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Developing students' scientific competencies using the school's environmental context in rural and semi-rural settings

Desarrollar competencias científicas de estudiantes utilizando el contexto ambiental escolar en entornos rurales y semi-rurales

John Andersson Gómez Soto[1*], Francisco Javier Gómez Vergara[2]

[1] Teacher at Institución Educativa Inem, Cali, Colombia.

[2] Teacher-Researcher at Unidad Central del Valle (UCEVA), Tuluá, Colombia.

[*] Corresponding author email address

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Abstract

The study implemented a didactic proposal to develop Scientific Competencies in secondary students from rural and semi-rural contexts by leveraging the school's environmental surroundings. Using an instrumental case study methodology, progression hypotheses were established, revealing a sufficient correlation (0.32) in scientific competency development between two targeted students, as determined by Kendall's Tau-B. The research focused on two students deemed suitable by their teacher, with evidence analyzed to create a performance rubric that assessed competency development. The findings indicated that the teacher's ecology teaching model aligned with a level 2 progression based on specialized literature, leading to specific didactic recommendations. The study concluded that effectively incorporating constructs for developing scientific competencies requires teachers to adopt critical perspectives on the inconsistencies in the Colombian educational system, understand scientific competencies in an international context, and engage as reflective researchers. This approach is essential for fostering scientific competency development in the classroom.

Artículo Original

Keywords: Ciencias de la Educación y el Medio Ambiente; Ambiente Educativo; Investigación Educativa, Desarrollo de Habilidades.

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Resumen

El estudio implementó una propuesta didáctica para desarrollar Competencias Científicas en estudiantes de secundaria de contextos rurales y semi-rurales, aprovechando el entorno ambiental de la escuela. Utilizando una metodología de estudio de caso instrumental, se establecieron hipótesis de progresión que revelaron una correlación suficiente (0.32) en el desarrollo de competencias científicas entre dos estudiantes seleccionados, según el índice Tau-B de Kendall. La investigación se centró en dos estudiantes considerados adecuados por su docente, y la evidencia recopilada se analizó para crear una rúbrica de desempeño que evaluara el desarrollo de competencias. Los resultados indicaron que el modelo de enseñanza de ecología del docente correspondía a un nivel 2 de progresión basado en la literatura especializada, lo que llevó a recomendaciones didácticas específicas. El estudio concluyó que, para incorporar efectivamente los constructos necesarios para desarrollar competencias científicas en el aula, es fundamental que los docentes adopten perspectivas críticas sobre las inconsistencias del sistema educativo colombiano, comprendan cómo se entienden las competencias científicas en el contexto internacional y asuman un rol como investigadores reflexivos. Este enfoque es esencial para fomentar el desarrollo de competencias científicas en el aula.

INTRODUCTION

Today's society is significantly influenced by technological development and access to urban stereotypes that promote territorial uprooting, especially in populations from rural areas, which are characterized by limited infrastructure and restricted access to basic services such as education and health. In Colombia, rural areas are usually far from urban centers, but there may be transition zones with the urban known as semi-rural areas. These areas maintain rural characteristics, such as agriculture and a lower population density, but they also show incipient development in basic services, due to their proximity to municipal capitals.

In this sense, an alternative proposal is to provide children with the opportunity to access knowledge and skills that can improve their quality of life and open doors to educational and employment opportunities in the future, contributing to reducing development gaps between rural and urban areas. This can be done through the development of scientific skills, as it provides students with the necessary tools to identify and solve specific problems in their communities, such as water management, improved agricultural practices, and the conservation of local fauna and flora. This fosters a sense of belonging and responsibility, and prepares them to be agents of change within their own communities. Developing scientific skills in students enables them to understand the importance of these resources and how to manage them sustainably, which is crucial to preserving their communities and natural environments in the face of challenges such as climate change and environmental degradation.

Today's society is significantly influenced by the development of scientific knowledge, which makes it necessary for students to take a more assertive approach to the study of natural phenomena (Adnan et al., 2021; Bahri, et al., 2021; Novaristiana, et. al., 2019). However, rote learning, summative assessment, decontextualization of phenomena, and assuming learners as passive agents (Rusmansyah et al., 2021) remain difficulties to be overcome in science education. For this reason, teaching by competencies has been the proposal adopted by the National Ministry of Education in Colombia for more than 20 years as an alternative to overcome these difficulties (National Ministry of Education, 1998, 2006, 2010, 2016a, 2016b, 2017).

These competencies are internationally evaluated by the Organisation for Economic Co-operation and Development (OCDE) through the PISA tests from the perspective of the construct Science Literacy (SL), and nationally by the Colombian Institute for the Promotion of Higher Education (ICFES), through the Saber-Pro tests from the competency-based approach. International results place Colombia in last place, and regional results show a similar picture. In the 2016 "Saber tests" (National Ministry of Education, 2016), the Municipality of Tuluá (Where this study was developed), results below the national average emerged, thus evidencing the scarce scientific skills developed in the students, a situation that worsened with the Covid-19 pandemic. In that sense, both before and after the pandemic, much of the pedagogical research has been directed at how to develop scientific skills and attitudes based on environmental education (Ekantini & Wilujeng, 2018; Hasan & Elster, 2018; Ichsan et al., 2019; Queiruga-Dios et al., 2020;)

The above contrasts with the claims of the Colombian educational system, which conceives competencies as the "how to do" in concrete situations that require the creative, flexible, and responsible application of knowledge, skills, and attitudes, responding to the "know what", "How", "Why" and, "What for". Specifically, the 7 scientific competencies defined by ICFES (2007) are: Identification, inquiry, explanation, communication, teamwork, willingness to accept and recognize science as something changing with a preponderant social importance. Of these 7 scientific competencies, only three are evaluated through standardized tests which are: Comprehensive use of scientific knowledge, explanation of phenomena, and inquiry. The OCDE (2017) also refers to the concept of scientific competency, which is considered a "ability to interact with science-related issues and science ideas as a thoughtful citizen" (p.96). The following is an attempt to demonstrate the homologation of the scientific competencies of the Saber-Pro tests with the scientific skills from the SL approach of the PISA tests in Figure 1:

Figure 1

Model of the global methodological design.

