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Urban Ecology and Socio-Environmental Problematization: contributions to scientific literacy

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A B S T R A C T

This study analyzes an Inquiry-Based Teaching Sequence (IBTS) in the context of urban ecology, integrating field investigation and critical analysis of socio-environmental media to foster scientific literacy in secondary education. The research adopts an interpretative approach and involved 26 students from a public school in Garanhuns, Pernambuco, Brazil. The instructional sequence comprised two integrated phases: a field-based ecological investigation and the analysis of a documentary on eucalyptus monocultures, followed by synthesis and argumentative writing activities. Data sources included field records, phytosociological tables, concept maps, and argumentative texts, analyzed through descriptive statistics and qualitative examination of student productions. Results indicate differences in species richness and floristic composition between the investigated areas, alongside a predominance of intermediate and advanced performance levels in tasks involving data interpretation, conceptual integration, and evidence-based argumentation. The findings suggest that scientific literacy develops as a gradual, non-linear process characterized by the integration of empirical data, multimodal representations, and socio-environmental discussion, with students progressively developing their interpretive and explanatory capacities. Combining field inquiry with socio-environmental media analysis enabled the circulation and recontextualization of evidence across different representational and discursive domains, supporting students' engagement with socio-environmental problematization and scientific reasoning. The study concludes that the IBTS promotes epistemic practices in science education — particularly data interpretation and scientific argumentation — and highlights the relevance of sustained inquiry-based approaches that integrate multimodal evidence in urban ecology teaching.

RESUMO

Este estudo analisa uma Sequência de Ensino Investigativo (SEI) no contexto da ecologia urbana, articulando investigação de campo e análise crítica de mídia socioambiental como estratégia para o desenvolvimento da alfabetização científica no Ensino Médio. A pesquisa, de natureza interpretativa, envolveu 26 estudantes de uma escola pública em Garanhuns, Pernambuco, Brasil, e foi organizada em duas etapas integradas: uma investigação ecológica em campo e a análise de um documentário sobre monoculturas de eucalipto, seguida de atividades de sistematização e produção argumentativa. Os dados foram constituídos por registros de campo, tabelas fitossociológicas, mapas mentais e textos argumentativos, analisados por estatística descritiva e análise qualitativa das produções estudantis. Os resultados indicam diferenças nos padrões de riqueza e composição florística entre as áreas investigadas, além de predominância de desempenhos intermediários e avançados nas atividades de interpretação de dados, integração conceitual e argumentação baseada em evidências. Observa-se que a alfabetização científica se desenvolve de forma gradual, marcada pela articulação entre dados empíricos, representações multimodais e discussões socioambientais, com progressiva ampliação da capacidade de interpretação e construção de explicações. A integração entre investigação de campo e análise de mídia favoreceu a circulação de evidências e a problematização de questões socioambientais. Conclui-se que a SEI promove práticas epistêmicas em Ciências, especialmente interpretação de dados e argumentação científica, reforçando a importância de abordagens investigativas contextualizadas e contínuas no ensino de Ecologia.

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Introduction

Biology education at the basic schooling level faces a persistent structural challenge: the predominance of expository, decontextualized approaches that dissociate scientific content from students' lived experiences and from the socio-environmental problems of their surroundings. In the field of Ecology, this dissociation is particularly limiting. It prevents ecological phenomena from being understood in their relational complexity — not as objects of description, but as processes situated in concrete territories, traversed by social, historical, and environmental tensions (El-Hani & Bizzo, 2002; Carvalho, 2013).

Overcoming this fragmentation requires approaches that coherently integrate empirical investigation, conceptual construction, and socioscientific problematization. Inquiry-Based Teaching (IBT) has been discussed as a pedagogical perspective capable of aligning classroom learning with the epistemic practices of science, fostering competencies such as data interpretation, hypothesis formulation, evidence-based argumentation, and reasoned decision-making (Azevedo, 2004; Carvalho, 2013; Sasseron, 2015). More than a methodology, IBT constitutes a way of organizing teaching so that students actively participate in constructing scientific explanations, rather than simply receiving ready-made ones.

This active participation is what the literature calls scientific literacy (SL) — understood here not as mastery of technical vocabulary, but as the capacity to read, interpret, produce, and evaluate evidence-based discourses across different social contexts (Norris & Phillips, 2003; Sasseron & Carvalho, 2011). In a broader perspective, scientific literacy also involves developing critical stances toward socioscientific issues: problems in which science, technology, society, and environment are inextricably intertwined (Hodson, 2014). Understood in this way, SL is not a fixed destination but a gradual process, dependent on specific pedagogical conditions and learning contexts that offer real problems to investigate.

Urban green environments are singularly relevant spaces for this kind of school-based investigation. Urban parks and green fragments enable connections between direct empirical observation, interpretation of ecological patterns, and local socio-environmental issues — bringing together, in the same physical space, concrete data, scientific concepts, and social problems (Araujo, Santana & Franzolin, 2023). When these environments carry a history of use associated with territorial occupation, the introduction of exotic species, and conflicts over natural resources, their educational potential is considerably expanded.

It is in this context that the Parque Municipal Euclides Dourado in Garanhuns, PE — known locally as the Parque dos Eucaliptos (Eucalyptus Park) — is situated. Originally established in the 1920s as a eucalyptus nursery to supply wood for the Great Western railway (Amador, 2012), the park condenses, in its very history, the logic of introducing exotic species in the service of economic modernization. Today, the predominant presence of species from the genus Eucalyptus constitutes a concrete local socio-environmental issue: its effects on spontaneous vegetation, water resources, and the park's ecological dynamics are open questions — questions that students can begin to investigate themselves.

Eucalyptus monocultures have been widely discussed in the literature under the metaphor of "green deserts," owing to the ecological simplification and biodiversity reduction associated with them (Meirelles & Calazans, 2006; Kröger, 2020). Beyond ecology, these monocultures involve disputes over land use, water availability, and conflicts with traditional communities — dimensions that expand their educational potential by linking ecological data to questions of socio-environmental justice (Zhouri, 2018). This articulation is precisely what distinguishes a school investigation into biodiversity from a socioscientific problematization: it is not enough to describe ecological patterns; one must understand the social and historical relations that produced them.

