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Critical environmental education with an investigative approach: emancipatory experience in teaching environmental issues

Educação ambiental crítica com abordagem investigativa: uma experiência emancipadora no ensino de problemas ambientais

Educación ambiental crítica con enfoque investigativo: una experiencia emancipadora en la enseñanza de problemas ambientales

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Abstract

The study aimed to investigate how an Inquiry-Based Learning Sequence (IBLS), grounded in Critical Environmental Education (CEE), can promote learning about environmental issues in Brazilian biomes, integrating concepts such as ecological imbalances, environmental racism, and One Health. Data collected from reflective journals and questionnaires, and analyzed through a combination of simple frequency and content analysis, revealed three key areas of progress: (1) High school students expanded their understanding of the

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multicausality of environmental problems, moving beyond generic explanations and recognizing structural factors such as agribusiness; (2) the concepts of environmental racism and One Health emerged in their conclusions, with emphasis on the unequal impacts on vulnerable populations; (3) the solutions evolved from punitive measures to educational actions and public policies. Students reported high levels of interest (classified as “very interesting” and “interesting”) in the stages of contextualization (85%), problematization (80%), hypothesis (75%), data collection (80%), dialogical exposition (75%), conclusion (60%), and communication (65%). The experience demonstrated that the articulation between IBLS and CEE developed in students the ability to analyze environmental problems across ecological, political, and social dimensions, constituting an emancipatory pedagogical practice aligned with contemporary demands for sustainability and environmental justice.

Keywords: Brazilian Biomes. Inquiry-Based Teaching. Environmental Justice.

Resumo

O estudo teve como objetivo pesquisar de que maneira uma Sequência Didática Investigativa (SDI), fundamentada na Educação Ambiental Crítica (EAC), pode promover a aprendizagem sobre os problemas ambientais nos biomas brasileiros, articulando conceitos como desequilíbrios ecológicos, racismo ambiental e saúde única. Os dados, coletados a partir de diários reflexivos e questionários e analisados por meio da combinação de frequência simples e análise de conteúdo, revelaram três eixos de avanços: (1) os estudantes do ensino médio ampliaram a compreensão da multicausalidade dos problemas ambientais, superando explicações genéricas e reconhecendo fatores estruturais como agronegócio; (2) os conceitos de racismo ambiental e saúde única emergiram nas conclusões, com destaque para os impactos desiguais em populações vulneráveis; (3) as soluções evoluíram de medidas punitivas para ações educativas e políticas públicas. Os alunos demonstraram elevados índices de interesse (muito interessante e interessante) nas etapas de contextualização (85%), problematização (80%), hipótese (75%), coleta de dados (80%), exposição dialogada (75%), conclusão (60%) e comunicação (65%). A experiência evidenciou que a articulação entre SDI e EAC desenvolveu nos estudantes a capacidade de analisar problemas ambientais nas dimensões ecológica, política e social, se configurando como prática pedagógica emancipatória e alinhadas às demandas contemporâneas por sustentabilidade e justiça ambiental.

Palavras-chave: *Biomas Brasileiros. Ensino por Investigação. Justiça Ambiental.*

Resumen

El estudio tuvo como objetivo investigar cómo una Secuencia Didáctica Investigativa (EDI), basada en la Educación Ambiental Crítica (EAC), puede promover el aprendizaje sobre los problemas ambientales en los biomas brasileños, articulando conceptos como desequilibrios ecológicos, racismo ambiental y Una Salud. Los datos, recopilados a través de diarios reflexivos y cuestionarios, y analizados mediante una combinación de análisis simple de frecuencia y contenido, revelaron tres áreas de progreso: (1) los estudiantes de secundaria ampliaron su comprensión de la multicausalidad de los problemas ambientales, superando las explicaciones genéricas y reconociendo factores estructurales como la agroindustria; (2) los conceptos de racismo ambiental y Una Salud emergieron en los hallazgos, destacando los impactos desiguales en las poblaciones vulnerables; (3) las soluciones evolucionaron de medidas punitivas a acciones educativas y políticas públicas. Los estudiantes demostraron altos niveles de interés (muy interesante y atractivo) en las etapas de contextualización (85%), problematización (80%), hipótesis (75%), recopilación de datos (80%), presentación dialogada (75%), conclusión (60%) y comunicación (65%). La experiencia demostró que la articulación entre SDI y EAC desarrolló la capacidad de los estudiantes para analizar los problemas ambientales desde perspectivas ecológicas, políticas y sociales, constituyendo una práctica pedagógica emancipadora alineada con las demandas contemporáneas de sostenibilidad y justicia ambiental.

Palabras clave: *Biomas brasileños. Enseñanza basada en la investigación. Justicia ambiental.*

Introduction

Brazilian vegetation formations face serious anthropogenic threats such as deforestation, burning, and agricultural expansion, which accelerate biodiversity loss and intensify socio-environmental conflicts (Souza, 2020; Pantoja, 2021). In this context, Critical Environmental Education (CEE) emerges as a transformative approach, integrating ecological, political, and historical analyses to understand the causes and seek solutions to these problems (Machado; Abílio, 2021). Grounded in dialogical principles, CEE challenges reductionist perspectives by connecting generative themes from reality to emancipatory practices, such as reflecting on environmental injustices that mainly affect vulnerable populations (Arrais; Bizerril, 2020; Costa; Loureiro, 2024; Dutra; Camargo; Souza, 2021; Freire, 2021; 2022).