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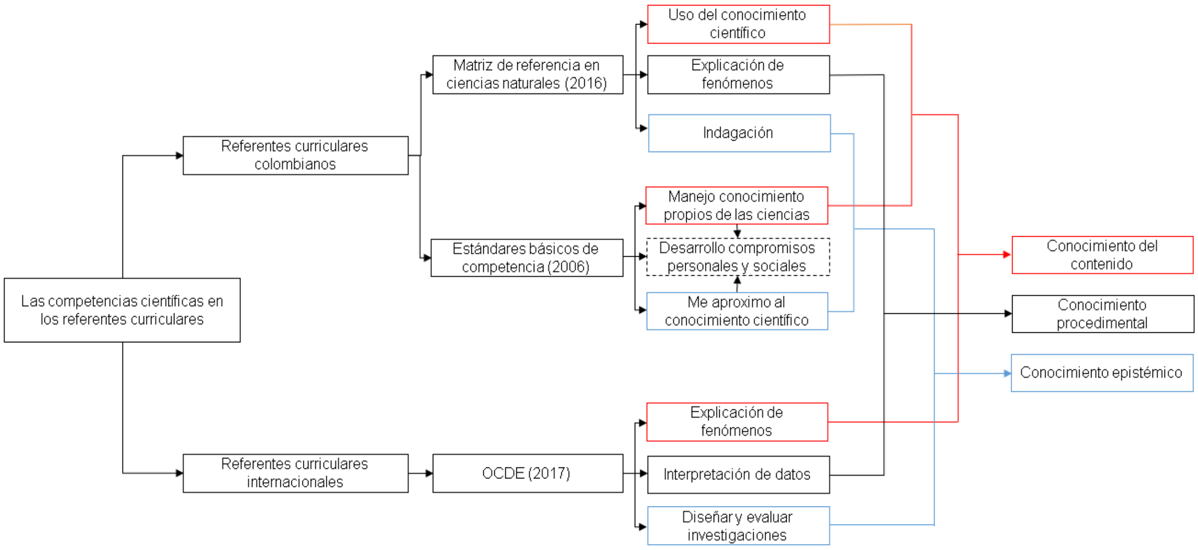

The above made it possible to identify that SL is a core construct of the PISA tests. (2017, 2018), that according to Sjöström & Eilks (2020), it lacks consensus, since its notions are still vague, due to different approaches, visions, orientations, or perspectives. However, in general, its different proposals evidence the tendency to make scientific knowledge increasingly useful for human beings' decision-making, assuming different critical positions of their environmental realities (Avargil, et al., 2018; Hagop, 2018; Sjöström & Eilks, 2020). In this sense, this concept is approached from different pedagogical elaborations such as didactic transposition (Sholikhakh et al., 2023), Technological Pedagogical Content Knowledge (Mishra & Koehler, 2006, 2008), socio-scientific issues (Herman et al., 2021), and education for sustainability (Amran et al., 2019; Queiruga-Dios et al., 2020), among others (Rodríguez Torres et al., 2024: Noa Guerra et al., 2024; Díaz Guerra et al., 2024; Fernández Miranda et al., 2024; Roman-Acosta y Barón Velandia, 2023; García García y Roman-Acosta, 2024; Román Acosta et al., 2024; Roman-Acosta 2023).

There are some derivations of SL, for example, the promotion of environmental literacy, from experiential or outdoor teaching processes. This has registered evidence of positive impacts on cognition, emotions, social skills, and physical development in students (Kinslow et al., 2019; Ardoin & Heimlich, 2021; Deveci & Karteri, 2022; Gungor et al., 2023). In view of this, students must develop an interrelated set of specific competencies such as I) systemic thinking of reality; II) analysis of problems from multiple perspectives; III) inquiry to take advantage of research opportunities; VI) construction of critical positions of reality.

There is another very common approach, which is to homologize scientific competencies with certain skills to execute the different stages of the conventional scientific method, as reflected in the studies by Wahyuni et al (2017), Adnan et al (2021), Rusmansyah et al., (2021) described below:

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In the proposal by Wahyuni et al. (2017), the conventional scientific method is used as a guiding route for the development of scientific skills in girls and boys, emphasizing observation, hypothesis building, posing of inquiry questions, problem-solving, analysis of results, and the establishment of final conjectures (Wahyuni et al, 2017). These desirable skills have been divided into two core categories: a) Scientific processing skills, that enable students to think critically, make decisions, search for answers, help students think logically, ask reasonable questions, and solve problems that arise in everyday life. b) Problem-solving, that implies, among other things, a complex understanding of reality, its characteristics, and the variables involved.

Adnan et al. (2021) proposes two major groups of scientific skills: Understanding research as a source of scientific knowledge production and the ability to analyze, organize and interpret quantitative information. With the help of a scientific literacy (SL) questionnaire instrument some scientific skills were identified such as reasoned argumentation, appropriate use of specialized literature, understanding the elements of research design, constructing and interpreting graphs from data tables, solving problems based on quantitative data, and producing conclusions consistent with the results.

Rusmansyah et al. (2021) implemented the Scientific Critical Thinking (SCT) Model in the context of the Covid-19 pandemic using platforms such as Google Meet and Google Classroom. After a sequence of activities, indicators of scientific skills were identified such as students' ability to observe, predict, classify, conclude, and communicate, highlighting that some students do not have the ability to communicate the results in written form, but they can communicate them orally during discussions in synchronous meetings.

The above background allows us to infer that both the scientific competencies from the Ibero-American tradition assumed by the MEN in Colombia and the SL at the international level are "semantic counterparts" as shown in Figure 1. For this reason, the following research question is posed: *How to develop scientific competences in high school students, based on an environmental situation in the school context?* Accordingly, the objective of this research was to analyze the development of scientific competencies in high school students and the role of the teacher in the implementation of a teaching proposal based on an environmental situation in the local context.

METHODOLOGY

In this study, a teaching proposal was implemented based on the environmental situation of the local context of the school where the research was conducted. Thus, the perspective used is qualitative through a case study (Martínez-Bonafé, 1988; Yin, 2014; Martínez-Roldan, 2020; Priya, 2021), which allowed elucidation how the knowledge resulting from classroom research, the

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curriculum, and the context, are articulated to allow the teacher to build pedagogical criteria that facilitate their students to achieve the development of certain scientific competencies.

Context of the Research

This research was carried out in Colombia, in the Municipality of Tuluá, located in the Department of Valle del Cauca, in an official educational institution. The implementation of the teaching proposal took place from August to November 2020, at that moment the classes were virtually due to the public health situation generated by Covid-19. The science class meetings were held synchronously once a week, using the Google Meet application. The administration of pedagogical processes was carried out with the help of the Moodle platform.

Despite the virtual modality, the conditions of the environmental context of the institution were taken into account through videos and photographs strategically taken by the researchers. The physical space of the establishment has ample green zones, and trees that serve as a habitat for insects, mammals, birds, and reptiles. Nearby there is a river severely polluted by the discharge of wastewater from an animal slaughter plant for the production of meat for human consumption. These environmental conditions that support the institution with which the students coexist, allowed using the structuring concept of "ecosystem dynamics" as an articulating axis of the teaching proposal that served to make an analysis of the scientific skills of the students.

Participants

The research was carried out with a mixed group of 44 seventh grade students between 12 and 14 years old, from rural and semi-rural areas of the Municipality of Tuluá. Two students (Eugenio and Andrés - fictitious names to protect the identity of the participants) were taken as the object of analysis, who showed a special attraction to the natural sciences class, demonstrating responsibility, participation, order and punctuality.

The teacher who implemented the proposal is a young graduate in Biology and Environmental Education, whose conduct and professional orientation belongs to the category of Enthusiastic Teacher (Goetz et al., 2019; Keller & Becker, 2020; Taxer & Frenzel, 2015), characterized by his expressive behavior, and a critical vision of environmental care, which aroused the interest of his students, becoming an exemplary figure, with whom the members of the group identified.