Against this backdrop, the present study analyzes how an Inquiry-Based Teaching Sequence (IBTS), developed in the context of urban ecology, mobilizes epistemic practices related to evidence interpretation, argumentation, and the construction of scientific explanations in secondary education. The IBTS combined two complementary entry points into the same problem: a quantitative ecological investigation conducted in the Parque dos Eucaliptos, and critical analysis of the documentary Desertos Verdes (Green Deserts), which situates forest monocultures at a national scale and discusses their socio-environmental impacts. This combination allowed different forms of evidence — field data, quantitative representations, multimodal records, and media discourses — to circulate and be recontextualized by students as they constructed explanations, constituting what this study calls the multimodal circulation of evidence in service of scientific literacy.

Theorical Framework

Scientific literacy as the theoretical axis of the study

Scientific literacy (SL) is the central conceptual axis of this study and is not limited to the acquisition of conceptual knowledge in the sciences. In its broader sense, it involves the capacity to understand, interpret, evaluate, and produce evidence-based discourses across different social contexts.

For Norris and Phillips (2003), scientific literacy is fundamentally a form of literacy in which reading and writing scientific texts are essential to participation in the social practices of science. Sasseron and Carvalho (2011) propose that SL can be understood through three structural axes: understanding of scientific concepts, understanding of the nature of science, and understanding of the relationships between science, technology, society, and environment.

Complementarily, Hodson (2014) emphasizes that scientific literacy involves developing critical stances and engaging in socioscientific practices, highlighting its formative and political character.

In this study, scientific literacy is treated as an analytical category, used to interpret the ways in which students mobilize ecological data, construct explanations, and connect scientific evidence to socio-environmental issues.

Urban ecology and the Parque dos Eucaliptos

The Parque Municipal Euclides Dourado presents, in its current spatial structure, ecological conditions that reflect its history of use. The predominance of Eucalyptus individuals in certain portions of the park creates distinct microenvironments, characterized by the accumulation of leaf litter, altered light availability in the understory, and possible modifications to soil physicochemistry. These differential conditions — between areas under direct eucalyptus influence and areas with predominantly spontaneous vegetation — constituted the empirical axis of the ecological investigation, offering students a concrete, situated problem to observe, compare, and interpret.

From an urban ecology perspective, green fragments such as the Parque dos Eucaliptos perform important ecosystem functions: microclimatic regulation, support for urban fauna, maintenance of ecological corridors, and contribution to local groundwater recharge. At the same time, the park's floristic composition results from economic and historical decisions, not spontaneous ecological dynamics, which makes its analysis pedagogically richer than that of preserved environments. Here, nature and history overlap in a visible, investigable way — and this overlap is what transforms the park into a genuine problem for science teaching, rather than merely a setting for illustrative fieldwork (Carvalho, 2013; Amador, 2012).

Ecological interactions and allelopathy in Eucalyptus

Ecological interactions among plants involve mechanisms of competition and chemical interference mediated by secondary metabolites (Taiz & Zeiger, 2013). Among these, allelopathy stands out: the release of substances capable of influencing the germination and development of neighboring species (Anaya, 1999). Studies indicate that Eucalyptus species may produce compounds associated with altered plant regeneration in areas under their influence (Hussain et al., 2020; Ferreira et al., 2019).

In this study, allelopathy-related concepts were not used as proven causal explanations for the observed ecological patterns. Instead, they served as a theoretical framework for interpreting explanatory hypotheses spontaneously formulated by students during the investigation — particularly in discussions about leaf litter, the distribution of spontaneous vegetation, and water availability.

The emergence of these hypotheses was understood as a manifestation of epistemic practices characteristic of Inquiry-Based Teaching: empirical observation, causal inference, and the elaboration of provisional explanations. Rather than experimentally validating specific ecological mechanisms, the investigative proposal sought to foster scientific problematization and the development of hypothetical reasoning in a school context.

Forest monocultures and “green deserts”

Monocultures of exotic tree species – especially *Eucalyptus* – are often described as "green deserts" due to ecosystem structural simplification and the reduction of biological diversity associated with them (Meirelles & Calazans, 2006; Kröger, 2020). Although economically significant — particularly in cellulose and charcoal production — these systems involve socio-environmental trade-offs that purely economic analysis fails to capture.

Key effects include biodiversity reduction, alterations in the hydrological cycle, soil depletion, and reduced water availability (Kröger, 2020; FAO, 2020). These systems can also generate socio-environmental conflicts related to land use and the distribution of natural resources (Zhouri, 2018), reinforcing the need for critical, integrated approaches to their analysis.

Methodology

Research design and characterization

This investigation is characterized as mixed-methods descriptive research, configured as a pedagogical experience report conducted in a basic schooling context. The study combines quantitative procedures for systematizing students' investigative performance with qualitative procedures for analyzing student productions, discursive interactions, and interpretations constructed throughout the didactic intervention.

The study is grounded in the principles of Inquiry-Based Teaching (IBT), understood as a pedagogical approach that fosters science learning through problematization, hypothesis formulation, data production and interpretation, evidence-based argumentation, and the construction of scientific explanations (Azevedo, 2004; Carvalho, 2013; Sasseron, 2015).

The research design sought to understand how students mobilized empirical observations, ecological data, scientific representations, and socio-environmental issues within an IBTS developed in the context of Urban Ecology. The IBTS constitutes the structuring didactic device of the intervention, described in detail below; subsequent analyses focus on the productions and interactions arising from it.

The investigation was developed with a single first-year secondary education class, without a control group and without a standardized pre- or post-test, since the objective was not to measure learning gains but to analyze processes of knowledge production, data interpretation, and scientific argumentation in an investigative context.

Quantitative procedures served a descriptive and complementary function relative to the qualitative analysis, given the pedagogical nature of the investigation and the small number of participants. The research respected the ethical principles applicable to school-based studies, ensuring the anonymity and confidentiality of all analyzed productions.

