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Environmental education and scientific inquiry for the development of ecological awareness

Educación ambiental e indagación científica para el desarrollo de la conciencia ecológica

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Abstract

The objective of this study was to evaluate the development of environmental awareness and scientific inquiry skills in secondary school students through a pedagogical experience based on monitoring the growth and development of Schinus terebinthifolius in an urban school environment in Lima, Peru. The research employed a quantitative, applied approach with a pre-experimental pretest/posttest design. Thirty students participated, observing, recording, and analyzing the morphological characteristics of 26 specimens of the species, as well as the associated biodiversity. The results showed improvements in knowledge, attitudes, and practices related to environmental stewardship, along with a strengthening of scientific inquiry skills. The experience allowed the school's green spaces to be used as a "living laboratory," where students connected scientific content with the direct observation of natural processes. It is concluded that the systematic monitoring of Schinus terebinthifolius constitutes a relevant pedagogical strategy for promoting meaningful learning, strengthening environmental awareness, and developing scientific skills in urban school settings.

Keywords: biodiversity, ecology, environmental education, secondary education, environment.

Resumen

El objetivo del presente estudio fue evaluar el desarrollo de la conciencia ambiental y las competencias de indagación científica en estudiantes de educación secundaria mediante la implementación de una experiencia pedagógica basada en el seguimiento del crecimiento y desarrollo de Schinus terebinthifolius en un entorno escolar urbano de Lima, Perú. La investigación se desarrolló bajo un enfoque cuantitativo, de tipo aplicado, con un diseño preexperimental de pretest y postest. En el mismo, participaron 30 estudiantes, quienes realizaron actividades de observación, registro y análisis de las características morfológicas de 26 ejemplares de la especie, así como de la biodiversidad asociada. Los resultados evidenciaron mejoras en los conocimientos, las actitudes y las prácticas relacionadas con el cuidado del ambiente, además de un fortalecimiento de las competencias de indagación científica. La experiencia permitió utilizar la infraestructura verde de la institución educativa como un "laboratorio vivo", en el que los estudiantes vincularon los contenidos científicos con la observación directa de procesos naturales. Se concluye que el seguimiento sistemático de Schinus terebinthifolius constituye una estrategia pedagógica pertinente para promover aprendizajes significativos, fortalecer la conciencia ambiental y desarrollar habilidades científicas en contextos escolares urbanos.

Palabras clave: biodiversidad, ecología, educación ambiental, enseñanza secundaria, medio ambiente.

Introduction

Worldwide, roughly 4.2 billion people live in urban areas exposed to high levels of environmental pollution, a situation linked, among other factors, to the shortage of green spaces. Between 2023 and 2024, air pollution was associated with close to seven million deaths per year (Programa de las Naciones Unidas para el Medio Ambiente, 2023). By 2023, some 23,000 schools worldwide had launched reforestation initiatives, with notable examples in Finland and Japan. In Latin America, the Development Bank of Latin America and the Caribbean (CAF, 2024) reported that approximately 340 million people live in cities affected by air, soil, and water pollution, problems tied to insufficient green space and linked to around 180,000 deaths each year. In Peru, more than 21 million urban residents face critical environmental conditions stemming from the limited availability of parks and gardens (Municipalidad Metropolitana de Lima, 2023).

In Peru, close to 12,000 deaths each year are attributed to respiratory illness stemming from air pollution. The problem is compounded by pronounced disparities in the distribution of urban vegetation cover, particularly in Lima, one of the country's most affected cities. Roughly nine million residents of the capital are exposed to elevated concentrations of nitrogen dioxide and particulate matter amid a chronic shortage of green space. The availability of such areas also varies sharply across districts: some exceed 20 m² of green space per inhabitant, while others fall as low as 3 m² (Municipalidad Metropolitana de Lima, 2023). This disparity has been linked to a rise in respiratory problems among both students and adults (Ministerio del Ambiente, 2024).

