ISSN 2316-9281

Scientific Electronic Archives
Issue ID: Vol.19 (2), March/April 2026, p. 1-9
DOI: http://dx.doi.org/10.36560/19220262182
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Textile Dye Removal as a Pedagogical Strategy in Environmental Education: A Multidisciplinary Experience at the Municipal School Prof. Dr. Amaro Fernandes de Oliveira Sobrinho

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Abstract. This study aimed to develop and evaluate a didactic sequence focused on environmental education, integrating theoretical activities, experimental practices, and a technical visit related to dye removal and water treatment in the textile industry. The research was characterized as an applied case study using a mixed-methods approach, integrating qualitative and quantitative data. The study was conducted between August and December 2025 in a public elementary school in the municipality of Surubim, Pernambuco, Brazil, involving ninth-grade students and their guardians. The methodological design was organized sequentially and included an initial diagnostic stage using a questionnaire, followed by guided readings and discussions of scientific and journalistic texts, dye removal experiments using biosorption with elephant grass biomass, spectrophotometric analyses, a technical visit to a textile laundry facility, and a final reflection stage.The results indicated that students demonstrated a satisfactory level of prior knowledge regarding the environmental impacts of the textile industry, although gaps were identified concerning sustainable technologies and natural alternatives for effluent treatment. The theoretical and experimental activities promoted scientific literacy, critical thinking, and meaningful learning. Experimental results showed dye removal efficiencies of up to 85% at lower initial concentrations. The technical visit allowed students to contextualize laboratory findings within an industrial environment, reinforcing the importance of effluent treatment and water reuse practices.Overall, the study highlights the potential of integrated and contextualized educational strategies to promote environmental awareness and more sustainable attitudes towards the environment.
Keywords: Environmental education; Dye removal; Textile industry; Didactic sequence; Sustainability.

Introduction

Water is a natural resource essential to life, social development, and economic activities, being widely used in various productive sectors, including the textile industry (Periyasamy, 2025). This sector is characterized by high water consumption and the generation of effluents containing dyes and other chemical substances which, when improperly discharged, compromise the quality of water bodies and pose environmental and human health risks (Ramírez, Vivas & Páez, 2025). In this context, wastewater treatment becomes essential for mitigating the environmental impacts associated with industrial activities (Periyasamy, 2025; Ramírez, Vivas & Páez, 2025).

The municipality of Surubim, located in the Agreste region of the state of Pernambuco, Brazil, is strongly influenced by textile activities, which play a relevant role in the local economy (Lima et al., 2020). However, the intensive use of water in these

processes highlights the need for sustainable practices in effluent management and treatment, especially in a region characterized by water limitations and recurrent periods of scarcity. Therefore, the adoption of appropriate water treatment technologies is of strategic importance for environmental preservation and for improving the population's quality of life (Giorgia & Santos, 2015; Lima et al., 2020).

Among alternative effluent treatment techniques, adsorption and biosorption processes stand out, as they use natural, low-cost, and readily available materials. These techniques have demonstrated efficiency in contaminant removal, in addition to offering operational simplicity and potential applicability in educational contexts (Fahira, Gareso& Tahir, 2025).In the school environment, experimental practices based on adsorption facilitate the visualization of physicochemical phenomena, making abstract concepts more understandable and stimulating students' interest in science (Ferraz et al., 2025).

The adoption of multidisciplinary and contextualized pedagogical practices that integrate contents from Science, Chemistry, Biology, and Environmental Education contributes to the construction of meaningful learning and the development of critical thinking (Mello et al., 2024). Experimental activities, the reading of scientific texts, guided discussions, and technical visits enable the articulation between theory and practice, promoting greater engagement, scientific curiosity, and student protagonism (Macêdo & Silva, 2022).

These educational practices positively impact both students' education and the local community by broadening the understanding of environmental problems within the territory and encouraging more sustainable attitudes (Ausubel, 2003; Oliveira et al., 2025). By understanding the importance of water treatment and the technologies involved, students become knowledge multipliers, contributing to the dissemination of environmentally responsible practices (Correia & Silva, 2025).

In this context, the present study aimed to develop and evaluate a didactic sequence focused on environmental education, integrating theoretical activities, experimental adsorption practices for dye removal, instrumental analyses, and a technical visit to a textile laundry facility in the municipality of Surubim, Pernambuco, Brazil. The study sought to promote meaningful learning, stimulate scientific literacy, and raise students' awareness of the importance of water treatment and the adoption of sustainable practices, contributing to the formation of critical and socially engaged individuals in the face of contemporary environmental challenges.

