, based on applied science in different foundational projects.
PBLScience I3P-3	Conduct a retrospective analysis of the experiences developed in the courses Animal Biology, Quantum Mechanics, and Formative Assessment and Competencies, to rethink and reflect on the factors and sociocultural perspectives of the exact and natural sciences for the benefit of communities in relation to the Sustainable Development Goals (SDGs).
Eukarya I3P-3	Promote meaningful learning of the content in the courses General Biology and Reading and Writing or Oral and Written Expression in a remote learning setting, through a synchronous-asynchronous class model and the use of technological tools.
Microbiology I3P-3	The student in the Microbiology course will understand and appreciate cultural diversity and will be able to apply the basic microbiology techniques covered in the course.
PhysicSounds I3P-3	Contribute to the creation of teacher-student interaction environments where intercultural dialogue is present, allowing the teaching-learning process to take place in a more empathetic manner.
Biodiversity I3P-3	Implement the use of ICT to create spaces for cultural exchange among first-semester students from different campuses, strengthening their knowledge of biodiversity and infrastructure at the National University, Bogotá campus.

Table 5. General Objective of Pedagogic Innovation Projects in Science

Considering that each I3P call for proposals had a specific focus influencing the project's objectives, Figure 2 presents the questionnaire results regarding PLC dimensions to analyze the relationship between the project's objectives and the degree of evolution of the PLCs.

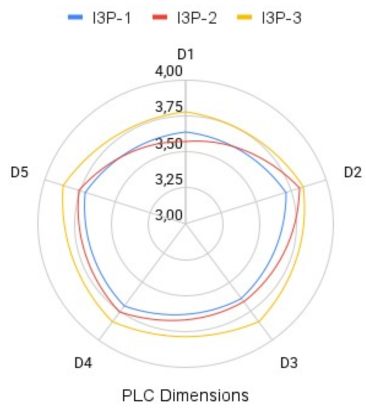

Figure 2. Comparison of the averages obtained in each PLC dimension, according to the I3P call

All dimensions had a mean greater than 3, indicating that teams from all three I3P calls are functioning as PLCs at the implementation stage; however, the values were higher for I3P-3. To assess whether the differences between calls are statistically significant, the p-value was calculated using the Mann-Whitney U test, and the effect size (ES) was determined using Cohen's d (see Table 6).

PLC Dimension	I3P-1 (n=14)	I3P-2 (n=21)	I3P-3 (n=32)	I3P-1 Vs I3P-2		I3P-1 Vs I3P-3		I3P-2 Vs I3P-3	
	media dev	media dev	media dev	Z p	ES	Z p	ES	Z p	ES
D1	3.64 0.50	3.57 0.60	3.78 0.49	-0.24 0.81	0.12	-1.14 0.25	0.28	-1.52 0.13	0.39
D2	3.71 0.47	3.81 0.40	3.84 0.37	-0.65 0.52	0.23	-1.01 0.31	0.32	-0.32 0.75	0.08
D3	3.64 0.50	3.67 0.48	3.84 0.45	-0.14 0.89	0.06	-1.72 0.09	0.43	-1.72 0.09	0.37
D4	3.71 0.47	3.76 0.44	3.84 0.37	-0.31 0.76	0.11	-1.01 0.31	0.32	-0.74 0.46	0.20
D5	3.71 0.47	3.76 0.54	3.87 0.34	-0.55 0.58	0.10	-1.31 0.19	0.42	-0.70 0.48	0.26

Table 6. Results of the Mann-Whitney U test and Cohen's d test for the comparison between the three I3P calls

The differences between the calls are not statistically significant for any of the dimensions. However, the effect size (ES) is low across all dimensions when comparing I3P-1 with I3P-3. When comparing I3P-2 with I3P-3, the ES is low in all dimensions except for D2. Meanwhile, between I3P-1 and I3P-2, a low ES was found only in D2. Thus, experimental science projects with objectives primarily focused on intercultural dialogues achieved a higher level of development compared to those with objectives more related to the cognitive dimension.