Context, participants, and investigative sequence

The study was developed with 26 first-year secondary education students from a state public school in Garanhuns, within the framework of the Scientific Investigation Curricular Unit of the New Secondary Education model of the Pernambuco State Education Network. The intervention took place between August and October 2022, encompassing activities related to Ecology and Environmental Education.

The proposal was developed over nineteen fifty-minute classes, distributed between classroom activities and field investigation at the Parque Municipal Euclides Dourado. The site was selected because it presents areas with eucalyptus leaf litter alongside areas with predominantly spontaneous vegetation, enabling ecological comparison by students.

During the initial phase of the investigative sequence, students raised spontaneous questions about the ecological characteristics of the investigated environment and their lived experiences in the local community. Among those that stood out: "*Could the smell of eucalyptus leaves have something to do with fewer plants growing in Area 1?"; "I live nearby... My father dug a well and no water came out. Could the eucalyptus trees have something to do with that?"; and "If eucalyptus is not a Brazilian plant, why not replace it with native trees like ipê and pau-brasil?" Questions about ecological competition also emerged: "What advantage does eucalyptus gain from preventing other plants from growing?"* These questions came to guide many of the hypotheses and discussions developed throughout the investigation.

Prior to the classroom activities, the teacher-researcher conducted a reconnaissance of the study area, a preliminary survey of spontaneous vegetation, and organized the pedagogical instruments used in the sequence. The botanical survey was supported by the applications iNaturalist, PlantNet, PlantSnap, and PictureThis, in addition to specialized literature in Botany and Plant Ecology. Based on this information, a simplified botanical identification guide was prepared for use during fieldwork.

The IBTS was organized into two articulated phases. The first focused on a quantitative ecological investigation of spontaneous vegetation in areas with and without eucalyptus leaf litter. Students participated in observation, species identification, data recording, and analysis of ecological parameters related to plant biodiversity.

The second phase focused on the socio-environmental analysis of forest monocultures, involving discussion of the documentary *Desertos Verdes*, construction of mind maps, and production of argumentative texts on the environmental and social impacts of the eucalyptus monoculture model.

The general organization of the IBTS is presented in Table 1.

Table 1.

Summary of the Inquiry-Based Teaching Sequence in Urban Ecology

Phase	Student activities	Teacher's role	Pedagogical objective
Planning and preparation	—	Reconnaissance of the area, botanical survey, and preparation of the identification guide	Organize the investigative space and instruments
Initial problematization	Discussion of differences between areas with and without eucalyptus, and hypothesis formulation	Mediation of investigative questions	Introduce the ecological problem
Field investigation	Observation, identification, and recording of plant species	Field guidance and technical support	Develop observation and data collection skills
Systematization and ecological analysis	Organization of tables, ecological calculations, and interpretation of results	Conceptual mediation and data analysis	Relate empirical data and ecological concepts
Socio-environmental discussion	Analysis of the documentary *Desertos Verdes* and debate on the impacts of monocultures	Contextualization and problematization	Integrate ecological and social dimensions
Conceptual systematization	Construction of mind maps and summary tables	Support for organizing ideas	Articulate scientific and socio-environmental concepts
Argumentative production	Elaboration and sharing of argumentative texts	Evaluation and final mediation	Develop evidence-based argumentation

Note: Elaborated by the authors

Field ecological investigation

The ecological investigation was conducted in two areas located in the western portion of the Parque Municipal Euclides Dourado. Area 1 contained individuals from the genus *Eucalyptus* and accumulated leaf litter; Area 2 did not present these characteristics to any significant degree.

Each area covered 60 m² and was subdivided into three 20 m² plots (10 m × 2 m), delimited with ropes. Students were organized into groups of four to five members to observe, identify, and record spontaneous plant species present in the sample plots.

The number of individuals per species, frequency of occurrence, spatial distribution, and floristic composition were recorded, then organized into phytosociological tables for analysis.

The phytosociological parameters used in the investigation are systematized in Table 2. Their presentation prior to the analysis procedures makes the quantitative framework transparent, allowing the reader to follow the criteria that guided both data collection and student interpretation.

Quantitative analysis included classical parameters of plant community ecology, such as frequency, abundance, density, and species richness (Mueller-Dombois & Ellenberg, 1974). Alpha diversity was estimated using the Margalef Index (Magurran, 2011), and floristic similarity between areas was assessed using the Sørensen Index (Silva, Matos & Ferreira, 2008).

Table 2.

Characterization of phytosociological parameters used in the study

Indicator	Definition
f (absolute frequency)	Values representing the number of individuals.
Xi (relative frequency)	Ratio between absolute frequency and total number of individuals (fi / Σfi).
fi% (relative percentage frequency)	Relative frequency expressed as a percentage (fi / Σfi × 100).
S (species richness)	Number of species found in the study area.
AA (absolute abundance)	Total number of individuals of a species.
AR (relative abundance)	Proportion of the number of individuals of a species relative to the community total.
D (density)	Number of individuals of a species per unit of sampled area.
Species–area curve	Graph relating the number of species to the increase in sampled area.

Note: Adapted from Mueller-Dombois and Ellenberg (1974).

Socio-environmental analysis of the "green deserts"

The second phase of the investigative sequence focused on the socio-environmental impacts of eucalyptus monoculture. The documentary used was Desertos Verdes: plantações de eucalipto, agrotóxicos e água (Green Deserts: eucalyptus plantations, pesticides, and water), produced by the Center for Studies and Research for the Development of the Extreme South of Bahia (CEPEDES).

After viewing the documentary, students conducted teacher-guided critical analysis activities, identifying environmental, social, and economic problems related to the expansion of forest monocultures. Groups then organized summary tables and mind maps articulating biodiversity, use of natural resources, socio-environmental conflicts, and impacts on traditional communities.

The documentary analysis was structured around thematic excerpts that guided classroom discussion. The material addresses the expansion of eucalyptus monocultures over areas of Atlantic Forest, the productive model oriented toward cellulose export, and the high consumption of natural resources. It also covers pesticide use, health and environmental impacts, land concentration, and conflicts with traditional communities. The documentary further highlights biodiversity reduction, the technological intensification of production, and the contradictions between economic development and environmental sustainability.