In the district of Puente Piedra, approximately 416,000 residents face a critical shortfall of green space, with availability under 2 m² per person. This deficit contributes to the deterioration of air and soil quality and has been linked to roughly 1,200 annual cases of respiratory and dermatological illness (MINAM, 2023; Municipalidad Metropolitana de Lima, 2023). Against this backdrop, school green spaces take on particular importance, not only for their ecological value but also for their pedagogical potential. Neglect, inadequate maintenance, poor waste management, and limited engagement from the educational community, however, continue to constrain their formative potential. Within this context, the study of Schinus terebinthifolius emerges as a strategy of both ecological and pedagogical interest, one capable of advancing environmental education through learning experiences that are contextualized and grounded in the school setting.

The aim of this study was to assess the development of environmental awareness and scientific inquiry skills among secondary school students through a pedagogical experience centered on monitoring the growth and development of Schinus terebinthifolius in an urban school setting.

Theoretical framework

Environmental conservation theory, as applied to the analysis of urban green spaces, draws on the principles of modern conservationism, which seek to promote the rational management of natural resources on the basis of sustainability criteria (Ryan, 2022). This approach treats green spaces as essential components of urban balance, a view that has gained traction since the late nineteenth century, when urbanization and industrial expansion placed growing pressure on natural ecosystems (Anees et al., 2023). From this vantage point, conservation entails more than mere preservation; it also calls for planning the rational and equitable use of resources and integrating green areas into the ecological infrastructure of cities (Lu, 2021). Parks, gardens, and

green corridors are accordingly understood as vegetated surfaces that fulfill ecological, recreational, and aesthetic functions, helping to mitigate environmental impacts, provide shade, regulate the microclimate, and support public well-being (Jabbar et al., 2022; Zhang & Qian, 2024).

Viewed through the lens of urban green infrastructure and ecosystem services, green spaces are inherently multifunctional: they help reduce noise pollution, foster recreation, strengthen social cohesion, and provide habitat for a range of birds, insects, and other organisms (Zhang & Qian, 2024; Reyes-Riveros et al., 2021). They also support water conservation, soil protection, and air purification, linking environmental sustainability to public health and urban quality of life (Reyes-Riveros et al., 2021; Jabbar et al., 2022). Within this context, the Peruvian pepper tree (Schinus terebinthifolius) stands out as a tree species of the family Anacardiaceae, distributed along the Peruvian coast, capable of reaching heights of up to 15 meters and living beyond 50 years. Its defining traits, a dense canopy, reddish fruit, drought tolerance, and the ability to thrive in poor soils, make it well suited to arid and semi-arid climates (Razzak et al., 2023). These qualities give the species clear advantages for use in urban settings, particularly in areas with limited water availability and unfavorable soil conditions. It also requires well-drained soil and direct sunlight, while its propagation through seeds and seedlings facilitates its use in revegetation efforts and in sustainable land-management strategies for urban areas (Máthé & Bandoni, 2021; Maité-Rodríguez-Díaz et al., 2024).

From an ecological-functional and biocultural standpoint, Schinus terebinthifolius offers a range of benefits for environmental conservation. Its presence helps regulate the local microclimate, provide shade, prevent soil erosion, promote water infiltration, and trap airborne dust particles, with positive effects in both urban and rural ecosystems (Razzak et al., 2023). It can also support the formation of microecosystems involving pollinating insects, biological control agents, birds, and soil microorganisms, thereby contributing to ecological balance. Beyond these benefits, the species carries cultural and medicinal significance, reflected in the traditional use of its aroma in purification rituals and in the anti-inflammatory, antimicrobial, analgesic, wound-healing, antiparasitic, digestive, diuretic, and expectorant properties attributed to its leaves, fruit, resin, and bark (Máthé & Bandoni, 2021). For these reasons, Schinus terebinthifolius may serve as a valuable resource for environmental conservation, the restoration of degraded areas, and the strengthening of ecological balance, provided its management is carried out in a planned and sustainable manner.