On the other hand, to analyze whether the degree of evolution of the PLCs is related to the initiating role of the innovation initiative, Figure 3 presents a comparison of the mean values for each dimension across the three different PLC types according to their initiating role.

According to Figure 3, all mean values in the five dimensions were above 3.0 for all three PLCs types. A trend toward higher values in Type E PLCs was observed, followed by Type D PLCs, with Type A PLCs showing the lowest values–except for dimension D2, where the highest value was recorded in Type A PLCs. To determine whether these differences are statistically significant, the results of the Mann-Whitney U test and Cohen's d are presented in Table 7.

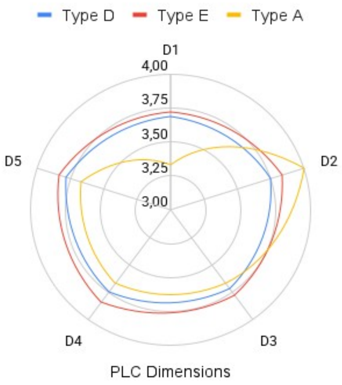

Figure 3. Comparison of the averages obtained in each dimension of the PLC (according to the role of the initiative promoter)

PLC Dimension	I3P-1 (n=14)	I3P-2 (n=21)	I3P-3 (n=32)	I3P-1 Vs I3P-2		I3P-1 Vs I3P-3		I3P-2 Vs I3P-3	
	media dev	media dev	media dev	Z p	ES	Z p	ES	Z p	ES
D1	3.69 0.53	3.72 0.52	3.33 0.58	-0.27 0.79	0.06	-1.27 0.20	0.68	-1.42 0.16	0.74
D2	3.75 0.44	3.84 0.37	4.00 0.00	-0.92 0.36	0.22	-0.97 0.33	0.59	-0.73 0.47	0.45
D3	3.72 0.52	3.78 0.42	3.67 0.58	-0.36 0.72	0.13	-0.27 0.79	0.10	-0.45 0.66	0.26
D4	3.75 0.44	3.84 0.37	3.67 0.58	-0.92 0.36	0.22	-0.31 0.76	0.18	-0.77 0.44	0.44
D5	3.78 0.42	3.84 0.45	3.67 0.58	-0.91 0.36	0.14	0.45 0.66	0.26	-0.92 0.36	0.37

Table 7. Results of the Mann-Whitney U test and Cohen's d test for the comparison between the three types of PLCs (according to the promoting role of the innovation initiative)

Although the Mann-Whitney U test indicates that the differences are not statistically significant in any case, Cohen's d reveals that notable differences exist in dimensions D1 and D2 between Type A PLCs and both Type D and Type E PLCs.

Thus, in Type A PLCs, shared leadership (D1) received a lower rating compared to Type D and Type E PLCs, indicating that the latter two demonstrated greater consensus regarding active participation in decision-making. Despite this, in Type A PLCs, there was a higher level of agreement than in Type D and Type E PLCs regarding the sharing of values and principles (D2), which guided the development of the innovation initiative.

Finally, Figure 4 presents the mean results in each dimension based on the type of connections that led to the formation of the PLCs.

Although one might intuitively expect that Type 3 PLCs–comprised of individuals who had previously worked together–would yield the highest values, this is not the case. In fact, no significant differences were observed in the assessment of the five dimensions based on the call for proposals. Specifically, D1 was rated highest in Type 1 PLCs, D2 in both Type 2 and Type 3 PLCs, D3 in Type 2 PLCs, D4 in Type 1 PLCs, and D5 in Type 3 PLCs. Table 8 presents the results of the Mann-Whitney U test and Cohen's d to determine whether these differences are statistically significant.

There are no significant differences between the three types of PLCs according to the connections. Additionally, the effect sizes are null in some cases and low in most. In this way, during the development of the innovation project, the different groups consolidated as PLCs, regardless of the type of connections that led to their formation. This result is directly related to the monitoring carried out for the teams since Type 1 PLCs required greater support from I3P professionals throughout the project than Type 2 and Type 3 PLCs. Thus, the management of the I3P leadership team was effective in promoting the formation and evolution of the teams as PLC, providing differentiated support according to the specific characteristics and needs of each group.