As a final activity, students individually produced an argumentative essay on "The impact of green deserts on society and the environment," integrating the scientific knowledge developed throughout the investigative sequence.

Assessment procedures

Learning assessment was procedural and formative throughout the IBTS, encompassing conceptual, procedural, and attitudinal dimensions, in line with science assessment perspectives oriented toward the development of scientific competencies (Zabala, 1998).

In the conceptual dimension, assessment considered understanding of ecological concepts, data interpretation, and the construction of evidence-based explanations. In the procedural dimension, field record organization, data systematization, ecological calculations, and the elaboration of graphic representations were observed. In the attitudinal dimension, engagement, collaboration, investigative autonomy, and participation in collective activities were analyzed.

Assessed productions included field records, systematization tables, mind maps, ecological data interpretations, and argumentative texts, constituting the corpus of learning analysis throughout the intervention.

Assessment criteria and classification of investigative performance

Student performance was analyzed using rubrics aligned with the IBTS objectives and the principles of Inquiry-Based Teaching, addressing competencies related to scientific observation, data interpretation, conceptual mobilization, and argumentation.

Performance was classified into three levels — basic, adequate, and advanced — defined according to the degree of conceptual appropriation and the complexity of student responses. For descriptive systematization, levels were converted to an ordinal scale (1 = basic; 2 = adequate; 3 = advanced), enabling integration of qualitative and quantitative analysis.

Assessment criteria were adapted to the specificities of each IBTS phase. In the ecological investigation, priority was given to observation procedures, record organization, and interpretation of ecological patterns. In the socio-environmental analysis and argumentative production phase, emphasis was placed on argumentative coherence, conceptual articulation, and the use of scientific evidence in problematizing the issues discussed.

Table 3.

Classification criteria for investigative performance in the IBTS activities

Level	**Ecological investigation**	**Socio-environmental analysis and argumentative production**
Basic	Partially identifies species and organizes data with inconsistencies. Interpretations remain descriptive and poorly articulated with ecological concepts.	Presents superficial descriptions of the documentary, with limited argumentation and little use of scientific evidence.
Adequate	Organizes records functionally, recognizing basic relationships between species richness, density, and distribution.	Partially articulates ecological and socio-environmental concepts, using some evidence to support arguments.
Advanced	Organizes and interprets data systematically, articulating ecological concepts and elaborating grounded explanations.	Integrates information from the documentary and field investigation, constructing consistent arguments and articulated critical analyses.

Note: Elaborated by the authors.

Data treatment and analysis

Data produced throughout the IBTS were organized through complementary quantitative and qualitative procedures, combined in a triangulation process across different sources of evidence.

Quantitative data were analyzed using descriptive statistics, with absolute and relative frequencies applied to student performance levels on an ordinal scale (1 = basic; 2 = adequate; 3 = advanced). Phytosociological parameters and ecological indices related to the composition of the investigated vegetation were also systematized. Given the small number of participants and the pedagogical nature of the investigation, inferential statistical tests were not employed.

Qualitative analysis followed the principles of Content Analysis (Bardin, 2016), with a corpus comprising field records, ecological tables, mind maps, investigative discussions, and argumentative texts. The analytical process involved coding of recording units and grouping into analytical categories related to ecological observation, causal inference, evidence-based argumentation, and socio-environmental problematization.

To ensure the reliability of the categorization process, an intra-rater reliability procedure was applied to student interpretive and representational productions (mind maps, ecological interpretation activities, documentary analysis, and argumentative texts). The field ecological investigation was excluded from this procedure, as it consisted of direct technical observation and measurement records.

Productions were re-evaluated at two distinct moments, with a two-week interval, using the same criteria and rubrics. Agreement between classifications was estimated using Cohen's Kappa coefficient ($\kappa \approx 0.80$), indicating substantial agreement according to Landis and Koch (1977), which confers stability to the categorization process.

Triangulation across the ecological investigation, student productions, and documentary analysis enabled examination of relations of convergence and complementarity among different forms of representation and interpretation, evidencing how students articulated empirical data, scientific representations, and socio-environmental discourses in the construction of explanations throughout the IBTS.

Results and Discussion

This section integrates ecological data, student productions, and theoretical analysis across four articulated axes. The findings are presented in dialogue with the literature so as to progressively build the central argument of the study, avoiding separate description of results followed by their repetition in discussion.

The results indicate that the IBTS fostered skills related to scientific observation, data interpretation, comparison of evidence, and the elaboration of grounded explanations. Throughout the activities, students mobilized different forms of evidence — field ecological records, phytosociological tables, graphs, a socio-environmental documentary, and textual productions — with variation in the level of organization and systematization of information.

Ecological patterns of the investigated areas

The ecological investigation was conducted in two sample areas of the Parque Municipal Euclides Dourado, differentiated by the presence of Eucalyptus individuals and by accumulated leaf litter. Comparing these areas constituted the empirical axis of the investigative activity.

The phytosociological data reveal differences in the structural patterns of spontaneous vegetation between the two areas. Area 1 showed lower species richness (S = 16) and lower individual density, while Area 2 recorded greater floristic richness (S = 30), greater total abundance, and greater relative density. The Margalef Index confirmed greater relative species richness in Area 2 (d = 4.16) compared to Area 1 (d = 2.28). The Sørensen Index (Cs = 0.71) indicated moderate floristic similarity between the areas.

The main phytosociological parameters are presented in Table 4.

Table 4.

Phytosociological parameters and ecological indices of the investigated areas

Variable	Area 1	Area 2
Number of species (S)	16	30
Number of individuals (N)	464	1,072
Exclusive species	2	16
Common species	14	14
Density (ind./m²)	7.73	17.86
Margalef Index (d)	2.28	4.16
Sørensen Index (Cs)	—	0.71

Note: Research data.

The detailed floristic composition, with species distribution across sample quadrants and variations in frequency and abundance, is presented in Table 5.

Table 5.