Considered through the lens of situated learning and the living-laboratory model, urban conservation takes on particular relevance in education, as it allows school green infrastructure to be connected with climate resilience and with the design of contextualized learning experiences. School green spaces, in this sense, can help mitigate the urban heat island effect, improve air quality, and create spaces conducive to environmental awareness and community participation (Jabbar et al., 2022). In densely populated urban settings marked by unequal access to such spaces, school-based afforestation calls for coordination among urban planning, environmental education, and participatory management. Within this framework, Schinus terebinthifolius stands out for its capacity to regulate the microclimate, its cultural value, and its contribution to school green infrastructure (Razzak et al., 2023), as well as for its drought tolerance and its potential to lower temperatures in revegetated schoolyards (Serrano-Jiménez et al., 2025). Its adaptation to non-conventional irrigation systems, such as fog capture, and its usefulness in passive designs aimed at reducing thermal stress in educational facilities have also been documented (León et al., 2022; Cuya et al., 2024). Sustainable management of the species, moreover, allows pruning waste to be repurposed for composting and other energy-related uses (Dapsopoulou et al., 2024). Its incorporation into ecological corridors and urban restoration projects can strengthen ecological connectivity and cultural identity (Larrea et al., 2024), while its growth rate, low water demand, and capacity to curb erosion support its use in educational institutions (Bejarano et al., 2025). Taken together, these characteristics suggest that the species can foster biodiversity, thermal comfort, and environmental education from an early age, particularly in communities exposed to climate vulnerability (Pérez et al., 2024; Sarigu et al., 2025; Hinojosa et al., 2021). Finally, its potential contribution to reducing particulate matter reaffirms its ecological, cultural, and educational relevance in urban settings (Gebreyesus et al., 2024).

Methodology

The study was conducted in the Science and Technology department of a secondary school located in the district of Puente Piedra, Lima, Peru, with the participation of 30 second-year students. It followed a quantitative, applied approach and a pre-experimental, single-group design with measurements taken before and after the intervention (pretest–posttest). The purpose was to assess changes in environmental awareness and scientific inquiry skills resulting from the use of Schinus terebinthifolius as a pedagogical resource. The experience was aligned with the National Curriculum of Peru's Ministry of Education and included activities related to formulating questions, conducting experiments, analyzing evidence, and constructing scientific explanations.

Data collection and production techniques

Data collection was organized around two components, educational and ecological. The educational component drew on data gathered from the 30 students through the pretest and posttest, together with evaluation rubrics and field logs. The ecological component involved assessing the 26 specimens of Schinus terebinthifolius present in the school's green area, for which morphological variables, height, basal diameter, number of branches, leaf length, and shaded area, were recorded, alongside environmental variables such as temperature, relative humidity, and associated biodiversity. Height was measured with a tape measure from the base of the stem to the apex, while basal diameter was taken at 5 cm above ground level.

Procedure

The intervention unfolded across four phases. In the first, students examined the environmental problems in their surroundings and identified the scarcity of green space and its possible effects on the school environment. In the second phase, guided by their teacher, they formulated inquiry questions and hypotheses, among them: “What factors influence plant growth?” and “How does soil management affect it?” During the third phase, they carried out hands-on activities involving planting, weekly monitoring, and systematic record-keeping for each specimen; their field logs captured the observation date, the variables assessed, environmental conditions, qualitative impressions, and personal reflections. In the fourth phase, participants analyzed and interpreted the data they had gathered and presented their findings at the school's Science and Technology fair. Data processing relied on descriptive statistics, including the mean, minimum and maximum values, standard deviation, and coefficient of variation, and pretest and posttest means were compared.

Results and discussion

Examining the 26 specimens of Schinus terebinthifolius located within the grounds of a school in Lima made it possible to characterize their morphological development, identify some of their ecological interactions, and assess their functional contribution to the school ecosystem. These findings were then considered in relation to the species' potential as a pedagogical resource for strengthening students' environmental awareness and scientific inquiry skills.