Methodology

Study Design

This study is characterized as a case study of an applied nature, conducted using mixed methods that integrate quantitative and qualitative data (Creswell & Creswell, 2021). The research was developed within the context of school-based environmental education and involved theoretical activities, experimental practices related to contaminant removal, and university outreach actions.

Study Site, Period, and Participants

The study was conducted between August and December 2025 in the municipality of Surubim, Pernambuco, Brazil. It involved 67 ninth-grade elementary school students, aged between 10 and 14 years of both sexes, as well as 50 parents, all affiliated with the Municipal School Prof. Dr. Amaro Fernandes de Oliveira Sobrinho.

Methodological Framework

The methodological design was organized sequentially and comprised the following stages: (i) initial diagnosis; (ii) theoretical activities; (iii) experimental procedure for dye removal; (iv) instrumental analysis; (v) technical visit; and (vi) systematization and final reflection.

Diagnostic Instrument

As a diagnostic instrument, a questionnaire composed of closed-ended yes/no questions was used. It was designed to identify students' prior knowledge and interests regarding textile dyes, water treatment, and the environmental impacts associated with the textile industry, following the methodological procedures described by Lunetta et al. (2023) and Nascimento Roldão et al. (2023).

The questionnaire was written in accessible language appropriate to the participants' age group and was administered prior to the implementation of the theoretical and experimental activities. The items included were as follows:

(Q1) Did you know that the textile industry uses dyes to color clothes?

(Q2) Did you know that some textile dyes can pollute river water?

(Q3) Did you know that the water used to dye fabrics must be treated before being discharged?

(Q4) Did you know that improper disposal of wastewater from the textile industry can cause environmental pollution?

(Q5) Did you know that there are ways to treat polluted water before returning it to rivers?

(Q6) Did you know that plants and natural materials can help treat water polluted by dyes?

(Q7) Did you know that water treatment helps protect fish and other aquatic animals?

(Q8) Did you know that the textile industry consumes large amounts of water in its processes?

(Q9) Did you know that the lack of water treatment can cause health problems for people?

(Q10) Did you know that textile dyes can cause environmental impacts when they are not properly treated before disposal?

Theoretical Activities

The theoretical activities consisted of guided readings and critical discussions aimed at contextualizing the environmental issues associated with the improper disposal of effluents and waste in the state of Pernambuco, Brazil, particularly those originating from the textile industry (Macêdo & Silva, 2022).

For this purpose, science communication materials and journalistic reports were used. The content was pedagogically adapted to facilitate students' understanding, taking into account the participants' age group, without compromising conceptual accuracy, as discussed by Rocha (2012). This stage provided the theoretical foundation for the development of the experimental activities (Macêdo & Silva, 2022).

Experimental Procedure for Dye Removal

The experimental dye removal procedure was initially carried out on the premises of the Municipal School Prof. Dr. Amaro Fernandes de Oliveira Sobrinho, with the participation of the school students and undergraduate interns from the Biological Sciences Teacher Education Program at the Federal University of Pernambuco (UFPE), Recife campus, under the supervision of the project coordinators.

The experimental assays were conducted according to the methodology described by Cruz et al. (2016) and consisted of the removal of the synthetic textile dye Remazol Black B from aqueous solutions through a biosorption process. Dye solutions were prepared at concentrations of 25, 50, and 100 mg/mL, using a reaction volume of 100 mL in Erlenmeyer flasks.

The experiments were performed under previously adjusted pH conditions of 2 and 8, with the addition of 10 g of elephant grass (*Pennisetum purpureum* Schum.), previously dried, ground, and sieved to an average particle size of 0.17 mm. The contact time for the removal process was 24 h.

Spectrophotometric Analysis

Spectrophotometric analyses were conducted at the Laboratory of Chemistry and Therapeutic Innovation (LQIT), affiliated with the Department of Antibiotics and the Center for Biosciences at the Federal University of Pernambuco (UFPE). The analyses were carried out by undergraduate interns from the Biological Sciences Teacher Education Program at UFPE.

Dye quantification was performed according to the methodology described by Cruz et al. (2016) using UV–Vis spectrophotometry at a wavelength of $\lambda = 597$ nm, corresponding to the maximum absorption of the Remazol Black B dye. This procedure enabled the determination of the initial and final concentrations of the solutions after the experimental removal process.

The dye removal percentage was calculated as the difference between the initial and final concentrations, divided by the initial concentration and multiplied by 100, with results expressed as percentages (%).