Absolute frequency and distribution of plant species recorded in the sample areas of the Parque Municipal Euclides Dourado (Garanhuns – PE)

Botanical family	Species	Area 1 (60 m²)	Area 2 (60 m²)	Σ Species	Σ Family
Asteraceae	*Ageratum conyzoides*	33	51	84	669
	Bidens alba	0	10	10	
	Bidens pilosa	0	14	14	
	Conyza bonariensis	0	27	27	
	Emilia fosbergii Nicolson	0	38	38	
	Galinsoga sp.	0	27	27	
	Gamochaeta pensilvanica	208	144	352	
	Parthenium hysterophorus	0	10	10	
	Soliva anthemifolia	25	71	96	
	Tridax procumbens	0	11	11	
Amaranthaceae	*Amaranthus spinosus*	5	8	13	28
	Amaranthus viridis	4	11	15	
Apiaceae	*Cyclospermum leptophyllum*	8	5	13	13
Boraginaceae	*Cardamine occulta*	0	16	16	70
	Heliotropium indicum	0	4	4	
	Lepidium virginicum	41	9	50	
Caryophyllaceae	*Drymaria cordata*	20	222	242	242
Commelinaceae	*Callisia repens*	2	3	5	132
	Commelina benghalensis	4	24	28	
	Commelina diffusa	0	38	38	
	Commelina erecta	47	14	61	
Cyperaceae	*Cyperus* sp.	4	5	9	9
Euphorbiaceae	*Euphorbia heterophylla*	0	13	13	30
	Euphorbia hirta	3	14	17	
Hypoxidaceae	*Hypoxis decumbens*	0	6	6	6
Phyllanthaceae	*Phyllanthus niruri*	0	38	38	38
Rubiaceae	*Borreria verticillata*	3	26	29	267
	Mitracarpus hirtus	0	103	103	
	Richardia grandiflora	30	105	135	
Solanaceae	*Solanum americanum*	5	5	10	10
Urticaceae	*Pilea hyalina*	3	0	3	22
	Pilea microphylla	19	0	19	
Total		**464**	**1,072**	**1,536**	**1,536**

Note: Phytosociological survey in two 60 m² units, comparing Area 1 (under the influence of Eucalyptus leaf litter) and Area 2 (spontaneous vegetation). Source: Research data

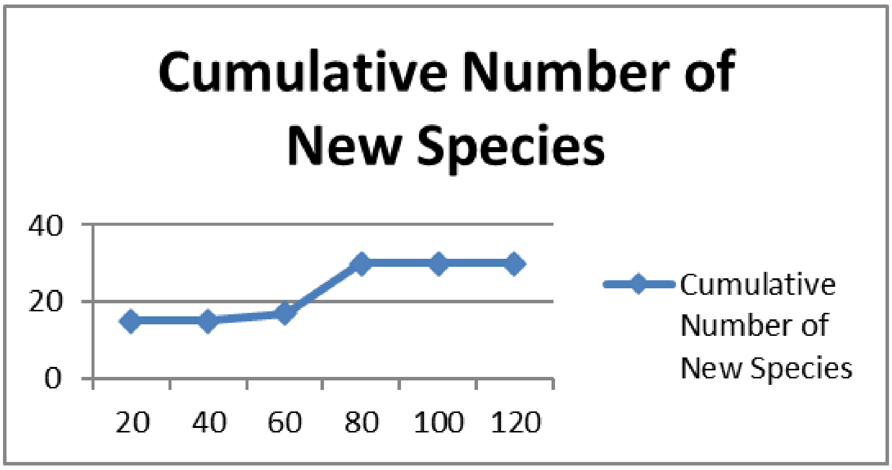
These patterns are consistent with what the literature describes in forest systems dominated by exotic species: environmental homogenization can reduce microstructural heterogeneity and limit the regeneration of herbaceous species (Meirelles & Calazans, 2006; Kröger, 2020). The lower representation of families such as Rubiaceae, Commelinaceae, and Caryophyllaceae in Area 1 — including species such as Mitracarpus hirtus (103 individuals found exclusively in Area 2) and Drymaria cordata (222 individuals in Area 2, compared to 20 in Area 1) — suggests that floristic composition reflects the distinct microenvironmental conditions between the areas.

These results do not authorize direct causal inferences. The absence of soil physicochemical analyses and experimental control prevents attribution of the observed patterns to specific mechanisms, such as allelopathy — discussed in the literature as a possible factor in interactions involving Eucalyptus (Anaya, 1999; Ferreira et al., 2019) — but not verifiable from school observational data alone.

The species-area curve showed a trend toward stabilization with increasing sampled area, indicating that the sampling effort was adequate for characterizing the plant communities in a school investigation context.

Graph 1.

Species-area curve Cumulative number of species as a function of cumulative sampled area (m²) in the investigated areas of the Parque Municipal Euclides Dourado



Graph: Source: Research Data

From an ecological standpoint, the results should be read with caution. The Sørensen Index (Cs = 0.71) indicates moderate floristic similarity between the areas, suggesting that the factors differentiating the plant communities are not drastic enough to produce radically distinct compositions — which is to be expected in fragmented urban environments, where propagule dispersal between nearby areas tends to partially homogenize the spontaneous flora. The lower richness and density in Area 1 may be associated with multiple microenvironmental factors — light availability, soil structure, moisture — rather than any single causal mechanism.

The distinction between the two areas created a rare condition in school investigations: the possibility of situated empirical comparison, with data collected by the students themselves. This transformed the park into a problem, not merely a setting — a dimension that distinguishes Inquiry-Based Teaching from merely illustrative fieldwork (Carvalho, 2013).

Epistemic practices in student productions

The investigative sequence generated different types of student productions — field records, ecological tables, mind maps, documentary interpretations, and argumentative texts — that evidence distinct forms of evidence mobilization and organization throughout the activities.

In the ecological investigation, variation was observed in the level of organization and systematization of field records. Some students produced complete, standardized tables, while others presented partial records or inconsistencies in species categorization and individual counts.

In ecological interpretation activities, some productions remained predominantly descriptive, limited to enumerating species and directly comparing areas. In other cases, students began to establish relationships among floristic richness, the presence of leaf litter, and vegetation distribution, suggesting the emergence of initial interpretations grounded in empirical data. This transition from description to explanation corresponds to what Sasseron and Carvalho (2011) call indicators of scientific literacy — capacities such as data serialization, organization, and classification that precede the elaboration of more structured arguments.