The classroom intervention was led by Professor Javier, a graduate in Biology and Environmental Education, with a marked enthusiastic style (Goetz et al., 2019; Keller & Becker, 2020; Taxer & Frenzel, 2015), coming from a peasant home formed and trained in a rural school in the Municipality of Dovio, Valle del Cauca. It is worth highlighting that before pursuing his professional career, he thought that his life project would be to culturally inherit his father's trades in masonry, however, a characteristic that stands out in him is the ability to make reasoned

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and evidence-based decisions. In this way, he identified that the best option was to become a professional. It is important to highlight that there is a correlation between the beliefs, values and knowledge of parenting of teacher Javier, with the professional decisions taken in his pedagogical practice, referred to in what Elbaz (1983) calls the "Social Orientation", which in the case of this teacher, consists of incorporating a high content of social values in his students through the introduction of environmental education to the school dynamics, assuming certain responsibility and commitment in different situations that require the development of a critical conscience by his students, overcoming the limits of the classroom, intervening in other institutional and community spaces. All this makes Javier a genuine dynamic teacher (Torres, 2002).

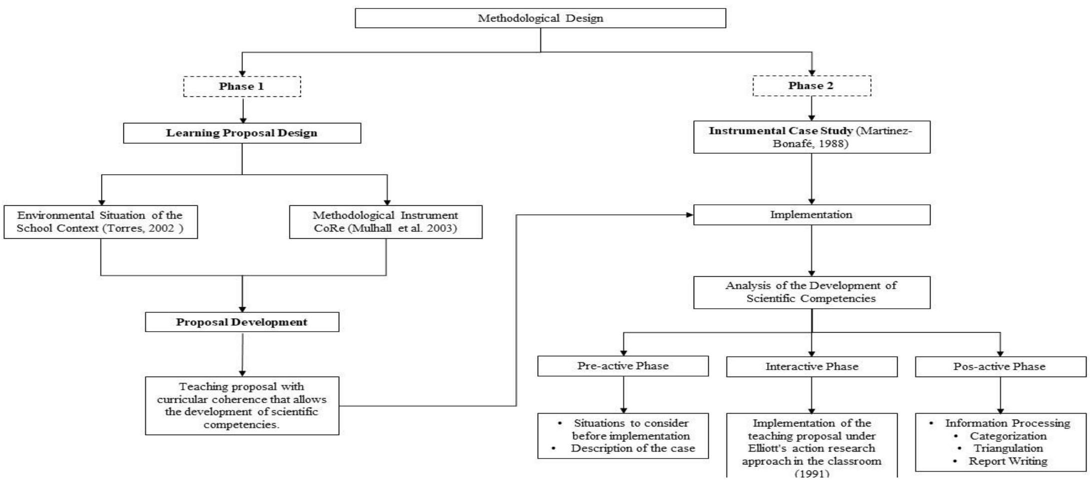
Given that the participation of the students in this research did not represent any risk and much less a public exposure of their identity and personal data, the academic council of the institution provided the endorsement for the teacher-researcher to collect the information in his virtual classroom in the framework of his autonomous professional practice, under the protection of the General Education Law 115 of 1994, articles 4, 109, and 150 paragraph d).

Methodological Design

In order to analyze the development of scientific skills in students, a methodology divided into two main phases was designed as shown in Figure 2. In Phase 1, two fundamental pillars were used, the first is the interpretation of the environmental situation of the school context, based on the Colombian environmental education reference framework (Torres, 2002; Ministry of National Education, 2003; Ministry of Environment and Sustainable Development, 2016) and the methodological tool of content representation -CoRe (Loughran, et al, 2001; Loughran et al, 2004; Candela & Viafara, 2014; Candela, 2017; Nilsson & Karlsson, 2019) where general and specific learning theories were collected to guide curricular decisions when selecting and sequencing the set of ideas that were represented in the classroom.

Figure 2

Model of the global methodological design.



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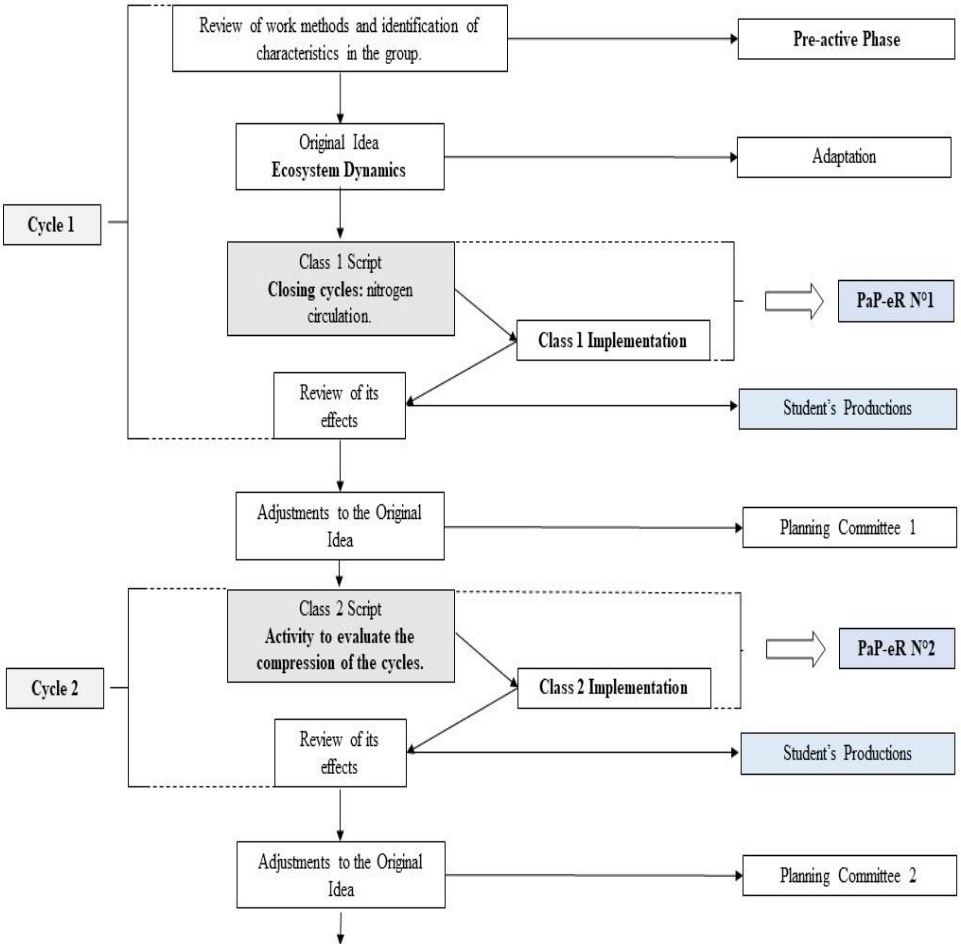
In phase 2 (implementation), scientific competencies were analyzed taking into account the stages of the instrumental case study (Martínez-Bonafé, 1988; Yin, 2014; Priya, 2021; Martínez-Roldan, 2020) which are:

- The pre-active stage: in this stage, the students participating in the research were characterized and the virtual classroom was built as a work dynamic.
- The interactive stage, in which the teaching proposal was implemented under the action research model from Elliot's model (1991, 2005), and enriched by the updates raised by Mertler (2019), and Feldman et al (2018) as shown below in Figure 3:

Figure 3.