Data Analysis

Data obtained from the questionnaires, systematic observations, and spectrophotometric analyses were organized and analyzed using a descriptive approach, allowing for the integration of the experimental and educational aspects of the study.

Technical Visit

As a methodological complement, a technical visit was conducted to the Parangolav laundry facility. This activity enabled the observation of fabric washing processes, water consumption, and effluent generation, relating industrial practices to the contents addressed throughout the study.

Ethical Considerations

Participation of all individuals involved was voluntary and occurred with authorization from the educational institution and the participants' legal guardians. Anonymity and confidentiality of the information were ensured in accordance with ethical principles applicable to educational research.

Results and Discussion

The application of questionnaires constitutes a relevant methodological strategy for assessing students' prior knowledge of environmental issues, as it enables the identification of perceptions, conceptions, and conceptual gaps related to topics such as environmental pollution (Marques et al., 2022; Macêdo & Silva, 2022; Abreu Santana & Narciso, 2025). Within the teaching–learning process, this initial diagnostic stage plays a fundamental role, as it supports pedagogical planning and the definition of instructional strategies that are more appropriate to the cognitive profile of the target audience (Luckesi, 2022).

In this sense, the use of diagnostic questionnaires contributes to the promotion of more meaningful learning by considering students' prior knowledge as the starting point for the construction of new knowledge, as proposed by Ausubel (2003). This methodological approach is aligned with the principles of environmental education, which aim to foster the development of critical, reflective, and socially aware individuals in relation to socio-environmental issues (Ferreira & Munhoz, 2023). This finding is evidenced by the results presented in Figure 1.

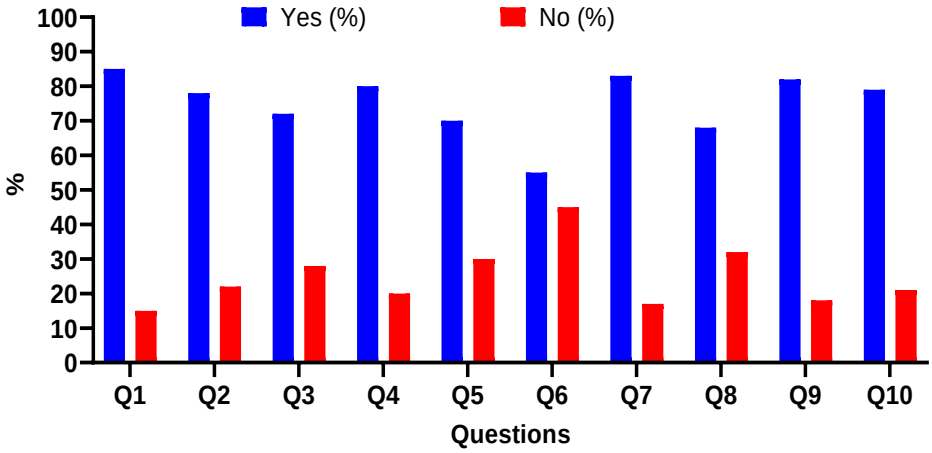

Figure 1. Percentage distribution of "Yes" and "No" responses to questions (Q1–Q10) of the questionnaire on knowledge of environmental impacts and water use in the textile.

Figure 1 presents the percentage distribution of "Yes" and "No" responses to the ten questions of the questionnaire applied, which aimed to analyze participants' level of knowledge regarding the use of dyes, water consumption, and the environmental impacts associated with the textile industry. A predominance of affirmative responses was observed for all questions, with "Yes" percentages ranging from 55% to 85%, indicating an overall satisfactory level of environmental awareness among the respondents.

The highest frequencies of positive responses were observed for questions Q1 (85%), Q7 (83%), and Q9 (82%), indicating that most participants recognize the use of dyes in the textile industry, the importance of water treatment for the protection of aquatic organisms, and the risks to human health resulting from the absence of adequate effluent treatment. Similarly high percentages were recorded for questions Q4 (80%) and Q10 (79%), suggesting that participants demonstrate consistent awareness of the environmental impacts associated with improper effluent disposal and the release of untreated dyes.

Conversely, lower proportions of affirmative responses were observed for questions Q6 (55%), Q8 (68%), and Q5 (70%), indicating more limited familiarity with the use of plants and natural materials in water treatment, as well as with the high water consumption involved in textile industry processes. These findings reveal the existence of specific knowledge gaps related to sustainable technologies and natural alternatives for effluent treatment.