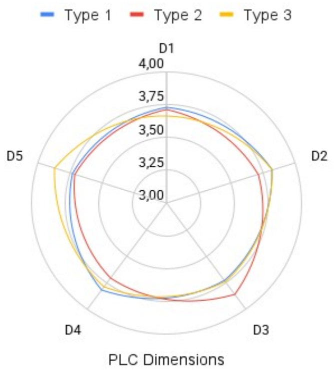

Figure 4. Comparison of the averages obtained in each dimension of the PLC (according to the type of connections)

PLC Dimension	I3P-1 (n=14) media dev	I3P-2 (n=21) media dev	I3P-3 (n=32) media dev	I3P-1 Vs I3P-2 Z p	I3P-1 Vs I3P-2 ES	I3P-1 Vs I3P-3 Z p	I3P-1 Vs I3P-3 ES	I3P-2 Vs I3P-3 Z p	I3P-2 Vs I3P-3 ES
D1	3.73 0.55	3.71 0.49	3.66 0.53	-0.24 0.81	0.04	-0.66 0.51	0.13	-0.19 0.85	0.10
D2	3.82 0.40	3.71 0.49	3.82 0.39	-0.58 0.56	0.26	-0.02 0.98	0.00	-0.61 0.54	0.27
D3	3.73 0.46	3.86 0.38	3.74 0.50	-0.69 0.49	0.29	-0.24 0.81	0.02	-0.56 0.57	0.25
D4	3.82 0.40	3.71 0.49	3.79 0.41	-0.58 0.56	0.26	-0.27 0.79	0.07	-0.44 0.66	0.19
D5	3.73 0.55	3.71 0.49	3.87 0.34	-0.24 0.81	0.04	-1.01 0.31	0.33	-1.02 0.31	0.44

Table 8. Results of the Mann-Whitney U test and Cohen's d test for the comparison between groups (according to the connections that originated the formation of CPA)

3.3. Factors that Contribute to and Hinder the Formation and Consolidation of PLCs During The Execution of Experimental Science Projects.

This section first describes the factors that contributed to the formation of PLC and then those that hindered the process, based on a content analysis of the final project reports.

Regarding the factors that helped the teams consolidate as PLC, the following categories were identified: common interests, communication systems, mutual learning, collaborative work, and UNAL values.

In the first category, common interests were recognized as the primary factor for joining and/or developing an innovation initiative within I3P, regardless of whether the teams were formed by individuals who did not previously know each other, those who already knew each other, or those who had previously worked together.

In this regard, for example, the PBLSciences team (Type 1 PLC) stated:

> *"During the connection stage, through the 'Let's Connect' forum, some exchanges took place around the interest in working with PBL. As we progressed through the I3P stages, the team became stronger, and we discovered other common aspects beyond PBL. For instance, we are women in the exact or natural sciences, teacher-researchers in our training spaces, and we share perspectives on the nature of scientific knowledge. Moreover, each member has prior experiences related to the transformation of their teaching practice, based on a critical and reflective stance on learning environments, which they promote in various training settings, both at the undergraduate and graduate levels."*

Similarly, the teams that had already worked together previously (Type 3 PLC) acknowledged that common interests were essential for their consolidation, as stated by WithActivScience:

> *"The group has been consolidating for several months now, given the shared concerns and interests that have brought us together on multiple occasions to develop work proposals that contribute to the well-being and advancement of the master's program in Teaching Exact and Natural Sciences, both at the faculty and student levels."*

In the next category, communication systems, the teams acknowledged the importance of both the tools designed by the I3P leadership team to facilitate synchronous and asynchronous communication and the tools they independently managed within their teams. Regarding the first aspect, the previous quote from PBLScience highlights the use of the forum available in the I3P virtual classroom. Regarding the second aspect, the BiochemicalAids team stated:

> *"The formation of the BiochemicalAids team and its constant communication through platforms such as WhatsApp, Meet, and Google Drive has facilitated the development of the planned work activities within the established schedule, fostering interpersonal as well as academic bonds within the team."*

In the next category, mutual learning, the teams highlighted the importance of learning from their peers. One of the teachers from the Chemistry team mentioned in their report: "*The learning I gained was enriching as I actively interacted with teachers from other programs and campuses in an experience like I3P, which was very novel for my work within the university."*

In Type E PLC, mutual learning also occurred among students, as stated by the Biodiversity team:

> *"It has been an enriching experience thanks to the learning we have gained from each other, the contributions of each participant in this interdisciplinary team, and the various knowledge acquired during interactions with students in the different meetings held as part of the project's execution."*

Regarding the collaborative work category, the ZoociedadUNAL and REDAScience teams stated, respectively:

> *"During the execution of the project, the need for smooth communication and collaborative work became evident, intending to fulfill the project's objectives."*

> *"Within our team, we always sought support and camaraderie, given each member's particular circumstances (...). Bonds of teamwork were strengthened through the distribution of activities and collaborative work, sharing acquired knowledge."*

Finally, in the last category, UNAL Values, phrases such as the following were found, reflecting the university's values and the sense of belonging to the institution:

> *"Participation in the I3P allowed the Eukarya team to further strengthen coordination, dialogue, and meaningful learning, with an excellent sense of belonging and values–respect, ethics, transparency, quality, and above all, dedication to service. We overcame obstacles and achieved our objectives."*

On the other hand, regarding the factors that hindered the consolidation of PLCs during the execution of the project, three categories were identified: administrative management, project scheduling, and personal non-compliance.

Regarding the first category, the Biodiversidad team stated: *"Some difficulties were not initially considered, such as the administrative timelines required to submit a request to the university"*, Similarly, the Microbiology team mentioned: *"The issues related to the disbursement of funds"*.

While it is true that the administrative management of the projects, involving public funds, was a labor-intensive process both for the I3P leadership team and the participating teams, significant efforts were made to minimize the impact. As the STEM team stated: "The delay in the disbursement of funds from the call for proposals slightly weakened the process, as we had to proceed more slowly and make adjustments along the way, but the objectives were never compromised."

In the second category, project scheduling, the Biology team stated:

> *"As a group, we believe that the implementation and development of the I3P model across its different stages are well-structured. However, it would be advisable to reassess the time allocated for each stage, giving priority to the execution and evaluation phases, so that activities can be fully completed."*

Finally, the category of personal non-compliance, identified by the WithActiveScience team as a challenge, also became an opportunity for collaborative learning:

> *"Teamwork requires the dedication and commitment of all members. Difficulties arose with one student who, unfortunately, did not fulfill their commitments, which negatively impacted our ability to complete one of the agreed-upon deliverables. The issue was taken as a learning challenge by the rest of the team, pushing us to collaborate on topics in which none of us were experts to meet our commitments."*

3.4. Strategies Through Which Pedagogical Innovations in Experimental Sciences are Achieved In The I3P

To attain the fourth objective of the study, Table 9 compiles the products and results of the pedagogical innovation projects, as well as the characterization of the innovation, based on the framework proposed by Tejada-Fernández (2022).

According to the reports and the monitoring carried out by the I3P leadership team, the 15 projects benefited approximately 1,800 students from different courses. Additionally, the innovations led to improvements in problematic aspects of science teaching and learning, which had been identified at UNAL as factors affecting the quality of education at the institution.