Within this scenario, pedagogical strategies such as Inquiry-Based Teaching (IBT) and Inquiry-Based Teaching Sequences (IBLS) stand out for promoting Scientific Literacy (SL), strengthening the connection between scientific knowledge and students' lived experiences (Sasseron, 2015; Silva; Sasseron, 2021). IBT fosters skills such as problematization, data analysis, and evidence-based argumentation (Andrade, 2011; Carvalho, 2018; Scarpa; Campos, 2018), while IBTS enables extended investigative activities, suitable for addressing the complexity of environmental imbalances (Motokane, 2015). SL, in turn, is structured around three pillars: (1) understanding scientific concepts; (2) the nature of science; and (3) interrelations between science, technology, and society (Sasseron; Carvalho, 2008). These pillars are essential for forming citizens who are sensitive to contemporary socio-environmental challenges and committed to an education guided by ethics and social transformation (Valladares, 2021). As Sasseron (2024) highlights, SL, when combined with IBT, broadens students' worldview, empowering them to understand and transform reality.

Despite the relevance of CEE, the Brazilian National Common Curricular Base (BNCC – Brazil, 2018) addresses the topic insufficiently, reducing Environmental Education to a superficial and transversal approach that fails to question the structures of socio-environmental injustice and inequality. While the BNCC seeks to raise students' awareness of environmental issues, it avoids addressing the structural causes of these problems, such as the capitalist model and its consequences (Nepomuceno et al., 2021). Although the document acknowledges the importance of environmental awareness, it minimizes the theme, limiting the potential of Environmental Education to fulfill its transformative role (Filipe; Silva; Costa, 2021; Xavier et al., 2024). In contrast, CEE proposes a critical and emancipatory education, going beyond the reductionist perspective of the BNCC by encouraging reflection on the relationships between society, nature, and environmental injustices. This creates space for pedagogical practices that promote conscious and transformative student action (Oliveira; Santos; Novais, 2024).

Given this context, the general objective of this study is to investigate how an Inquiry-Based Teaching Sequence (IBTS), grounded in Critical Environmental Education (CEE), can foster learning about environmental issues in Brazil's continental biomes (Amazon, Cerrado, Caatinga, Pantanal, Atlantic Forest, and Pampas) in high school education. The specific objectives are: (1) to develop an IBTS that addresses the causes, consequences, and mitigation measures of ecological imbalances; (2) to evaluate its application in the classroom, focusing on the intellectual and argumentative development of students; and (3) to investigate whether the IBTS contributes to a critical stance on environmental issues, articulating scientific knowledge with discussions on environmental justice, environmental racism, and One Health.

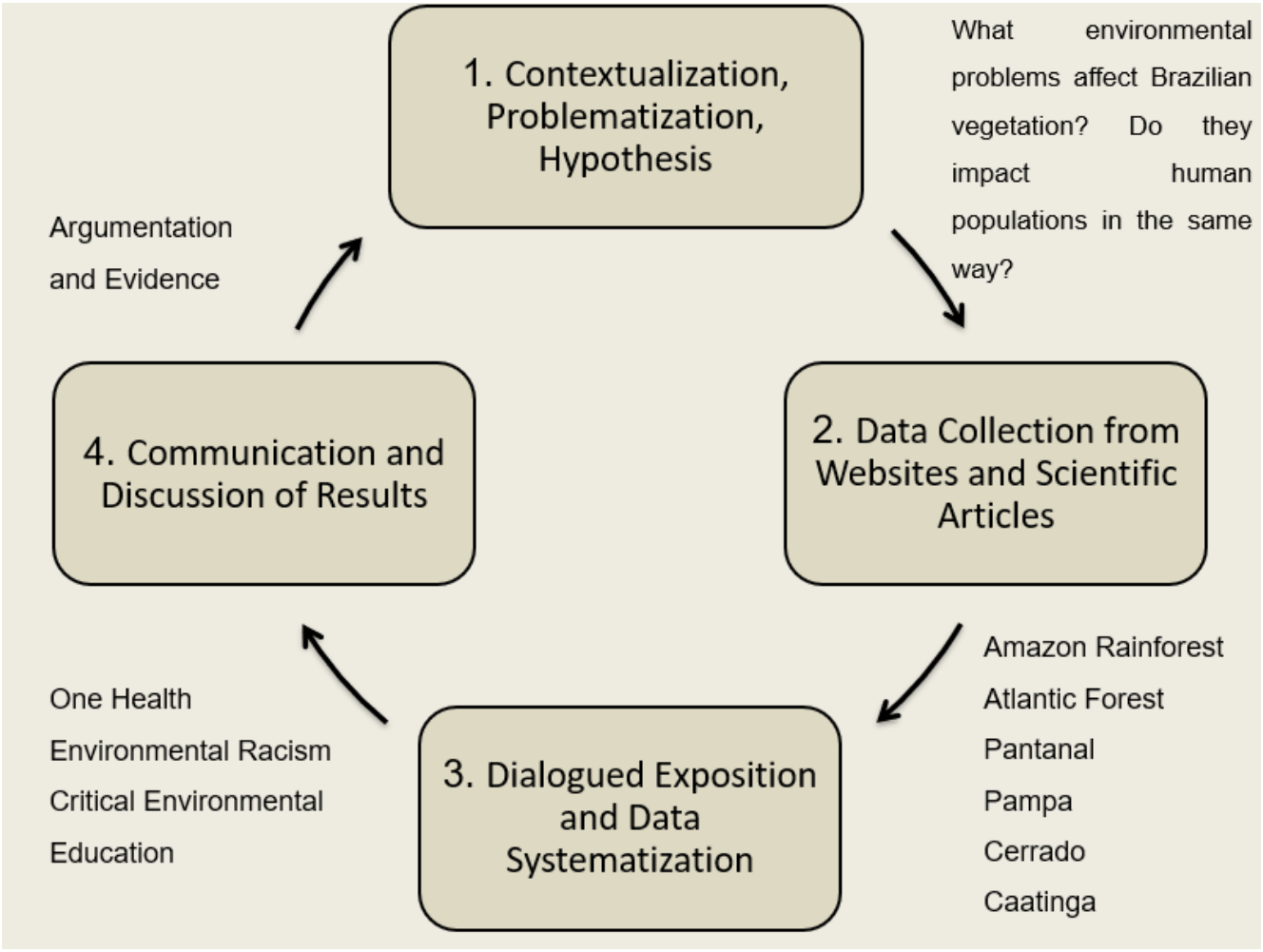
Based on the guiding question — "How can CEE, mediated by an IBLS, promote learning about environmental imbalances in Brazilian biomes from an emancipatory perspective ?" — this study aims to overcome the limitations of the BNCC, demonstrating how critical and inquiry-based approaches can connect political analysis of environmental conflicts with Biology education, reinforcing the role of schools in building more just and sustainablesocieties.