One of the most significant findings of the sequence lies not in the ecological data themselves, but in the questions they generated. Questions such as "*Could the smell of the leaves have something to do with fewer plants growing here?*" or "*My father dug a well nearby and no water came out — could the eucalyptus trees be connected to that?"* are not conceptual errors to be corrected. They are manifestations of nascent hypothetical-deductive reasoning, sustained by direct observation and lived experience.

This type of formulation corresponds to what the science education literature identifies as epistemic practices inherent to school scientific investigation: the production of provisional explanatory hypotheses based on observed patterns (Driver, Newton & Osborne, 2000; Lederman, 2007). What distinguishes a legitimate epistemic practice from an erroneous response is not whether the hypothesis is correct, but the relationship the student establishes between evidence and explanation. In this sense, the question about the leaf litter's odor is epistemically more sophisticated than a correct answer copied from a text, because it involves inference from concrete data.

Pedagogical mediation was decisive in this process. Treating these hypotheses as starting points for deeper inquiry — rather than as errors to be eliminated — is what characterizes the teacher's role in IBT, and what allowed hypothetical reasoning to develop throughout the sequence rather than being prematurely interrupted (Azevedo, 2004).

The distribution of performance levels across assessed activities is presented in Table 6.

Table 6.

Distribution of students by performance levels in the investigative activities

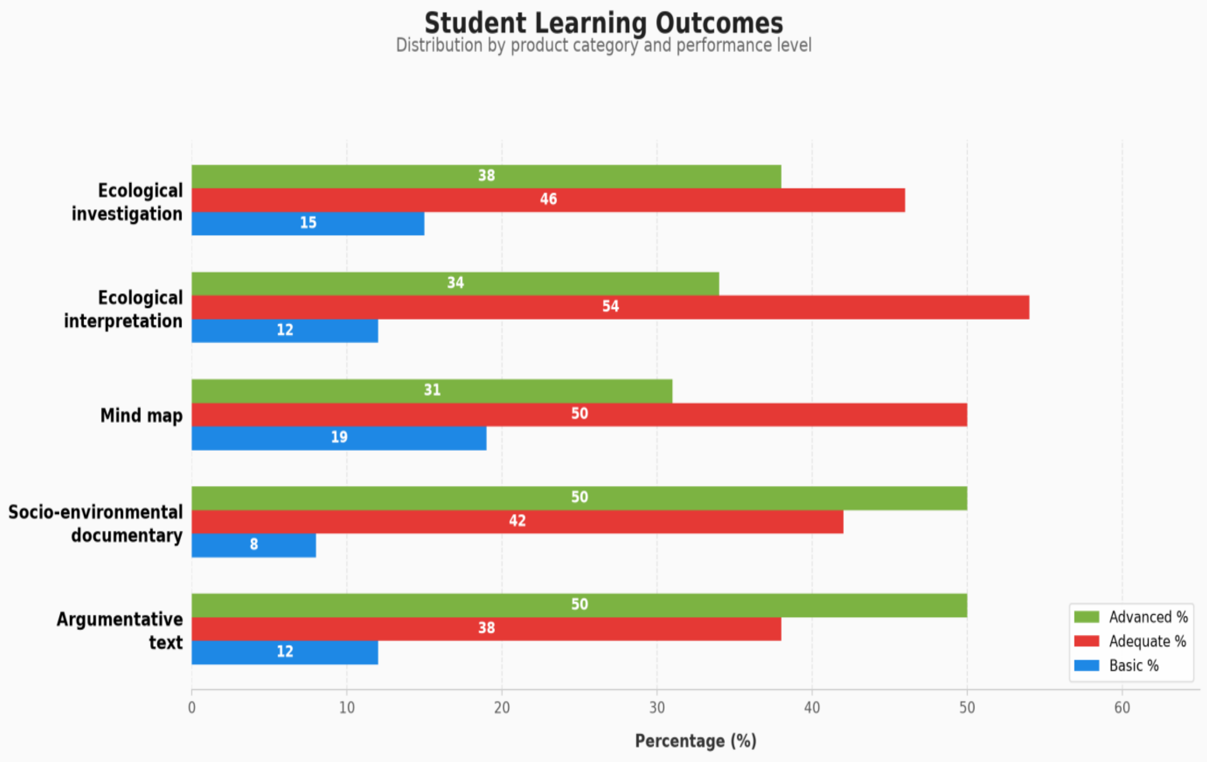
Activity	Basic n (%)	Adequate n (%)	Advanced n (%)
Ecological investigation	4 (15.4%)	12 (46.2%)	10 (38.5%)
Ecological interpretation	3 (11.5%)	14 (53.8%)	9 (34.7%)
Mind map	5 (19.2%)	13 (50.0%)	8 (30.8%)
Socio-environmental documentary	2 (7.7%)	11 (42.3%)	13 (50.0%)
Argumentative text	3 (11.5%)	10 (38.5%)	13 (50.0%)

Note: Performance levels defined by categorical rubrics (1 = basic; 2 = adequate; 3 = advanced), with intra-rater reliability coefficient κ ≈ 0.80 (Landis & Koch, 1977). Source: Research data.

The distribution shows a predominance of adequate and advanced performances across the five assessed activities, with the lowest proportion of basic performances recorded in documentary analysis (7.7%) and written production (11.5%). This pattern suggests that activities requiring integration across multiple sources and argumentative positioning more effectively mobilized students' interpretive capacities than ecological recording and systematization tasks did.

Graph 2.

Distribution of student performance levels by investigative activity (n = 26)



Graph: Source: Research data.

Scientific argumentation and the circulation of evidence

In the final argumentative production, relevant qualitative differences emerged. Basic-level texts described the impacts of eucalyptus based solely on information from the documentary, without drawing on field investigation data. Advanced-level texts, by contrast, articulated empirical evidence from the phytosociological tables with audiovisual information and ecological concepts discussed throughout the sequence — approaching what Norris and Phillips (2003) describe as the use of scientific reading for the active construction of meaning, not merely information extraction.