Team	Product	Innovation Results	Innovation Characterization (Tejada-Fernández, 2022)
Biology	Learning experiences using the Flipped Classroom strategy and associated didactic resources.	Autonomous, critical, and contextual learning was promoted.	New fields of training: Teaching planning. Modernization: Development of materials.
Parasitology	Augmented reality resource for parasite life cycles.	Significant improvement in learning about parasite life cycles. Improvement in the understanding of concepts and in students' academic results.	Modernization: Development of materials. New realities: Didactics of the discipline.
Chemistry	Five interactive didactic resources on the topics: - Electronic transitions. - Solutions and water quality. - Nutritional balance. - Solutions with empathy. - Carboxylic acids.	Improvement in the understanding of concepts and the academic performance of the beneficiary students. Reduction in the failure rate.	Modernization: Development of materials. New realities: Didactics of discipline. Digital literacy: New technologies.

Team	Product	Innovation Results	Innovation Characterization (Tejada-Fernández, 2022)
BiochemicalAids	Playful virtual tools for learning Biochemistry disseminated through Instagram. Instagram profile, followed in Colombia, Mexico, Venezuela, Chile, and Bolivia. Resource bank to be used by other UNAL teachers.	Appropriation and restructuring of biochemical concepts in the creation of educational content, as it is necessary to determine which are the most relevant and which allow a learning impact on the student population.	Modernization: Development of materials. New realities: Didactics of the discipline.
Science+	Academic support system for students in the Basic Chemistry course.	Creation of collaborative workspaces with role horizontality, which allowed the development of close bonds of trust and fluidity in student responses. It was demonstrated that the emotional dimension is fundamental to the learning process.	New realities: Tutoring. Learning and motivation.
ScienceForAll	Inter-campus student tutoring system. Pedagogical support material for learning.	Improvement in the academic performance of tutored students. Improvement in the way tutors convey information.	New realities: Tutoring. Modernization: Development of materials.
WithActiveScience	5 experimental kits per student: - Pega-2 (Electrostatics). - Induced Fall (Magnetic Induction). - Strings or Crazy? (Acoustics). - Watch the Focus! (Optics). - The Dance of the Pendulum (Waves)	Transformation of the dynamics of non-presential classes through the development of meaningful experiences. Improvement of the learning experience for participants, who will later act as agents of change in schools.	New realities: Didactics of discipline. Learning and motivation.
REDAScience	Open Educational Didactic Resources (REDA) on the subjects: Heat Transfer, Wastewater, Environmental Chemistry, Mass and Energy Balance.	Each team member gained significant knowledge about interaction, teamwork, and the use of virtual tools. Additionally, knowledge in each member's area of study was strengthened, as creating the electronic resources required extensive preparation on the topics.	Modernization: Development of materials.
STEM	Electronics kits with Arduino. Model for the STEM classroom.	Collaborative construction of a pedagogical methodology to identify cognitive, social, and motivational aspects of the learning process. Reduction in the failure rate of the course compared to previous semesters.	Disciplinary integration: Practices. New realities: Learning and motivation.

Team	Product	Innovation Results	Innovation Characterization (Tejada-Fernández, 2022)
PBLScience	Learning experiences with the PBL approach.	Interdisciplinary reflections on problem-contexts related to various aspects of Natural Sciences, particularly the socio-cultural aspect. A sociocultural perspective on exact and natural sciences was promoted, enhancing a critical stance on students' scientific and academic competencies concerning their relevance in communities.	Formation of social exchange networks: Methodological strategies.
Eukarya	Academic support model based on peer learning.	It was demonstrated how the implementation of an academic model supported by tools that enable the free development of peer dialogues, whether social, academic, cultural, or ideological–can enrich the learning generated within a General Biology course.	New realities: Tutoring. Disciplinary integration: Course coordination. Digital literacy: New technologies.
Microbiology	Audiovisual didactic material to promote intercultural dialogue through microbiology. Student meeting of regional teams.	Active and authentic learning of microbiology was promoted, with an intercultural approach. Reconstruction of prior "ancestral" knowledge with new information.	Formation of social exchange networks: Methodological strategies. Modernization: Development of materials.
PhysicSounds	6 physics podcasts for distribution on social media: - Time Travelers. - Physics and Society. - Medical Physics. - Econo-Physics. - Mobility. - Physics in History.	Creation of teacher-student interaction environments through intercultural dialogues. Increased student motivation, allowing them to experience their courses from a more empathetic perspective.	Creation of teacher-student interaction environments through intercultural dialogues. Increased student motivation, allowing them to experience their courses from a more empathetic perspective.
Biodiversity	Web development with information on the infrastructure and biodiversity present at the Bogotá campus.	Construction of intercultural learning communities around the university's infrastructure and the biodiversity present at the Bogotá campus.	Formation of social exchange networks: Methodological strategies. Digital literacy: New technologies.
ZoociedadUNAL	Virtual course "Zoociedad UNAL" for the exchange of knowledge and issues related to Animal Science from different regions of the country.	Promotion of autonomous learning, actively integrating students and graduates from the animal production departments through intercultural dialogue.	Formation of social exchange networks: Methodological strategies. Digital literacy: New technologies.