Metodologia

We adopted a qualitative approach to understand the dynamic relationships and subjectivities of the individuals involved in the educational context. In qualitative research, the meanings attributed to experiences emerge as central elements of the investigation, with the researcher's eyes, ears, and attention also serving as essential tools for data collection and analysis (Eiterer, 2016). Thus, realities are permeated by an interpretive richness that favors the construction of meanings and cannot be captured solely through indices and numbers (Ludke; André, 2017).

This is an interventionist study of the research and development type, which, according to Teixeira and Megid-Neto (2017), is characterized by the design and evaluation of educational processes or products. The product investigated was a Teaching Sequence (IBLS) on environmental imbalances in Brazilian biomes, organized into four stages:Contextualization/problematization/Hypotheses; Data Collection; Dialogued Systematization; Communication of Results (Fig. 1).

Figure 1 - Flowchart of the Investigative Didactic Sequence: Environmental Imbalances in Brazilian Vegetation



Source: Authors (2025).

Lesson 1: The class begins with an analysis of images depicting different biomes (climate, relief, fauna, and flora) through a dialogued discussion (20 minutes). Next, students are divided into six groups, each investigating a specific biome (Amazon, Atlantic Forest, Pantanal, Pampa, Cerrado, or Caatinga).

Guided by key questions about environmental issues and their social impacts, the groups formulate hypotheses regarding causes, consequences, and possible solutions (30 minutes).

Lesson 2: Students search for bibliographic evidence to test their hypotheses, learning to identify reliable sources, conduct autonomous research, and build arguments—essential skills for the following stages.

Lesson 3: The class begins with a dialogued presentation (20 minutes) on the concepts of Critical Environmental Education (CEE), Environmental Racism, and One Health. Then, groups dedicate time to consolidating their research (30 minutes), organizing the collected data, and developing critical conclusions in response to the guiding questions.

Lesson 4: The groups present their conclusions, establishing a critical dialogue between their initial hypotheses and final findings, with emphasis on the triad: causes, impacts, and solutions to the investigated environmental issues. This session is characterized by: (1) evidence-based argumentation; (2) collective debate mediated by the teacher; and (3) conceptual refinement through targeted pedagogical interventions.

The Didactic-Instructional Sequence (DIS) was implemented in four 50-minute lessons with 30 students from the 3rd year of high school in a public school located in a peripheral neighborhood of Fortaleza, Ceará, in compliance with ethical standards (Resolutions 466/2012 and 510/2016 - CEP/UECE 6.858.431). For data collection, the following tools were used: (1) the teacher-researcher's field diary, with records of student participation in activities, hypothesis formulation, research, and presentation of conclusions; (2) student forms, containing data from all DIS stages; and (3) an evaluative questionnaire with open and closed questions about student interest in the activities. According to Conde et al. (2020), reflective journals serve as memory aids for teachers, supporting the analysis of experiences and contributing to reflections on pedagogical practice.

For data analysis, the teacher's field diaries (1) and student forms (2) were reviewed in order to compare hypotheses and conclusions, identifying conceptual progress, critical thinking, engagement, and challenges faced during the intervention. Responses to the questionnaire were examined through simple frequency and content analysis (Bardin, 2016), grouping meaning units into emerging semantic categories. These procedures enabled an integrated analysis of both qualitative and quantitative aspects.

These techniques were chosen for their ability to reveal meanings present in the responses, allowing for a deeper understanding of the contributions of the DIS to the teaching-learning process, from both the teacher's and students' perspectives. Although simple quantification was used, as supported by Scarpa and Marandino (1999), it does not detract from the qualitative approach but complements it, helping to organize and communicate results without sacrificing interpretative depth.

Results and Discussion

Assessment of Learning Mediated by the IBLS

The IBLS mobilized skills such as hypothesis formulation, data analysis and interpretation, explanatory modeling, as well as the construction and justification of conclusions in problem-solving situations. The ability to clearly communicate results was also highlighted. These competencies are aligned with the BNCC (Brazil, 2018), as they promote discussions on relevant scientific and sociocultural topics, and contribute to Scientific Literacy (SL), as advocated by Zômpero and Laburú (2011), by bringing students closer to the conceptual and procedural content of science and encouraging both oral and written communication of results.

The Pantanal group only participated in the initial stage of the IBLS but chose not to continue due to absenteeism and refusal of its members. As participation was voluntary, according to the consent form, there was no harm to the students. Thus, the data from five biomes will be analyzed: Caatinga, Cerrado,

Atlantic Forest, Amazon Rainforest, and Pampas. Deforestation was identified as the main issue in the Caatinga, Cerrado, and Atlantic Forest, while wildlife trafficking was highlighted in the Amazon Rainforest, and wildfires in the Pampas (Tables 1–5). These findings are consistent with the assessments of Souza (2020) and Pantoja et al. (2021), who point to deforestation and wildfires as the most serious environmental threats in Brazil.