Adaptation of Elliot's model, and the approaches of Loughram et al. in the interactive stage.



The post-active stage corresponded to the processing of the information and evidence collected for its subsequent triangulation with the different documentary sources (recorded classes, student productions, field diary, specialized literature, and student interviews, among others), thus obtaining categories of analysis to discuss the results and determine some final considerations of the study.

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RESULTS

The research question of this study, served for the teacher to mobilize professional thinking schemes about his school scientific activity in the classroom. In this sense, the first product generated from this process is a performance rubric (McNamara & Englund, 2020) composed of three degrees of cognitive demand, in order to determine the progress of Eugenio and Andrés from the homologation with the OECD proposal (OECD 2017, 2019), and the most important curricular documents of the Colombian education system (Ministerio de Educación Nacional, 1998, 2006, 2010, 2016a, 2016b, 2017) as shown in Figure 1.

Different authors in the specialized literature on levels of progression or performance (Jian-Xin & Yu-Ying, 2018; Liu & Teresa, 2019; Scott et al, 2019; Jin, et al, 2019), express that level 1 is a starting level, and that level 2 is the one that is regularly reached at the end of the processes since it corresponds to the average expected by the students, and aligned with that, level 3, fulfills the function of being an ideal topic of reference for the progress that is rarely reached. With these references, it was possible to obtain, as part of the research results, a rubric enriched with the scientific competencies to be developed in the students, as shown in Table 1 below:

Table 1

Levels of performance and evidence of learning to assess student progress case.

		Performance Levels		
Competence	**Evidence**	**Level 1**	**Level 2**	**Level 3**
Use of scientific knowledge (UC by its Spanish acronym)	**UC-EBC1**	The student shows conceptual difficulties in the recognition of ecosystems and the analysis of the dynamic equilibrium among their populations.	The student describes some basic ecosystems and recognizes certain characteristics of the dynamic equilibrium among their populations.	The student characterizes ecosystems and analyzes the dynamic equilibrium among their populations.
	UC-EBC2	The student does not recognize the pollution factors in his/her	The student recognizes with difficulty some pollution factors in	The student adequately exemplifies the pollution factors in

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		environment and their implications for health.	his/her environment and their implications for health.	his/her environment and their health implications.
	UC-MR	The student does not identify the biotic and abiotic components involved in ecosystem dynamics and the interrelationships between these components.	The student partially identifies the biotic and abiotic components involved in the dynamics of ecosystems and the interrelationships between these components.	The student identifies and differentiates the biotic and abiotic components involved in ecosystem dynamics and the interrelationships between these components.
	UC-DBA	The student does not identify relationships between the carbon and nitrogen cycles and the maintenance of soils in an ecosystem.	The student recognizes relationships between the carbon and nitrogen cycles with the maintenance of soils in an ecosystem.	The student establishes relationships between the carbon and nitrogen cycles and the maintenance of soils in an ecosystem.
Explanation of phenomena (EF by its Spanish acronym)	**EF-EBC**	The student does not recognize the dynamics of an ecosystem, taking into account the energy and nutrient needs of living beings.	The student recognizes the dynamics of an ecosystem, taking into account the energy and nutrient needs of living beings.	The student explains the dynamics of an ecosystem, taking into account the energy and nutrient needs of living beings.
	EF-DBA	The student does not identify the types of nutrition	The student identifies the types of nutrition	The student explains the types of nutrition

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		(autotrophic and heterotrophic) in food chains and food webs within ecosystems.	(autotrophic and heterotrophic) in food chains and food webs within ecosystems.	(autotrophic and heterotrophic) in food chains and food webs within ecosystems.
	EF-MR	The student does not recognize the interrelationships between the different components of an ecosystem from the analysis of the dynamics within it.	The student Describes the interrelationships between the different components of an ecosystem based on the analysis of the dynamics within it.	The student explains the interrelationships between the different components of an ecosystem based on the analysis of the dynamics within it.
Inquiry (IN by its Spanish acronym)	**IN-EBC1**	The student finds it difficult to formulate possible explanations, based on everyday knowledge, theories, and scientific models, to answer questions.	The student formulates possible explanations based on everyday knowledge, theories, and scientific models to answer questions.	The student represents in different registers, possible explanations based on everyday knowledge, theories, and scientific models, to answer questions.
	IN-EBC2	The student does not record his/her observations and results using diagrams, graphs, and tables.	The student records observations and results using diagrams, graphs, and tables based on examples.	The student uses his/her different records and observations such as diagrams, graphs, and tables, in exercises that require basic processing to obtain useful information.

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IN-EBC3	The student does not support his/her answers with different arguments.	The student supports his/her answers with some arguments.	The student supports his/her answers with different arguments, establishing relationships between them.
IN-DBA	The student does not distinguish examples of the effects of human intervention (erosion, pollution, deforestation) on the biogeochemical cycles of soil (carbon, nitrogen) and water and their environmental consequences and proposes possible actions to mitigate or remedy them.	The student recognizes from case studies the effects of human intervention (erosion, pollution, deforestation) on the biogeochemical cycles of soil (carbon, nitrogen) and water and their environmental consequences.	The student relates from cases of the effects of human intervention (erosion, pollution, deforestation) on the biogeochemical cycles of soil (carbon, nitrogen) and water and their environmental consequences and proposes possible actions to mitigate or remedy them.
IN-MR1	The student presents difficulties in the interpretation of data represented in text, graphs, drawings, diagrams, or charts.	The student Partially interprets data represented in text, graphs, drawings, diagrams, or tables.	The student Interprets and analyzes data represented in text, graphs, drawings, diagrams, or tables.
IN-MR2	The student does not demonstrate the ability to represent data in graphs and	The student represents data in graphs and tables supported by	The student represents and analyzes data in graphs and tables

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	tables.	examples.	supported by examples.

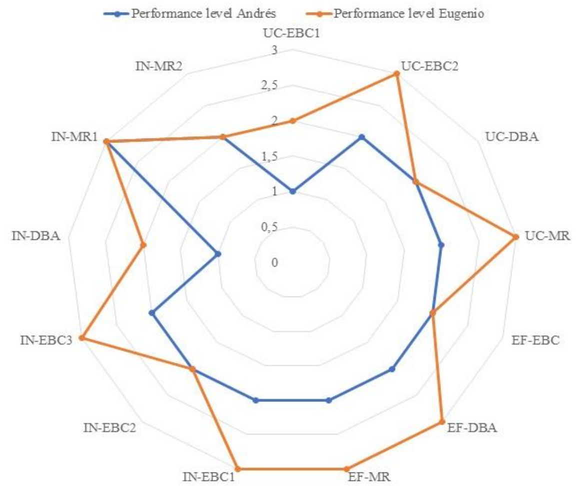
Note. The following acronyms were used for the codification of the Colombian curriculum documents in the natural sciences and they are based on their names in Spanish: EBC= Basic Competency Standards; MR= Reference Matrix; DBA= Basic Learning Rights.