The progression in performance levels across IBTS activities is not uniform. The highest performance occurred precisely in activities requiring greater integration — documentary analysis and argumentative text production — rather than in ecological recording and systematization, which might be considered more elementary as they involve concrete data.

This pattern suggests that the central epistemic challenge for students lay not in collecting or organizing data, but in recontextualizing it: using field evidence to sustain arguments about socio-environmental problems at a larger scale. When this occurred — in texts that connected phytosociological data to documentary information — it produced the kind of argumentation that Norris and Phillips (2003) describe as scientific reading in its fullest sense: not mere information extraction, but the active construction of a position from multiple sources.

Combining the field investigation with the documentary *Desertos Verdes* was the device that made this circulation possible. The documentary did not function as a replacement for, or merely a thematic complement to, empirical investigation — it functioned as a second entry point into the same problem, at a different scale. Students who had already observed differences in floristic richness between contiguous areas in the park found, in the documentary, a narrative that gave social and political meaning to those differences. This scale-expansion movement is central to socioscientific problematization (Hodson, 2014; Zhouri, 2018).

This expansion — from local data to socio-environmental problems at a national scale — was only possible because the different representational forms mobilized throughout the IBTS did not operate as independent didactic resources. Field records, phytosociological tables, graphs, mind maps, the audiovisual documentary, and argumentative texts functioned as complementary modes of constructing and circulating evidence: each opened a distinct entry point to the same problem, and the passage between them was the movement through which students progressively broadened and deepened their explanations.

Multimodal circulation of evidence and construction of meaning

The different representational forms mobilized throughout the IBTS — field records, phytosociological tables, graphs, mind maps, textual productions, and the audiovisual documentary — did not operate as independent didactic resources, but as complementary modes of constructing and circulating evidence. This perspective resonates with multimodal science education, which understands different semiotic systems as meaning-making resources that structure distinct forms of apprehension of phenomena (Kress & van Leeuwen, 2006; Tytler, Prain & Hubber, 2013).

Mind maps illustrate this process particularly clearly. While some productions showed a linear structure — listing concepts without articulating them — others revealed connections among biodiversity, monoculture, the hydrological cycle, and social impacts, indicating more elaborate conceptual integration. This variation reflects not only individual differences in ability, but the nature of the instrument itself: a mind map requires students to select, hierarchize, and relate information from distinct sources, a cognitive operation that goes well beyond content transcription.

Figure 1.

Example of a mind map elaborated by a student (advanced performance level)

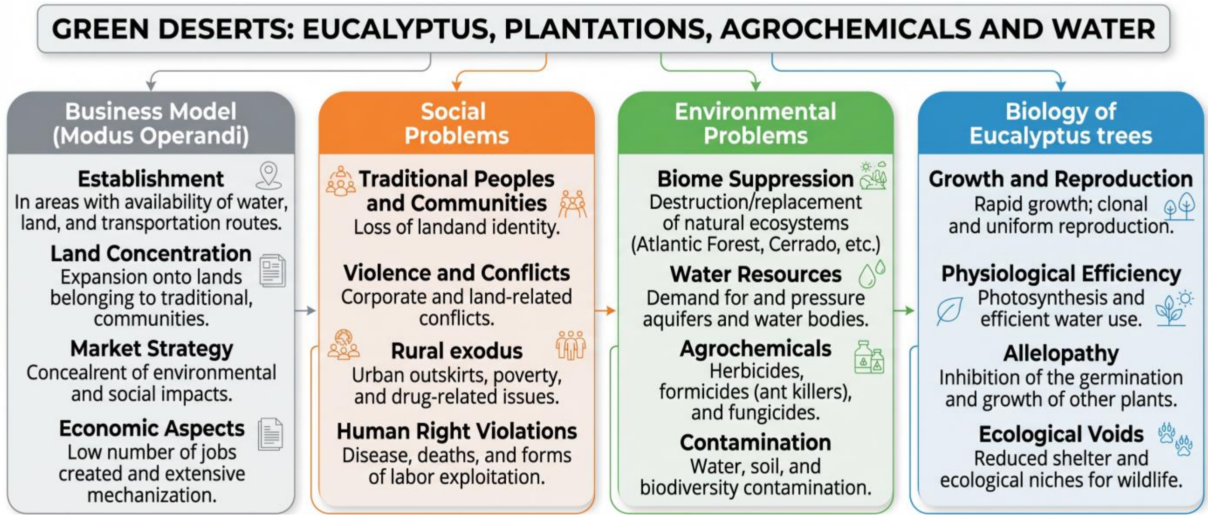


Figure: Source: Research archive (identification suppressed to preserve anonymity).

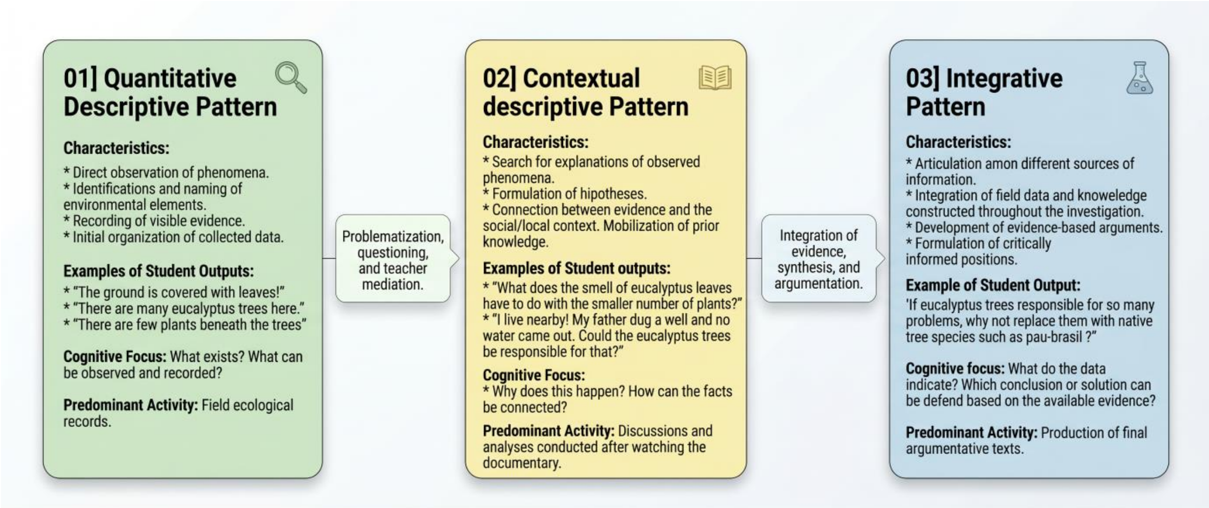
The documentary *Desertos Verdes* fulfilled a distinct function from the other representations. Whereas field records and tables anchored the investigation in situated, local data, the documentary expanded students' interpretive repertoire to larger-scale contexts: the expansion of monocultures over the Atlantic Forest, land conflicts, and impacts on traditional communities. This recontextualization movement — carrying local evidence into dialogue with broader issues — is central to scientific literacy in its socioscientific dimension (Hodson, 2014; Zhouri, 2018).