Table 1 – Systematized information on environmental problems in the Caatinga and impacts on human populations

Data for the hypothesis	Data for conclusion	Caatinga
Problem: Deforestation. Cause: Human activity in extracting native forests for firewood and charcoal production. Consequence: Ecosystem destruction and animal extinction. Mitigation measures: Anti-deforestation projects, arrests, and prosecutions of companies that support deforestation. Equally affecting populations: Yes	Problem: Deforestation Cause: Human action, agribusiness growth. Consequence: Reduced humidity and rising temperatures contribute to global warming and reduce soil quality, making forest management unfeasible and preventing biodiversity loss. Mitigation measures: Buy recycled products, recycle waste, and participate in campaigns. Equally affect populations: Yes, because it affects things that humans cannot control.	Hypothesis: Deforestation by people for firewood production, which destroys the ecosystem and affects the general population. Conclusion: According to the research, everything is correct.

Source: Authors (2025).

Caatinga (Table 1) – The problem identified in the hypothesis was deforestation caused by the extraction of native vegetation for the production of firewood and charcoal. The conclusion confirms that human activity is one of the main causes but expands the explanation by including agribusiness and its consequences for the climate and soil quality, demonstrating a deeper understanding. The consequences were also expanded in the conclusions, as students began to consider other impacts beyond biodiversity loss already mentioned in the hypothesis, such as reduced air humidity, increased temperatures, worsening of global warming, and loss of soil quality.The mitigating measures initially focused on punitive actions such as imprisonment and legal proceedings, while the conclusion placed greater emphasis on environmental education and social mobilization, reflecting a significant shift by students from a more legalistic view to an educational and preventive approach. Regarding the impact of deforestation on populations, in both stages the students agreed that it affects everyone equally.

As pointed out by Ribeiro et al. (2016) and Sampaio et al. (2017), deforestation in the Caatinga is driven by several causes, including: (i) the expansion of agriculture and livestock; (ii) exploitation for the production of firewood and charcoal; and (iii) urbanization and infrastructure development. The consequences include biodiversity loss, soil erosion, climate changes, decreased availability of essential natural resources such as water and non-timber forest products, directly affecting the most vulnerable local communities. The authors alsod iscuss that to mitigate deforestation in the Caatinga, itis essential to adopt measures such as: (i) strengthening environmental monitoring and law enforcement; (ii) promoting sustainable economic alternatives; (iii) sustainable vegetation management; (iv) environmental education and awareness among local populations; and (v) the creation and management of conservation units.

The students' conclusions reveal a broader perspective, aligned with what is presented in scientific literature, especially by incorporating agribusiness as an environmental pressure factor among the causes of deforestation, expanding the range of consequences, and including educational measures in the mitigation of the problem. However, they also show difficulties in critical understanding, as the recognition of environmental racism was not expressed in the written conclusion (Table 1), emerging only during the communication of results and discussion with peers, including participation from students in other groups and the teacher. According to Sasseron (2015) and Scarpa and Campos (2018), Inquiry-Based Education (IBE) involves both the active engagement of students and the conceptual corrections and additions made by the

teacher. Therefore, the discussion and communication activities contributed to the collective construction of knowledge. Furthermore, the exclusion faced by populations in the Brazilian Northeast, who live with drought and lack access to water to meet basic needs, constitutes a socio-environmental problem. Thus, environmental justice emerges as an essential approach to combating the marginalization of vulnerable groups (Abreu, 2013).

Table 2 – Systematized information on environmental problems in the Cerrado and impacts on human populations

Data for the hypothesis	Data for conclusion	Cerrado
Problem: Deforestation Cause: Human-caused deforestation. Consequence: Animals die due to drought and lack of water. Mitigation measures: Prevent forest fires. Affects populations equally: Animals and vegetation are the biggest victims.	Problem: Deforestation Cause: The main causes of deforestation in Brazilian forests are related to human activity, especially agricultural activities. Consequence: Deforestation has serious consequences for the environment, including biodiversity loss, soil degradation, and changes in climate patterns. Mitigation measures: Manage wildlife during vegetation removal. Prohibit workers from any hunting-related activities. The following equally affect populations: However, the environmental impact is uneven between rich and poor, almost always affecting the poorest people most pervasively.	Hypothesis: Deforestation is caused by humans and results in the death of animals. Mitigation measures include monitoring and raising awareness. It affects the population in the same way. Conclusion: Yes, according to the data collected, they are similar to the research data. Humans are largely to blame, but it can also be caused by weather patterns, which harms animals. Regarding the last item, the data found do not support the hypothesis.

Source: Authors (2025).

Cerrado (Table 2) – The students initially identified deforestation as a consequence of human activity, with an emphasis on the death of animals due to drought and water scarcity. The mitigation measures proposed in the hypothesis were limited to fire prevention. However, in the conclusion, the students came to recognize agricultural activities as the main causes of deforestation, linking them to biodiversity loss, soil degradation, and changes in climate patterns. They also proposed broader mitigation measures, such as wildlife management and a ban on hunting. Another important advancement was the shift in perception regarding the impacts of deforestation. While in the hypothesis the students stated that the effects equally impact the entire population, in the conclusion they acknowledged that rural and low-income communities are more severely affected, as they depend directly on natural resources for their survival. This shift points to a greater awareness of the social inequalities involved in environmental issues.

Studies such as those by Monteiro et al. (2020) and Rodrigues et al. (2022) highlight the complexity of the factors driving deforestation in the Cerrado, among which agricultural expansion, forest fires, road construction, and climatic conditions stand out. The consequences include biodiversity loss, reduced evapotranspiration and water security, rising temperatures, increased carbon emissions, and soil erosion. The mitigation measures suggested by these studies include public policies for environmental control, sustainable agricultural practices, and the expansion of protected areas. By proposing mitigation measures that go beyond fire containment—incorporating sustainable practices and actions to protect wildlife—the students demonstrate an understanding aligned with the solutions suggested by the authors, such as strengthening public policies, expanding protected areas, and promoting responsible environmental management. Furthermore, by recognizing that the effects of deforestation disproportionately affect more vulnerable populations, the students show progress in developing critical thinking and socio-environmental awareness. This type of reflection, as emphasized by Andrade (2011), is essential for a scientific approach that considers both natural aspects and social implications.