It could be observed that Andrés remained in 9 categories of the learning pieces of evidence, at performance level 2, showing that he partially complied with them. In contrast, he only reached level 3 (the ideal) in the competencies that refer to the representation and interpretation of information in graphs. This is due to the fact that throughout the 10 classes analyzed, various activities were carried out that led him to develop this skill. In this sense, although Andrés demonstrated with all his actions that he had sufficient capacity to reach level 3, he remained at level 2 because he was not given the opportunity to exercise them to turn them into skills, a situation that was evidenced in a moderation of his effort that was perceived in the performance of the assigned tasks.

Eugenio, on the other hand, presented a more notable development. First, it is recognized that he reached level 3 (the optimum) in 7 learning evidences and the others remained at level 2 since none was identified at the lowest level. This undoubtedly reflected Eugenio's behavior throughout the classes, demonstrating that he was able to fully comply with actions that allowed him to follow up on the development of his scientific competencies. However, the pieces of evidence that Eugenio only partially achieved become an opportunity to enrich the activities in order to rethink their design for improvement. All these results are expressed in the following radial model in Figure 4

Figure 4

Performance levels achieved by Andres and Eugenio in relation to the learning pieces of evidence.



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In the results of the performance levels for each of the scientific competencies in Eugenio and Andrés, it can be noted that they are not normally distributed, they also correspond to a small sample, and it can be seen that they present a large number of ties in their ordinal scales. These conditions allowed the application of the non-parametric statistic, Kendall's Tau B (Permata et al, 2023; Elzainy et al, 2020; Huang et al, 2018), whose summary is shown in Table 2.

According to the information provided by the Statistical Package for the Social Sciences (SPSS - Version 2020), cited in the research of Permata et al, (2023), the correlation scale of Kendall's Tau B between the two computed columns can be evaluated through the following correlation scale: weak (0.00-0.25), sufficient (0.26-0.50), strong (0.51-0.75), very strong (0.76-0.99), perfect (1.00).

Table 2

Data processed for the calculation of Kendall's Tb.

<table>
<tr><td colspan="6">N = Number of observations = 13</td></tr>
<tr><td>Evidence</td><td>Andrés (a)</td><td>Eugenio (e)</td><td>Higher values in the range (M)</td><td>Lower values in the range (m)</td><td>Difference between M and m</td></tr>
<tr><td>UC-EBC1</td><td>1</td><td>2</td><td>7</td><td>0</td><td>7</td></tr>
<tr><td>IN-DBA</td><td>1</td><td>2</td><td>7</td><td>0</td><td>7</td></tr>
<tr><td>UC-EBC2</td><td>2</td><td>3</td><td>0</td><td>4</td><td>-4</td></tr>
<tr><td>UC-MR</td><td>2</td><td>3</td><td>0</td><td>4</td><td>-4</td></tr>
<tr><td>UC-DBA</td><td>2</td><td>2</td><td>5</td><td>0</td><td>5</td></tr>
<tr><td>EF-EBC</td><td>2</td><td>2</td><td>5</td><td>0</td><td>5</td></tr>
<tr><td>EF-DBA</td><td>2</td><td>3</td><td>0</td><td>2</td><td>-2</td></tr>
<tr><td>EF-MR</td><td>2</td><td>3</td><td>0</td><td>2</td><td>-2</td></tr>
<tr><td>IN-EBC1</td><td>2</td><td>3</td><td>0</td><td>2</td><td>-2</td></tr>
<tr><td>IN-EBC2</td><td>2</td><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>IN-EBC3</td><td>2</td><td>3</td><td>0</td><td>1</td><td>-1</td></tr>
<tr><td>IN-MR2</td><td>2</td><td>2</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>IN-MR1</td><td>3</td><td>3</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td colspan="2" rowspan="2">Calculation of T for Eugenio ties (Te)</td><td>15</td><td rowspan="2">36</td><td rowspan="4">S Value</td><td rowspan="4">12</td></tr>
<tr><td>21</td></tr>
<tr><td colspan="2" rowspan="2">Calculation of T for Andrés ties (Ta)</td><td>1</td><td rowspan="2">46</td></tr>
<tr><td>45</td></tr>
</table>

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$$Tb = \frac{S}{\sqrt{\frac{1}{2}N(N-1) - T_a} * \sqrt{\frac{1}{2}N(N-1) - T_e}}$$

$$Tb = \frac{12}{\sqrt{\frac{1}{2}(13)(13-1) - 46} * \sqrt{\frac{1}{2}(13)(13-1) - 36}} = 0{,}32$$

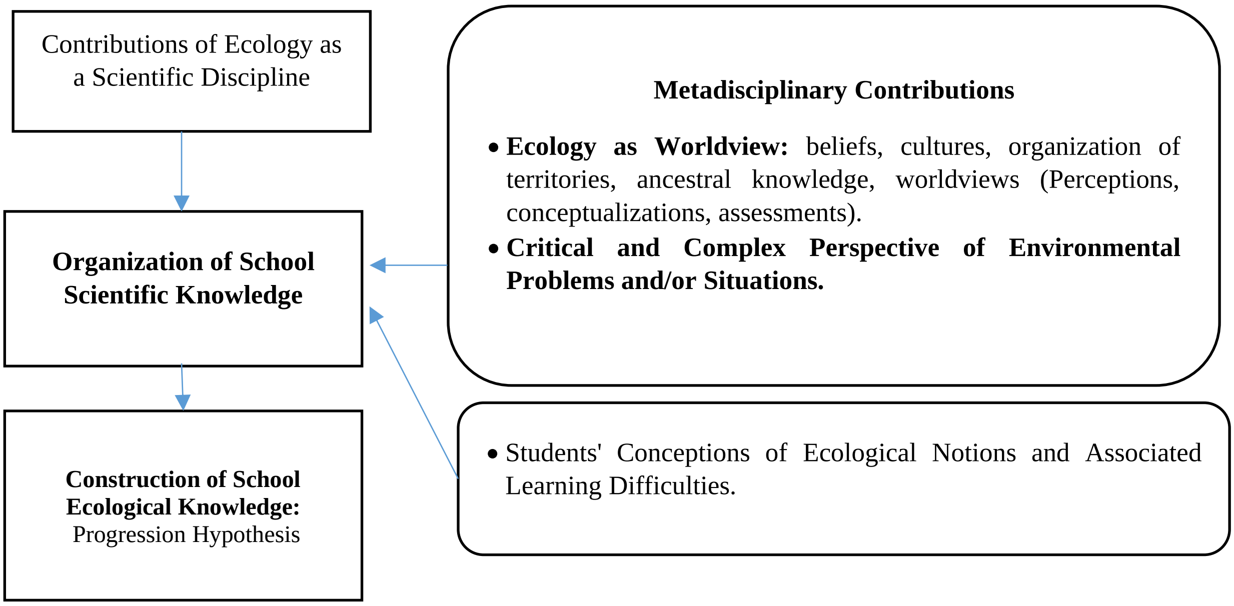
According to the above, the performances of Eugenio and Andrés have a sufficient relationship (0.32). This correlation can be improved in order to scale a better performance of these two students to the whole group. At this point, variables such as students' well-being, family supervision, access to technological resources and connectivity, improvement of study methodologies, and appropriate student behaviors regarding their autonomy and responsibility, among others, come into play. Next, we will review in more detail the results of teacher Javier's didactic intervention.