Overall, data obtained from the diagnostic questionnaire indicate that, although students demonstrated a satisfactory level of knowledge regarding the environmental and health impacts associated with the textile industry, there remains a need to expand environmental education initiatives focused on the dissemination of sustainable practices, particularly those related to effluent treatment and the rational use of water resources.

In this context, the application of the questionnaire proved to be a relevant methodological strategy for assessing students' prior knowledge, enabling the identification of conceptions and conceptual gaps and supporting the planning of pedagogical interventions more appropriate to the teaching–learning process (Ausubel, 2003; Luckesi, 2022).

Following this diagnostic stage, activities involving the reading of scientific texts and journalistic reports addressing the issue of contaminants derived from textile dyes were developed. These contaminants are recognized in the literature as significant agents of environmental pollution and degradation of water quality (Rocha et al., 2013).

The use of these materials, previously selected and pedagogically adapted to the students' cognitive and linguistic levels, enabled the connection between scientific concepts related to environmental pollution, water treatment, and the impacts of industrial effluents (Costa & Schneider, 2024). This approach facilitated the establishment of links with situations from students' daily lives, thereby promoting more meaningful learning experiences (Santos et al., 2020).

Studies in the field of Science Education indicate that guided reading of scientific texts and journalistic materials contributes significantly to the development of scientific literacy by fostering skills such as interpretation, argumentation, and critical analysis of information widely disseminated in society (Borges & Benetti, 2015). These competencies are considered central to science teaching at the elementary school level, as emphasized by Ribeiro (2025), since they promote the formation of individuals capable of understanding, questioning, and making informed decisions in response to contemporary socio-environmental issues.

Furthermore, this approach facilitated the understanding of complex topics, such as environmental contamination by textile dyes, by enabling students to relate scientific data to real

environmental problems and their social and ecological implications (Guimarães et al., 2022).

The integrated use of scientific texts and journalistic reports also expanded students' informational repertoire and strengthened dialogue between science, technology, and society, fostering greater interest, curiosity, and engagement in the proposed activities, as well as encouraging questioning and the search for scientific explanations for observed environmental phenomena (Guimarães et al., 2022; Ribeiro, 2025).

After assessing prior knowledge and deepening theoretical content, contaminant removal experiments of an initially qualitative nature were conducted to complement the teaching–learning process (Creswell & Creswell, 2021). These experimental practices aimed to demonstrate that alternative effluent treatment techniques can be developed using low-cost, easily accessible materials, thereby bringing scientific knowledge closer to the school context (Silva et al., 2023).

In this context, the adsorption technique was explored, allowing students to visualize, in a concrete manner, the physical and chemical principles involved in the process of dye removal from water (Ferraz et al., 2025). Consequently, these activities fostered the integration of theory and practice and contributed to understanding the applicability of such techniques in addressing real environmental problems, particularly those related to water pollution caused by industrial effluents (Araujo et al., 2025; Ferraz et al., 2025).

The experimental activities involved the participation of undergraduate interns from the Biological Sciences Teacher Education Program, promoting interaction among different levels of education and strengthening the connection between the school and the university context (Tomaz, 2025). This integration contributed to enhancing the educational process by encouraging knowledge exchange, scientific dialogue, and pedagogical mediation during the activities (Ferreira et al., 2024).

For the preservice teachers, engagement in the school environment enabled the development and refinement of essential teaching skills, such as communicating scientific concepts, conducting experimental activities, and adapting language to students' levels of understanding (Guimarães & Costa, 2022). Additionally, this experience supported the articulation between theoretical knowledge acquired during undergraduate training and pedagogical practice (Lugle& Magalhães, 2013).

For elementary school students, the presence of the undergraduate interns provided greater proximity to the academic environment, increased interest in the proposed activities, and stimulated scientific curiosity (Bezerra & Santos Silva, 2023). Thus, the involvement of the interns significantly enriched the teaching–learning process, strengthening both initial teacher education and students' learning outcomes (Lugle& Magalhães, 2013; Bezerra & Santos Silva, 2023).

In the subsequent stage, the interns conducted spectrophotometric analysis of the treated water, a technique widely used to assess the efficiency of contaminant removal processes, such as textile dyes. The application of this methodology enabled participants to practically understand the principles of instrumental analysis, including the relationship between absorbance and concentration, as well as the interpretation of experimental data.

The results indicated that lower initial dye concentrations led to higher removal rates, reaching approximately 85%, thereby demonstrating greater adsorption efficiency under these conditions.

Data analysis allowed discussion of the influence of initial contaminant concentration on the efficiency of the applied technique, contributing to understanding variables that affect effluent treatment processes (Araujo et al., 2025; Ferraz et al., 2025).