Table 9. Products, Results, and Innovation Characterization of the Projects

4. Discussion

In this section, the discussion of results has been structured according to the specific objectives of the research.

Regarding the first objective, during the open innovation stages of I3P, connections were successfully established between faculty members who had not previously worked together. Kloser, Edelman, Floyd, Martínez, Stecher, Srinivasan et al. (2020) note that science teaching is both a social and solitary act, as teachers often make classroom decisions in isolation without interacting with their colleagues. This issue, also identified at UNAL (2019), provided the impetus for I3P's adoption of a PLC-based strategy. The results indicate that this strategy effectively promoted collaborative work among teachers and fostered their professional growth, aligning with the findings of Kazemi and Franke (2004), Bolam et al. (2005), and Bolívar (2007).

However, it cannot be overlooked that only a small fraction of UNAL faculty members participated in the I3P, considering that, according to the most recent statistics, there are 3,001 full-time professors (UNAL, 2023). Although faculty from all campuses were invited through institutional dissemination channels, the highest participation in the I3P was observed at the Bogotá campus. This is explained by the fact that Bogotá is UNAL's largest campus, but it also introduces a limitation in the research, as it affects the generalization of the results for the entire university.

Alternatively, although I3P was initially designed to connect faculty members, the dynamic nature of open innovation facilitated new interpretations of the initiative and the emergence of alternative approaches to address the challenges and scenarios brought about by the pandemic. Consequently, connections between faculty and students emerged, enriching the pool of innovative ideas.

Faculty members recognized the value of collaborating with students to enhance their teaching practices. For example, the Parasitology team noted, "The motivation of students from the new generations, known as digital natives, challenged us to create new strategies for remote education." Similarly, students observed that "teachers become sufficiently involved with students to enable the execution of these types of proposals and the generation of new ideas" (Ciencia+).

The connections established between faculty and students during the development of innovation projects provided a favorable setting for reflection on how students learn, which, according to Aparicio-Molina and Sepúlveda-López (2018), is a key factor in improving teaching practices. Furthermore, the improvement of teaching practices leads to enhanced student learning outcomes (Bolívar, 2007).

Another important factor in the connections established within I3P was the involvement of UNAL's administrative and management staff, as well as alumni. Although the project was not initially designed to encourage participation from these groups, their inclusion–and the fact that one of the PLCs in science was led by administrative staff–demonstrates how open innovation facilitates the integration of new members, promoting learning across all roles within the organization. This aspect is crucial for fostering learning throughout the entire educational community (Bolívar, 2007).

However, it is important to note that the low representation of these roles in the study limits the generalizability of the results.

Regarding the Second Objective, the development of educational innovation projects in Science facilitated, in some cases, the formation and evolution of PLCs among individuals who had not previously known each other or worked together, and in other cases, it enabled the consolidation of work teams that evolved into PLCs. These findings align with Peña-Ruz (2023), who noted that interdisciplinary projects offer a favorable environment for the establishment of PLCs, even within a university setting. Working toward a common pedagogical goal fostered dialogue, reflection, and peer evaluation, as evidenced in the project reports. Consequently, the groups functioned as PLCs regardless of the specific objective that guided the development of the innovation projects.