Table 3 – Systematized information on environmental problems in the Atlantic Forest and impacts on human populations

Data for the hypothesis	Data for conclusion	Atlantic Forest
Problem: Deforestation Cause: Sunlight and humans themselves. Consequence: Significantly affects the environment, animals, and oxygen, causing significant destruction. Mitigation measures: Charitable actions for affected people, NGOs that can treat the health of affected animals and people. Affects populations equally: No, because social inequality still exists, and minorities are unable to survive amid this problem.	Problem: Deforestation Cause: Caused by the removal of native vegetation from an area. Consequence: Loss of biodiversity and consequent extinction of species. Mitigation measures: Enforcement of environmental law through oversight. Participation of public and private sectors in developing environmental preservation actions. Affects populations equally: The impact of environmental degradation is unequal between the poor and the rich, almost always affecting the poorest people in the most perverse ways, and can inflict serious harm on the poor.	Hypothesis: Deforestation is caused by logging for human consumption, and the consequences primarily affect oxygen, animals, and the environment. We can help with social projects for affected people, NGOs, awareness-raising projects, and charitable work. It doesn't affect the general population in the same way. Conclusion: Based on the data found, the hypothesis is valid.

Source: Authors (2025).

Atlantic Forest (Table 3) – In the hypothesis, students attributed deforestation to solar rays and human activity, with consequences such as environmental destruction, animal deaths, and loss of oxygen. The proposed mitigating measures focused on social actions, such as supporting NGOs and providing treatment for affected people and animals. In the conclusion, the human cause was clarified, being attributed to the removal of native vegetation. The consequences included loss of biodiversity and species extinction, and the proposed measures were more institutional, including enforcement of environmental laws, monitoring, and collaboration between the public sector and private initiatives for preservation. This group, even in the hypothesis stage, recognized that the impacts of deforestation do not affect populations equally, with poorer communities being the most severely impacted.

Deforestation in the Atlantic Forest is a complex and multifaceted environmental issue, with various causes, consequences, and mitigation measures (Tabarelli et al., 2010; Guimarães et al., 2023). According to these authors, the causes include agricultural and livestock expansion, logging, urbanization, and forest fires. The consequences are biodiversity loss, soil degradation, climate change, reduced water availability, and loss of essential ecosystem services. Mitigation measures include public preservation policies and environmental monitoring, restoration of degraded areas, promotion of sustainable agricultural practices, creation of ecological corridors, conservation units, and environmental education.

The environmental racism identified by the Atlantic Forest team is supported by Chiarini (2009), who argues that environmental degradation more intensely affects poor populations, who rely on natural resources for survival and face greater vulnerability to pollution and precarious living conditions. The students' recognition is also aligned with Ferreira (2023), who highlights how deforestation in the Atlantic Forest undermines the living conditions of poorer populations, worsened by socioeconomic factors and ineffective public policies, with unequal impacts depending on the social group and region.

Table 4 – Systematized information on environmental problems in the Amazon Rainforest and impacts on human populations

Data for the hypothesis	Data for conclusion	Amazon Rainforest
Problem: Animal Trafficking Cause: They traffic animals for illegal use. Consequence: Trafficked animals may not adapt to the new environment they'll be taken to, and species may	Problem: Animal Trafficking Cause: Animal trafficking is related to different desires and interests in wild animals. Consequence: It also contributes to the extinction of countless species beyond those that are hunted.	Hypothesis: Animal trafficking is caused by the sale of animals and results in animal deaths. Mitigation measures include lectures and laws to prohibit

Data for the hypothesis	Data for conclusion	Amazon Rainforest
become extinct if they don't adapt to the new environment. Mitigation measures: Prohibit hunting through laws and educational programs. Equally affecting populations: Only the animals themselves.	Mitigation Measures: The best way to combat wildlife trafficking is to discourage this illegal practice, that is, to raise awareness through environmental education. Affects populations equally: It doesn't affect the population in the same way; it's different because they have diseases that they transmit from animals, such as bacteria and other diseases.	hunting. It affects humans differently. Conclusion: Some of them do, but most others are different. Mitigation measures involve teaching environmental education to prevent animal deaths or extinction. Therefore, laws are necessary to protect animals. After collecting the data, it was understood that the environmental problem affects humans differently.

Source: Authors (2025).

Amazon Rainforest (Table 4) – In their initial hypothesis, the students attributed wildlife trafficking to illegal trade, emphasizing that the consequences should include the death of animals, with the risk of extinction due to their inability to adapt to a new environment. The proposed mitigation measures focused on banning hunting through laws and educational lectures. At first, the team believed the impact would affect only animals, without considering implications for humans. In the conclusion, the students broadened their understanding of the issue, recognizing that wildlife trafficking is tied to various human interests, such as the demand for wild animals. The consequences were expanded to include the contribution to the extinction of other species, given the disruption of food webs and chains that may be affected. The mitigation measures shifted toward awareness-raising through environmental education. Furthermore, the students came to understand that the impact does not affect all populations equally, as humans can also be affected by diseases transmitted by animals, such as bacteria and other pathogenic agents.