Javier's School Science Activity Within the Specific Topic

Professor Javier made an effort to integrate didactically the contributions of ecology as a scientific discipline, as a worldview (beliefs, organization of the territory, worldviews, values of the environment, ancestral knowledge, among others), as a critical perspective of the environmental situation of the school context, specifically of the Rio Morales, the construction of scientific knowledge through the hypothesis of progression, and the students' conceptions about ecological notions and the associated learning difficulties, as shown in Figure 5:

Figure 5

Model of didactic integration proposal in the teaching of ecology.



Note. Scheme adapted from Garcia (2003).

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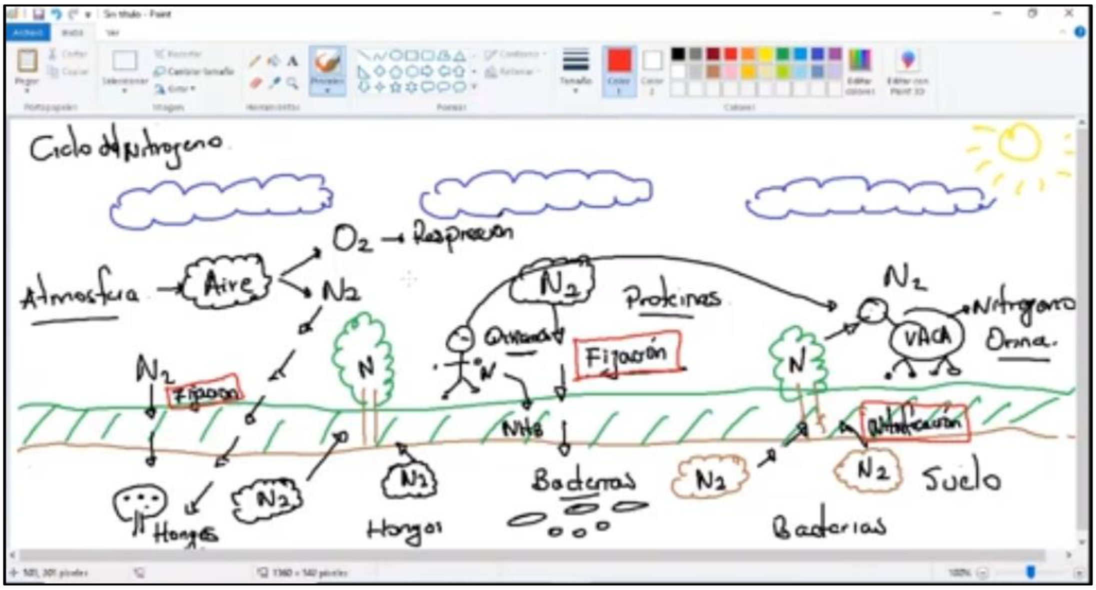
The integration of the elements of the perceived reality was evidenced in a dichotomous discursive form corresponding to biotic-abiotic, animal-plant, natural-artificial, and aquatic-terrestrial. Here the conjugation of the different levels of perspective, microscopic and macroscopic, was not very evident, because it was centered on the mesoscopic, which is evidenced through the senses.

The scientific explanatory models came from explanatory rhetoric, as was the case with the water, nitrogen, and carbon cycles, the representation of biotic and abiotic factors, individuals, populations, and communities, as well as the different ecosystemic relationships (intra- and interspecific) as shown in Figure 6.

Figure 6

Model constructed by the teacher during class 1 to explain nitrogen circulation.



When using a pre-designed model such as Goffin's scheme (Mendoza, et al, 2005), it was more efficient in terms of understanding for students all the abstraction processes implicit in this class. The analysis of the cycles, and in the intra- and interspecific relationships, the trophic relationships, corresponded to a simple causal reasoning pattern, based on cause-effect relationships of unidirectional and direct characteristics (Alonzo, 2018; Bell-Basca et. al, 2000; García-Rodeja et. al, 2020). All of this corresponds to a level 1 model, within the hypothesis of progression of this structuring concept as shown in Figure 7:

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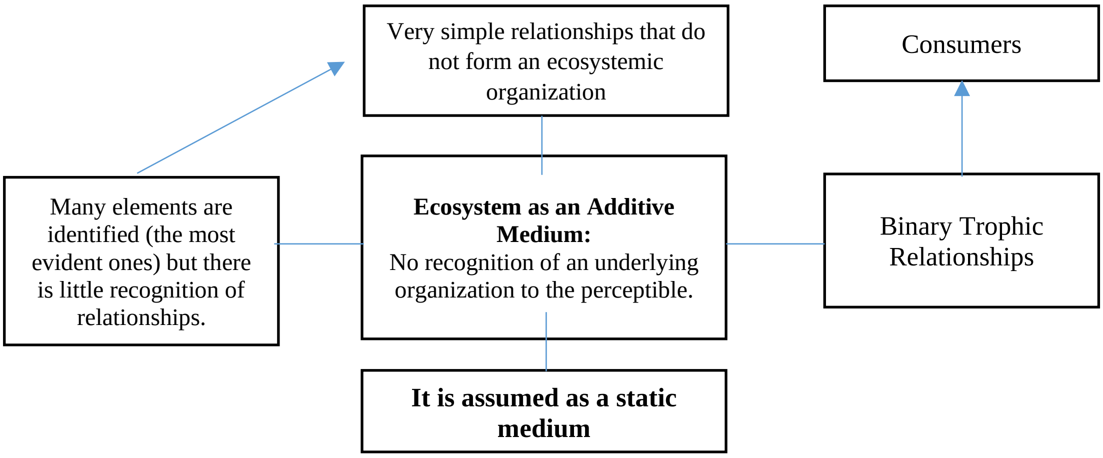
Figure 7

Level 1 model (MN1) of progression hypothesis in the teaching of ecosystem dynamics.



Note. Scheme adapted from Garcia (2003).

The idea of the ecosystem evolved being a simple organization (Garcia, 2003) illustrated in Figure 8. There, a series of simple relationships of the elements that constitute the environment were recognized, and some emergent properties in this regard, such as trophic relationships, assigned importance to some components that are not perceptible by the senses as the function of microorganisms. At this point, the binary discourse continued to prevail when working on interspecific relationships such as commensalism, mutualism, predation, competition, and parasitism, corresponding to the following model presented in Table 3:

Table 3

Tabulation model of binary type relationships in the teaching of ecosystem dynamics identified in Javier's ACE.