According to García (2011), one of the main challenges in higher education is faculty resistance to critically reflecting on their teaching practices. However, the execution of the I3P projects and the formation of work teams helped overcome this resistance. Professors engaged in dialogue, reflected on their practices, and created spaces to share their experiences to improve student learning. Additionally, the development of these innovation projects served as a space for reflection and growth for students, as described in the various project reports.

Regarding the Third Objective, Educational research in the 1990s identified individualism and teacher isolation as key factors in the failure of school reform (Bolívar, 2007). This culture of privacy, which was still identified in recent years as a challenge at UNAL (2019), led to the creation of the I3P project to build collaborative and reflective spaces among teachers within PLCs, aimed at providing students with new learning experiences. The fact that the execution of the I3P project coincided with the Covid-19 pandemic further accelerated the formation of PLCs, as the situation intensified the need to implement collaborative models. In the case of I3P, this process was enhanced by the mediation of ICT tools, which facilitated teamwork among individuals from different UNAL campuses.

Thus, the execution of the Science projects marked a breakthrough in the individualistic culture that had predominated at UNAL. Faculty members united around a common educational challenge, enhancing their teaching practices through the exchange of best practices, reflective dialogue, and mutual learning within their professional contexts–facilitated by communication systems. As Bolívar (2007) notes, collaboration among colleagues–characterized by listening to and sharing experiences–is a key mechanism for forming a PLC.

Nonetheless, I3P was not only a space for teacher reflection; the integration of students and administrative staff as managers of innovation projects further enriched collaborative work. As a result, teams were able to transform challenges into learning opportunities across the different sectors of the UNAL community. Consequently, during the development of science projects, faculty, students, and administrative staff shared needs, knowledge, and experiences–circumstances that, according to Peña-Ruz (2023), are essential for building collaborative cultures that transform educational practices.

Regarding the Fourth Objective, the strategies used to achieve innovations in science during the I3P project were diverse, yet all aimed to modify the entrenched practices typical of traditional science teaching–practices identified as detrimental to the quality of education at UNAL. In this sense, these initiatives can be considered innovations, as they led to tangible improvements in specific science courses. According to Tejada-Fernández (2007), classroom-scale innovations have the potential to evolve into broader educational reforms if they are widely adopted within the institution.

Moreover, innovation is also reflected in the formation of PLCs, which, as Bolívar (2007) notes, represent an innovation in themselves within compulsory education. In this regard, Bolívar argues that educational institutions should be structured not merely as workplaces, but as centers for continuous teacher training and innovation, with the ultimate goal of enhancing student learning outcomes.

Finally, during the development of innovation projects in Science, faculty members were encouraged to reflect on their practices and engage in dialogue with other institutional sectors to explore new ways of understanding education within specific contexts. In this process, innovation became intertwined with research, aligning with Tejada-Fernández's (2007) perspective that "research and innovation are two sides of the same coin" (Tejada-Fernández, 2007: page 662). Consequently, UNAL proposes strengthening educational innovation processes–and understanding them as research processes–as a strategy to ease the tensions between research and teaching, tensions that often lead to negative incentives toward the latter.

In conclusion, the results from applying the I3P model, which is based on Open Innovation and Professional Learning Communities, to address pedagogical and didactic challenges in Science can be transferred to other fields of knowledge or educational contexts. To achieve this, it is essential to establish common interests that guide teamwork, enhance group communication systems, and implement strategies that enable faculty to learn from and share their practices with peers.

Additionally, it is important to provide spaces for groups to learn how to manage their own challenges and turn them into opportunities for learning and improvement.

5. Conclusion

Open innovation, along with the transformation of higher education institutions into Professional Learning Communities, shifts the prevailing culture of individualism to one of collaboration. Through reflective practices, the academic community learns to address problems in context, fostering the professional development of all members and enhancing student learning outcomes–ultimately improving the quality of university education.

Declaration of Conflicting Interests

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