Three patterns of scientific reasoning organization were identified in student productions: a descriptive-quantitative pattern, predominant in ecological records; an interpretive-contextual pattern, more frequent in activities related to the documentary; and an integrative pattern, present in argumentative texts that articulated both phases of the sequence. The transition between these patterns did not occur spontaneously; it was strongly mediated by activity structures and teacher intervention — which reinforces that scientific literacy is a social practice dependent on specific pedagogical conditions, not a skill that naturally emerges from exposure to data (Azevedo, 2004; Carvalho, 2013).

These three patterns do not represent fixed stages of cognitive development, but modes of reasoning organization that coexisted in student productions and alternated according to activity type and the degree of available pedagogical mediation. The descriptive-quantitative pattern predominated in field ecological records, where the central task was to name, count, and organize. The interpretive-contextual pattern emerged more frequently in documentary-related activities, when students needed to establish relationships between data and broader contexts. The integrative pattern appeared mainly in the final argumentative texts, where connecting both IBTS phases was a necessary condition for constructing a consistent argument.

Figure 2.

Patterns of scientific reasoning organization identified in student productions throughout the IBTS



[Figure: Source: Elaborated by the authors based on the analytical categories of the research.]

Methodological limitations and pedagogical implications

The adopted design presents limitations that should be considered when reading the results. Ecologically, the data reflect a single time point and a reduced spatial scale — compatible with school investigations, but insufficient to support claims about broader urban vegetation dynamics. The absence of soil physicochemical analyses and experimental control prevents verification of specific ecological mechanisms, keeping causal interpretations at a hypothetical level — which, it should be noted, is epistemically appropriate to the context.

Methodologically, the use of intra-rater reliability ($\kappa \approx 0.80$) ensures internal consistency of the analytical categories. The absence of independent rater validation is acknowledged as a limitation and points to the need for future research with more robust inter-rater reliability procedures. The single-class experience report design — without a control group or standardized pre/post-test — is consistent with the study's declared objectives (analyzing processes, not measuring gains), but limits the possibility of systematic comparisons.

Pedagogically, the results indicate that the development of epistemic practices — especially data interpretation and evidence-based argumentation — demands continuity and curricular progression. Isolated interventions, however well-structured, produce partial and heterogeneous advances. The IBTS described here constitutes a promising pedagogical device, but its formative potential depends on its being embedded in more extensive learning trajectories, in which students have recurring opportunities to engage with contextualized investigative problems.

The proposal also presents specific implementation conditions that are not always available in Brazilian public schools: extended teaching time, access to urban green spaces, availability of digital botanical identification tools, and detailed sequential planning. These conditions directly influence the quality of investigative practices and must be considered in proposals for replication or adaptation of the sequence.

Conclusion

This study analyzed an Inquiry-Based Teaching Sequence (IBTS) in urban ecology that combined field investigation and critical analysis of socio-environmental media to promote scientific literacy in secondary education.

The results indicate that the proposal fostered the mobilization of epistemic practices related to observation, ecological data interpretation, comparison of evidence, and the construction of grounded arguments. Adequate and advanced performances predominated, particularly in activities demanding integration across empirical data, graphic representations, and argumentative production.

Field investigation enabled the production of situated ecological data, subsequently mobilized in the analysis of the documentary *Desertos Verdes*. This process supported connections between local observations and broader socio-environmental discussions, expanding opportunities for interpreting the studied phenomena.

The findings suggest that scientific literacy develops in a gradual, non-linear manner, involving the transition from initial descriptions to more elaborated forms of evidence-based interpretation and argumentation. This process depended on teacher mediation and the organization of investigative activities — especially in articulating the conceptual, procedural, and socioscientific dimensions of learning.

Pedagogically, the results reinforce the potential of investigative approaches in urban ecology, integrated with socio-environmental media analysis, for engaging students in school scientific practices. Combining fieldwork with socioscientific problematization proved relevant for expanding opportunities for interpretation, argumentation, and the construction of scientific meaning.

Theoretically, the results contribute to discussions of scientific literacy in its multimodal dimension. The circulation of evidence across different representation systems — field records, phytosociological tables, graphs, mind maps, the audiovisual documentary, and argumentative texts — was not an accessory didactic resource, but the central mechanism through which students constructed progressively more elaborate explanations. Each mode of representation opened a distinct entry point to the same problem; moving between them enabled the recontextualization of local evidence into arguments about socio-environmental issues at a broader scale. This perspective suggests that the development of epistemic practices in urban ecology depends not only on the quality of field data, but on the pedagogical conditions that allow those data to circulate, be reinterpreted, and become arguments — which requires careful sequential planning, consistent teacher mediation, and sufficient instructional time for the process to unfold.

As an educational implication, the importance of continuity of investigative experiences throughout the curriculum is highlighted, given that competencies related to data interpretation and scientific argumentation depend on recurrence and pedagogical progression.

Finally, the results should be understood in their situated character, linked to the specific implementation context of the IBTS, and as a contribution to ongoing discussions on inquiry-based teaching and scientific literacy in Natural Science education.

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