The transformation in the social understanding of the environmental problem of wildlife trafficking became evident at the end of the investigation carried out by the Amazon Rainforest team. The risk of zoonoses, impacting public health—especially in vulnerable communities—highlights an advance in the understanding of the One Health concept. One Health is based on the premise that human, animal, and environmental health are interconnected and interdependent, in such a way that environmental imbalances, such as deforestation, wildfires, pollution, and wildlife trafficking, have direct and indirect implications for both ecosystem (Nogueira et al., 2015; Stehle& Schulz, 2015; Pontes-Filho, Mendonça &Mamed, 2021) and human health (Evans & Leighton, 2014; Deps & Rosa, 2021; Ellwanger et al., 2020; Gibb et al., 2021).Also included was the understanding of environmental inequalities—currently referred to as environmental racism—which is based on the premise that the crisis of capitalism causes socio-environmental harm unequally across different social classes (Santos, Silva & Silva, 2022). Additionally, the team acknowledged the need for stricter laws and more effective enforcement, aligning with the recommendations found in the literature (see Destro et al., 2020). This reinforces the idea that combating wildlife trafficking in the Amazon—which is also a phenomenon related to economic and cultural interests—requires a coordinated effort involving public policies, enforcement, and public awareness.

Table 5 – Systematized information on environmental problems in the Pampas and their impacts on human populations

Data for the hypothesis	Data for conclusion	Pampas
Problem: Wildfires. Cause: Humans. Consequence: Pollution, lack of vegetation. Mitigation measures: Prohibit wildfires. Affect populations equally: No, as some people usually live further away.	Problem: Wildfires. Cause: Lightning, fires, and land clearing. Consequences: Global warming, loss of biodiversity, and lack of vegetation. Mitigating measures: Do not throw cigarette butts, cans, or bottles on highway shoulders or in forested areas. Affects populations equally: The impact of environmental degradation is unequal between the poor and the rich, almost always affecting the poorest more severely.	Hypothesis: Human-caused fires generate pollution and deforestation and should be prohibited because they can cause lung disease in both humans and animals. Conclusion: The causes, consequences, and mitigating measures were expanded through research. It was confirmed that the environmental problem does not affect the population in the same way.

Source: Authors (2025).

Pampas (Table 5) – In the hypothesis, students attributed the fires in the Pampas biome to human causes without detailing what they were. They mentioned pollution and vegetation loss as consequences, and proposed banning fires as a mitigation measure. In the conclusion, students broadened their analysis, recognizing multifaceted causes such as lightning and the use of fire in agriculture. As consequences, they included global warming and biodiversity loss. As mitigation measures, they began to propose awareness campaigns on solid waste disposal.

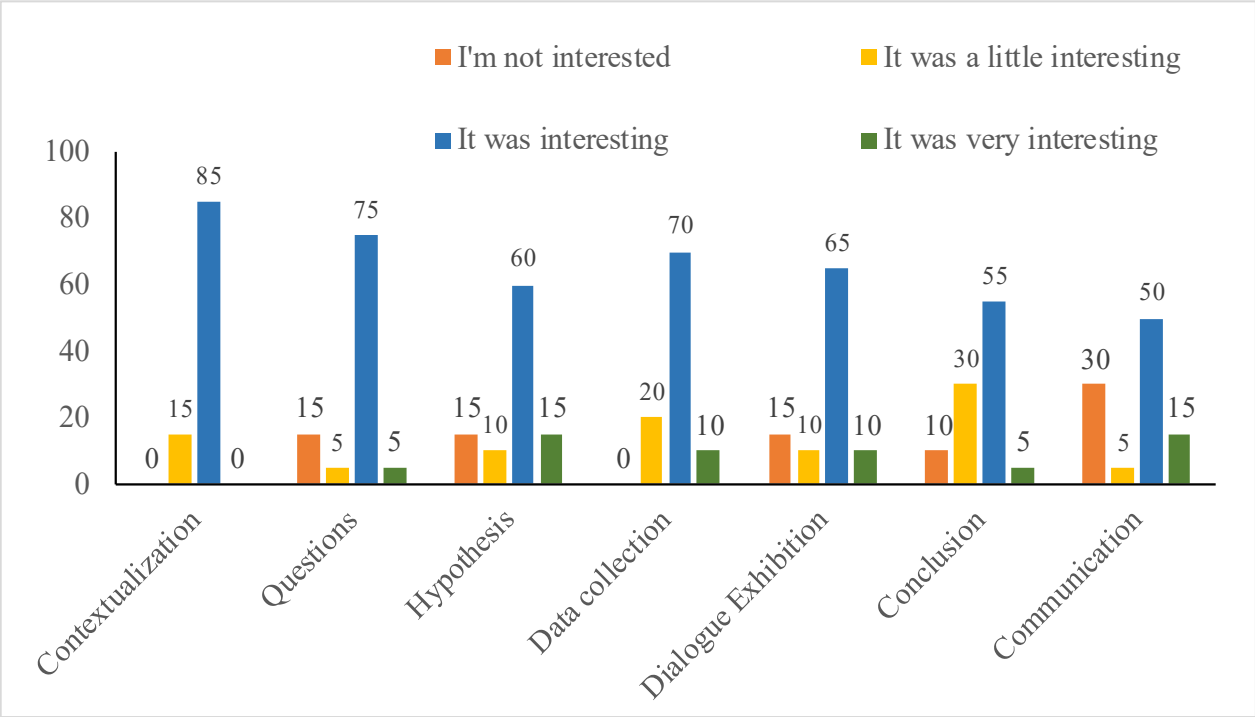
It can be stated that the causes of fires in the Pampas biome are related to agricultural practices, especially the use of fire for pasture clearing and land preparation for crops, as well as urban expansion and climate change (Berlinck& Lima, 2021;Pivello et al., 2021). The consequences include biodiversity loss, soil degradation, air pollution, and climate changes thatharm the quality of life of local populations. Mitigation measures involve adopting sustainable agricultural practices, intensifying environmental monitoring, implementing education and awareness programs, promoting ecological restoration initiatives, and encouraging sustainable economic alternatives.