0 / 0	+ / 0	+ / -	+ / +	- / -
Organisms that share space and resources neither benefit nor harm each other.	This relationship means that while one organism benefits, the other neither benefits nor is harmed.	It refers to the benefit of one organism from the detriment of another.	It is a relationship that indicates that both organizations benefit from.	It is a relationship in which organisms in their quest for survival affect each other.

Nota. 0 = Non-benefiting and non-harming organism; + = Organism that benefits; - = Organism that is harmed.

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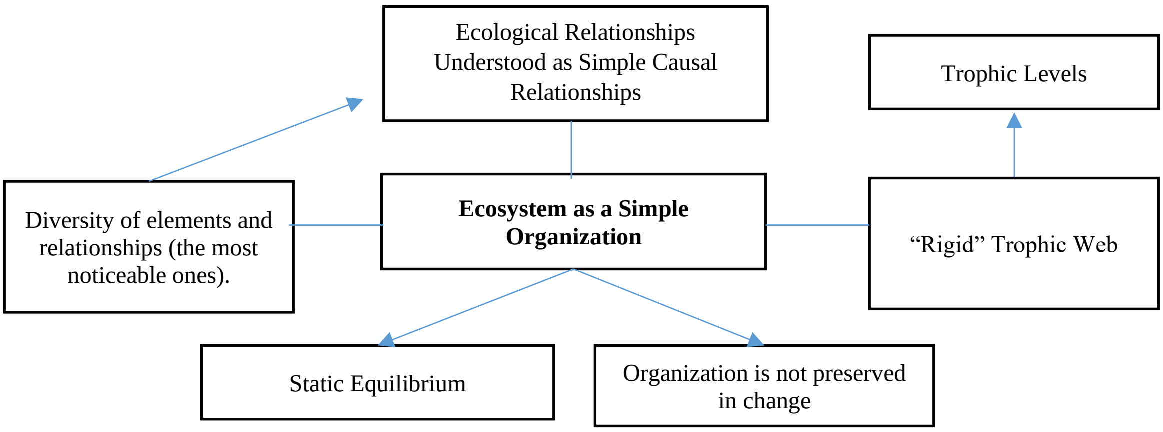
Figure 8

Level 2 model (MN2) of progression hypotheses in teaching ecosystem dynamics.

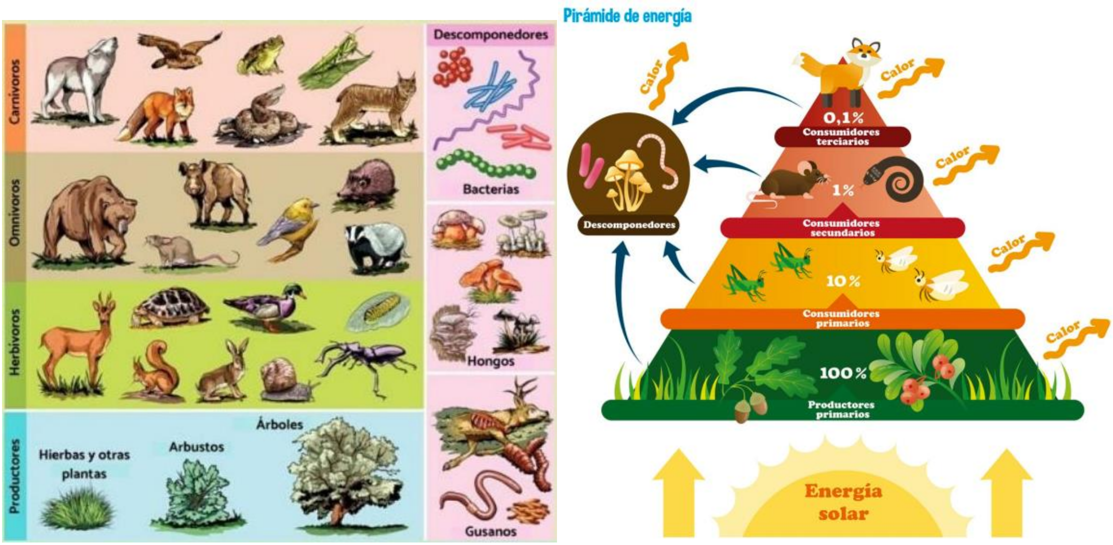


Note. Scheme taken from García (2003).

In the trophic relationship models, the teacher did not incorporate at least one corresponding to the pyramidal or matrix model as shown in Figure 9, which are essential for the understanding of the trophic links. Paradoxically, the environmental context of the I-A had the Morales River ecosystem as a protagonist, but the trophic networks worked on were exclusively terrestrial.

Figure 9

Example of matrix and pyramid models of the trophic links that Javier omitted in his I-A process.



Source: Green Ecology (n.d.)

Based on the above, it is proposed to overcome some epistemological obstacles regarding this teaching topic to move towards the third level of the hypothesis of progression, for which some specific didactic recommendations are discussed below in light of the results obtained.

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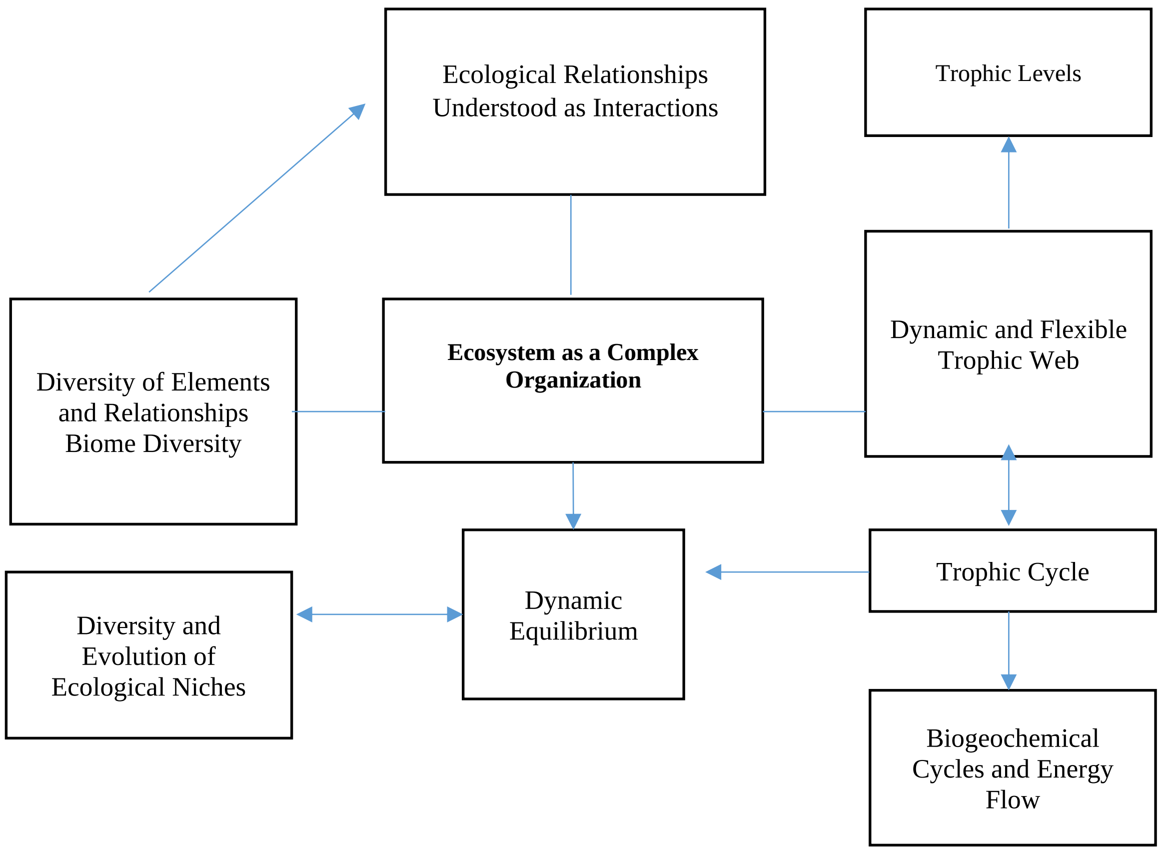
DISCUSSION