From a pedagogical perspective, this stage supported the development of important scientific skills, such as systematic observation, critical analysis of results, and interpretation of physicochemical phenomena (Beck & Uhmann, 2022).

Moreover, the experimental activity reinforced the integration of theory and practice within the training process by enabling the concrete application of concepts previously addressed in the classroom, strengthening meaningful learning and understanding of the relevance of these techniques in addressing real environmental challenges (Paro et al., 2024).

In continuity with the experimental activities conducted in the classroom and laboratory, particularly those related to evaluating dye removal efficiency through spectrophotometry, a technical visit was carried out at the Parangolav laundry facility. This activity allowed students to observe, in a real industrial context, the different stages of denim washing and dyeing processes, establishing

connections between laboratory experiment results and practices adopted in the textile industry. During the visit, students followed the fabric finishing stages and analyzed resource consumption throughout the production chain, with emphasis on water and energy use in industrial processes, thereby enhancing their understanding of the environmental impacts associated with textile activities.

It is noteworthy that the visited laundry facility operates an effluent treatment plant in which water used in production processes is treated and reused within the industrial system. Observing this process enabled students to concretely understand the application of technologies aimed at mitigating environmental impacts, linking laboratory principles such as dye removal and pollutant load reduction with solutions effectively implemented in the productive sector. This experience reinforced understanding of water reuse as a key strategy for

reducing water consumption and controlling environmental pollution (Santos et al., 2025).

Figure 2 – Didactic sequence of the stages developed in the study: (A) application of a questionnaire for initial diagnosis; (B) reading and discussion of texts for theoretical grounding; (C) conducting dye removal experiments; (D) technical visit to Parangolav for contextualization of processes in an industrial environment; and (E) final reflection and consolidation of the acquired knowledge.

Thus, the technical visit was consolidated as a highly relevant complementary pedagogical activity, integrating theoretical knowledge, experimental practices, and industrial reality (Lucca & Petersen, 2022). This articulation contributed to strengthening meaningful learning, promoting environmental awareness, and fostering the development of a critical stance among students regarding socio-environmental challenges related to the textile industry, reinforcing the importance of sustainable practices in the contemporary productive context (Lucca & Petersen, 2022; Maraschin et al., 2025).

Overall, the development of the study occurred in a sequential and integrated manner, as illustrated in Figure 2. The initial diagnosis, carried out through the application of questionnaires (Figure 2A), enabled an understanding of the investigated problem, while the theoretical activities, based on the reading and discussion of texts (Figure 2B), provided the conceptual foundation necessary for conducting the research. The experimental procedure for dye removal (Figure 2C) enabled the practical application of the studied concepts. The technical visit to Parangolav (Figure 2D) contributed to the contextualization of the processes in a real-world scenario, strengthening the relationship between theory and practice. Finally, the final reflection and consolidation of the acquired knowledge (Figure 2E) allowed for the discussion of the main findings of the study.**Conclusion**

This study demonstrated that a sequential and integrated didactic approach, combining initial diagnosis, theoretical activities, practical experimentation, instrumental analysis, and a technical visit, strengthens environmental education by linking scientific concepts to real socio-environmental challenges. The diagnostic questionnaire indicated a satisfactory level of prior knowledge regarding the use of textile dyes and their impacts, while also revealing gaps related to sustainable technologies and natural alternatives for effluent treatment. Guided readings and discussions contributed to the development of scientific literacy and critical thinking. The dye removal experiments, supported by spectrophotometric analyses, promoted meaningful learning by making abstract concepts observable and by developing scientific skills such as data interpretation and critical analysis of results. The technical visit to Parangolav consolidated learning by connecting school and laboratory practices to the industrial context, highlighting the importance of effluent treatment and water reuse. Overall, the results reinforce the potential of contextualized methodologies and university–school outreach actions to promote environmental awareness and more informed attitudes toward sustainability in the textile sector.

Acknowledgment

The authors thank the Municipal Government of Surubim, Pernambuco, and the Municipal Secretariat of Education and Culture for the support and funding provided for the activities carried out in this study. The authors also acknowledge the Laboratory of Chemistry and Therapeutic Innovation (LQIT) at the Federal University of Pernambuco, Recife campus, for the technical support and for conducting the spectrophotometric analyses. In addition, the authors express their gratitude to the Parangolav laundry facility for allowing the students to undertake a technical visit to its facilities, thereby contributing to the integration of theory, practice, and industrial reality.

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