Regarding environmental racism, the group confirmed the hypothesis that low-income populations are the most affected, as the most impacted areas are located far from urban centers. According to Cascio (2018) and Berlinck& Lima (2021), air pollution caused by fires has direct impacts on human health, such as an increase in respiratory diseases, especially among populations most exposed to the smoke.

Students' Perception of the IBLS Stages

Of the 30 students who participated in the IBLS, 20 responded to the perception questionnaire. Aged between 17 and 20 (12 girls and 8 boys), the students showed high interest (summing the categories "interesting" and "very interesting") in stages such as contextualization (85%), problematization (80%), hypothesis formulation (75%), and data collection (80%). The interactive lecture on Critical Environmental Education (CEE), environmental racism, and One Health was also well-received (75%). More complex stages, such as drawing conclusions (60%) and communication (65%), generated slightly less interest, though still positive (Fig. 2).

Figure 2 – Percentage of students' interest level in the stages of the Investigative Didactic Sequence



Source: Authors (2025).

The total absence of disinterest during the contextualization stage indicates that the images used aroused curiosity and connection with the students' realities. The most cited justifications were the broadening of knowledge and the appreciation of images (Table 6), in line with Aguiar (2010), who highlights the role of visual culture in engaging students and fostering their critical thinking.

During the problematization phase, students valued the focus on environmental, socio-environmental issues, and environmental racism (Table 6), aligning with the investigative learning approach advocated by authors such as Andrade (2011), Motokane (2015), and Sasseron (2024). The hypothesis formulation was well received, as it allowed for the mobilization of prior knowledge and reflections on social issues such as hunger and water scarcity (Table 6). However, some students (20%) reported difficulties with the investigative approach, preferring traditional methods, especially due to insecurity in formulating hypotheses (Table 6). According to Castellar (2016) and Roldi, Silva, and Trazzi (2018), hypothesis formulation is a fundamental stage as it stimulates the mobilization of prior knowledge and a reflective stance among students, although it may represent a challenge for those not yet accustomed to the autonomy and freedom required by this approach.

The data collection stage generated great interest (Fig. 2), attributed to the hands-on nature of the activity, knowledge expansion (45%), and the appreciation of mistakes as part of the learning process (Table 6), a perception that aligns with Carvalho (2018) and Sasseron (2015), who argue that mistakes offer students the opportunity to evaluate, critique, and validate the procedures and knowledge acquired throughout the investigation. Easeof internet access (30%) was also mentioned, highlighting its role as a pedagogical resource, as advocated by Kenski (2015).

The teacher's field journal indicated that students initially struggled to identify consequences and mitigation measures for environmental issues, especially during hypothesis formulation. However, throughout the IBLS, significant conceptual progress was observed, with greater appropriation of content and development of argumentation. These results highlight the importance of teacher mediation in guiding the

investigative process and validating the constructed evidence, as pointed out by Moreira, Souza, and Almassy (2015) and Scarpa and Campos (2018), who emphasize the role of the teacher as a facilitator of critical thinking, promoting student engagement and the construction of new knowledge.

Students showed interest in the expository-dialogued lesson, especially regarding the focus on socio-environmental problems and environmental racism (30%), the ease of understanding and idea exchange (25%), and the expansion of knowledge (15%) (Table 6). Moreover, students who were initially unfamiliar with the concepts of Critical Environmental Education (CEE), environmental racism, and One Health reported understanding them by the end of the lesson. During the conclusion stage, students valued data analysis (45%) and student protagonism (15%), recognizing the importance of verifying coherence between data and hypotheses. Still, 25% presented vague or absent responses, and 15% reported disinterest or difficulty. In the communication of results, 65% classified the activity as interesting or very interesting, while 35% showed little or no interest. The main reasons for appreciation were the importance of communication (40%) and knowledge expansion (30%) (Table 6). The teacher observed in the Field journal na initial reluctance from some groups to present their results due to shyness, which was later over come through collective dialogue.

These results suggest that the critical and contextualized approach to the lesson, as proposed by Layrargues and Lima (2014), favored engagement by highlighting the relationship between social inequality and environmental impacts. Students' understanding of the concepts reinforces the potential of the IBLS to promote Critical Environmental Education (CEE) and criticalthinking, as emphasized by Sasseron and Carvalho (2008) and Sasseron (2015, 2024). This conceptual advancement aligns with Carabetta (2022), who points out the challenges in appropriating scientific concepts in science education. The principles of CEE, in this sense, contribute to a more critical understanding of environmental inequalities (Costa; Sale; Mesquita, 2022).

Regarding the conclusion stage, data indicate student involvement with the scientific method, which reinforces the importance of student protagonism, but also highlights the challenges of this complex stage (seeTrivelato and Tonidandel, 2015). Despite initial resistance, the communication of results proved formative by promoting socialization, debate, and collective meaning-making—key aspects of the IBLS according to Scarpa and Campos (2018). The teacher'srole as a guide, adjusting the level of support based on the groups' autonomy, alongwith a final reflection on the investigative process, contributed to consolidating this stage as a moment of critical deepening. This aspect is essential in the investigative cycle, as highlighted by Carvalho (2018), as it breaks with the transmission-based logic and fosters the formation of individuals who are sensitive and intellectually prepared to deal with socio-environmental issues.

Table 6 – Emerging categories of students' perceptions of the stages of the Investigative Didactic Sequence. Percentages for each category are in parentheses, and sample responses are in quotation marks

Contextualization with images
1. Breadth of knowledge (55%)."We learned a little about everything"; "it talks about the Cerrado, which is a critical área, and the local conditions."
2. . Appreciation for contextualization through images (25%): "Working with images sparks my interest."
3. Vague answers (10%): "It was interesting, it was cool".
4. Disinterest and Difficulty (10%): "Because I don't remember much of it"; "I wasn't that interested because it wasn't that cool."
Guiding questions
1. Focus on environmental issues (35%): "We learned about environmental issues"; "Learn more about the issues".
2. No justificstion (25%): "yes"; "I didn't understand".
3. Focus on socioenvironmental issues and environmental racism (15%): "Things we don't usually think about, whether the issue affects humans in the same way"; "Environmental issues include droughts, water shortages, and also hunger".
4. Breadth of knowledge (10%): "Discovering more about something I knew nothing about"; "It made me curious and knowledgeable".
5. Emphasis on future environmental actions resulting from learning (10%): "It generates a larger movement of good deeds"; "We can show several examples for improving cities".