Level 3 of the progression hypothesis represented in Figure 9, is assumed as a reference model that consists of viewing the ecosystem as a complex organization that incorporates three types of reasoning essential patterns (Bell-Basca et al, 2000; García-Rodeja et. al, 2020) to overcome the simple causality pattern in the study of ecosystem dynamics: (a) complex causal relationship patterns, which allow the understanding of energy flow in trophic networks; (b) cyclic causal relationship patterns, necessary to understand biogeochemical cycles and cycles of other substances such as water; (c) interactive causal reasoning patterns, which facilitate the understanding of any eventuality or event with mutual and simultaneous effects on various ecosystem components, for example, in the relationship between biotic and abiotic factors in a given context; (d) interactive causal reasoning patterns, which facilitate the understanding of any eventuality or event with mutual and simultaneous effects on various ecosystem components, for example, in the relationship between biotic and abiotic factors in a given context.

Figure 10

Level 3 model (MN3) of progression hypotheses in teaching ecosystem dynamics.



Note. Scheme adapted from García (2003).

To achieve the above, it is necessary to epistemologically strengthen the concept of interaction, as well as the scientific model, by incorporating different debates and controversies around ecology according to the integrated perspective proposed by García (2003), prioritizing those models and examples in which a greater diversity of kingdoms is evident and not only remain in the binary protagonism of plant-animal or animal-animal.

It is also necessary to develop didactic strategies that favor the understanding and application of the principle of conservation and transformation of matter and energy, overcoming beliefs oriented towards the disappearance of energy or that there is no relationship between its different types. In the face of this, it must be taken into account that the flow of energy is epistemologically different from the cycle of matter. In both, the core concept is that of transformation under the principle of conservation, but in the former, there is a dissipation-degradation, and in the latter a recycling of materials.

This will help to overcome the vision of soil as an inexhaustible source of resources, in which the role of microorganisms is not very visible, believing that in the soil there is a decomposition of materials per se. Therefore, it is important to go deeper into the ecosystemic function of decomposers, since it is very important for the students to understand that they transform organic matter into inorganic matter. All this is closely related to the prioritization of the conceptualization of autotrophic and heterotrophic nutrition, as well as its ecosystemic importance.

An example of the latter should become evident when differentiating whether CO2 is a carbon source or a pollutant. But all this is achieved if the interrelation between the functioning of ecosystems (cycles, energy flows, intra and interspecific relationships, population dynamics, etc.) and physiological processes (photosynthesis, nutrition, respiration, decomposition) is made evident, allowing a better understanding of their dynamics and the relationship between their processes.

CONCLUSIONS

Globally, a semantic vision of science is advocated through its teaching (Adúriz-Bravo, 2020; Guerrero, 2012), however, in research in the field of science education, this is not very usual. Many authors propose very similar constructs with certain nuances of difference that according to the context, academic tradition, or translations to other languages are "semantically homologous". This happened in the process of inquiry with the concept of scientific competencies (Hernández, 2005; Acosta-Silva & Vasco, 2013; García-Rodeja et, al. 2020) and scientific literacy (Wahyuni et. al, 2017; Kinslow et. al, 2019; Sjöström & Eilks, 2020; Adnan et. al,

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2021; Rusmansyah et. al, 2021), allowing us to conclude that both terms advocate the promotion of complex and integrative thinking, which allows the understanding of reality, where students give usefulness to scientific knowledge in specific contexts, assuming a critical stance and making coherent decisions accordingly.

In view of the above conceptualization, it was possible to recognize an institutional incoherence of the Colombian educational system regarding scientific competencies, since these are officially evaluated through a textual test of a summative nature (Saber-Pro), which does not allow students to demonstrate their being and know-how, since these components are evaluated in these tests from theoretical situations that end up demanding other types of capabilities that are also important.

This is a very necessary consideration, because in order to determine the development of scientific competencies in this process, it was necessary to adopt the case study methodology and obtain qualitative information directly in the work scenario (even if it was virtual). In addition, as can be seen in Table 1, there are many evidences of learning within the scientific competencies established for a single structuring topic, which necessarily leads to the need to implement other forms of evaluation that the competency-based system in the end does not recognize.

The development of scientific competencies demanded the coherent incorporation of different constructs, coming from different investigative aspects, such as School Scientific Modeling (Ariza et al., 2020), Technological Pedagogical Content Knowledge (Mishra & Koehler, 2006, 2008), Action-Research (Oranga & Gisore, 2023), and Structuring Concepts (De Carvalho et al., 2020), among others, whose use in the classroom, promoted the participating teacher to conceive himself as a reflective researcher in the field of science education, since by incorporating the situations of the environmental context, he necessarily had to adopt critical positions far from the neutral and elemtary science that is embodied in the different curricular documents of reference of the Colombian educational system.

This allows us to conclude that the different theoretical and methodological tools provided by the Ministerio Nacional de Educación are not enough, and that the teacher must take his own actions and decisions to undertake assertive research processes where the student is the main character.

Thus, environmental education becomes a vehicle for the promotion of different types of knowledge systems, beliefs and values that structure the models of citizens (Turrini et al., 2018; Siswanto et al., 2019) that educational institutions in Colombia have wished to form according to what is established in their respective Institutional Educational Projects. Therefore, it is necessary to continue this line of work, which is transversal to other constructs coming from specific

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didactics, where the theoretical and methodological frameworks in this regard continue to be strengthened and can continue providing the field of education in its different areas with more enriched pedagogical repertoires and professional experience.

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About the Authors

John Andersson Gómez Soto

Teacher-Researcher specializing in Environmental Education and Classroom Research. He has worked as an occasional lecturer at various universities, contributing his experience in student training and the implementation of educational projects focused on developing scientific competencies.

Francisco Javier Gómez Vergara

Teacher-Researcher in Environmental Education, with a particular focus on biological sciences. He is currently an adjunct lecturer at the Central Valley Unit, where he contributes to teaching and research in his field of expertise.

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Author contributions

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