6. Valuing the guiding question (5%): "Besides being very direct, the question isalso very objective and well-explained."
Hypothesis raising
1. Appreciation of the hypothesis (50%): "Because it was a hypothesis without research"; "Because the hypothesis was correct". **2. Disinterest and difficulties (20%):** "Theoretical classes are easier for me"; "I wasn't interested because I don't understand". **3. Vague or absent answers (15%):** "It was cool"; "That's cool". **4. Focus on socioenvironmental (10%):** "We can think about how we can help them"; "It talks about hunger, lack of water, and living conditions". **5. Focus on environmental (5%):** "It was interesting to thing about the problems affecting this Braziliam vegetation".
Internet data collection
1. Extent of knowledge (45%): "If someone makes a mistake, they go online, and if they're wrong, you correct it. It's throung mistakes that you learn". **2. Ease of and access to the internet (30%):** "It's Always good to know how to research things on the internet"; "Everyone likes the internet" **3. Vague or absent response (15%):** "It wasn't very interesting"; "Because I really liked it". **4. Focus on socioenvironmental issues (5%):** "The data shows that animals die from lack of water and food because of the severe drought". **5. Disinterest (5%):** "Because there's a part of the research that isn't very interesting"
Dialogued presentation of the themes critical environmental education, environmental racismo and One Health
1. Focus on socio envirionmental issues and racism (30%): "There are several topics related to envirionmental education; this is very importante and brings many benefits to our lives." **2. Valuing the expository-dialogued class (25%):** "Dialogue is importante for all o fus to learn"; "The way the class was designed helped some points". **3. Vague or absent response (20%):** "Very cool"; "It was very good". **4. Breadth of knowledge (15%):** "To have a bater understanding"; "Because we can understand more about the subject". **5. Disinterest and Difficulty (10%):** "I think I whasn't interested, after all, I don't remember anything about it".
Preparation of conclucions
1. Data appreciation and relevance (45%): "To determine if the collected data is consistent with the hypothesis developed". **2. Vague or absent response (25%):** "Because I don't know"; "It was so-so". **3. Disinterest and difficulty (15%):** "Not very interesting because I liked it, but I don't remember much"; "I don't remember the topic" **4. Appreciation of protagonism (15%):** "It was very interesting ideas and opinions"; "It was a kind of summary of everything, what we concluded".
Communication of results
1. Value of communication (40%): "The communication was very interesting, allowing everyone to share their thoughts on the results"; "Because it was important for presenting the work, both individually and as a group" **2. Breadth of knowledge (30%):** "We can see not only our own work, but also that of the entire class"; "Because we learn more and know how to talk about the subject" **3. Disinterest and difficulty (25%):** "The presentation isn't good"; "Because I'm embarrassed" **4. Vague or absent response (5%):** "Because not"

Source: Authors (2025).

Final Considerations

The implementation of the Inquiry-Based Learning Sequence (IBLS) based on Critical Environmental Education (CEE) proved to be a suitable methodological approach to promote Critical Awareness (CA) regarding environmental imbalances in Brazilian vegetation, aligning with the proposal of emancipatory education. The three specific objectives proposed were achieved.

The first objective, related to the development of a IBLS addressing causes, consequences, and mitigation measures of ecological imbalances, was accomplished through the creation of a sequence structured in activities that enabled the discussion of ecological and socio-environmental concepts. This was achieved through problematization, hypothesis formulation, data collection, systematization, and communication of conclusions, all interwoven with critical discussions and reflections.

The second objective, aimed at assessing the potential of the IBLS to stimulate students' intellectual development, was evidenced by the progression between hypotheses and conclusions. It was observed that: (i) students expanded their understanding of the multiple causes of environmental problems, demonstrating an ability to move beyond generic explanations and recognizing structural factors such as agribusiness; (ii) concepts such as environmental racism and one Health emerged in their conclusions, highlighting the unequal impacts on vulnerable populations; and (iii) mitigation proposals evolved from punitive measures to educational actions and public policies.

The third objective, focused on fostering a critical stance towards environmental issues, was achieved through the engagement and autonomy demonstrated through out the different stages of the IBLS. Factors such as the relevance of the topics covered, the use of digital tools, and the emphasis on student autonomy were cited as motivating elements. Although students initially showed insecurity in formulating hypotheses and communicating results, this challenge was gradually overcome with teacher support and the understanding that mistake is also part of the learning process. We consider that expanding this practice to other content areas may streng then familiarity with the investigative approach and reduce initial disinterest and difficulties, allowing students to progressively develop skills such as autonomy, evidence-based argumentation, and scientific communication, turning initial challenges into opportunities for growth.

In addition to advances in student engagement and learning, the results of the pedagogical proposal demonstrate the potential of investigative-based CEE to fill gaps present in official documents such as the BNCC (Brazilian National Common Curricular Base). While such guidelines tend to address Environmental Education in a transversal and depoliticized manner, the critical approach adopted here promoted reflection on the structural causes of environmental imbalances, such as the hegemonic development model and its consequences for vulnerable populations. Thus, the experience contributed to highlighting the viability and necessity of critical and investigative pedagogical practices in Biology education, broadening the formative role of the schoolbeyond the prescribed curriculum toward emancipatory education.

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