Results of the educational impact on environmental awareness

To gauge the impact of the inquiry-based pedagogical intervention, a Likert scale was administered before and after the activities. The results point to a rise in students' environmental awareness, particularly with respect to environmental knowledge, attitudes toward caring for their surroundings, and sustainable practices. Posttest scores exceeded pretest scores, suggesting a positive effect of the educational experience. The evaluation rubrics and field logs likewise reflected gains in scientific inquiry skills, evident in students' observation, recording, and analysis of the morphological and ecological variables of Schinus terebinthifolius within the school environment.

Table 1

Comparison of pretest and posttest scores

Dimension	Pretest (Mean)	Posttest (Mean)
Knowledge	2.8	4.1
Attitudes	3	4.3
Practices	2.7	4

Table 1 shows a marked increase in the average scores across the three dimensions assessed, with environmental knowledge rising from 2.8 to 4.1, attitudes from 3.0 to 4.3, and sustainable practices from 2.7 to 4.0, results that point to a positive effect of the inquiry-based pedagogical intervention.

Table 2

Environmental awareness levels before and after the intervention

Level	Pretest (%)	Posttest (%)
Low	40%	5%

Moderate	50%	30%
High	10%	65%

Table 2 documents a clear improvement in environmental awareness: whereas low (40%) and moderate (50%) levels predominated on the pretest, the high level rose to 65% on the posttest while the low level fell to just 5%. This shift reflects a favorable change in students' environmental perception, values, and behavior.

Morphological results of the species

Table 3
Morphology of the Schinus terebinthifolius specimens

Variable	Mean	Median	SD	Minimum	Maximum
Height (cm)	135.5	136.5	31.7	56	200
Stem diameter (cm)	2.81	2.8	0.59	1.9	4.1
No. of branches	8.62	8	4.11	2	20
Leaf length (cm)	5.9	6	0.99	4	8.5
Foliage color	—	—	—	—	Light green to dark green (with intermediate shades such as lime green)

Table 3 reveals considerable variability in height, stem diameter, branching, and leaf length among the specimens assessed, underscoring the adaptive capacity of Schinus terebinthifolius within the school environment. These differences gave students the opportunity to examine how nutrients, sun exposure, and management practices influence plant growth, strengthening their skills in systematic observation, data interpretation, and hypothesis formulation.

Table 4
Associated fauna and flora observed on Schinus terebinthifolius specimens

Category	Main observations	Frequency / approx. %
Insects	Ants were present on nearly all specimens; flies, spiders, crickets, ladybugs, mealybugs, caterpillars, and bees were also recorded.	Ants: 92%; other insects: 38%
Birds	No birds were observed on any of the specimens.	0%
Understory plants	Succulent species predominated, with grass, tomato, and squash present occasionally.	Succulents: 73%; other species: 27%
Additional notes	Organic fertilizer was detected on 35% of specimens and inflorescences on 23%, while issues such as fungal growth, dead branches, waste, decomposing squash, wrappers, and ash were observed on 19%.	—

Table 4 indicates that Schinus terebinthifolius functions as a microhabitat for associated organisms, chiefly ants and other arthropods. These observations enabled students to identify ecological relationships within the school ecosystem and to appreciate the role of biodiversity in maintaining environmental balance. The presence of fungi, solid waste, and differences in management practices further encouraged critical analysis of human impact on green spaces.

Table 5
Traditional medicinal uses of Schinus terebinthifolius (Peruvian pepper tree)

Part used	Traditional preparation	Conditions treated	Method of use
Fruit	Used as a substitute for pink pepper (in moderation and with caution)	- Mild digestive disorders - Urinary tract infections - Intestinal parasites - Menstrual pain	- Digestive infusion - Mouthwash or gargle for dental pain - Sitz baths for urinary infections - External application for inflammation or muscle pain
Leaves	Medicinal water (for external use)	- Muscle pain - Respiratory problems - Natural disinfectant (for external washing) - Arthritis and osteoarthritis	- Infusion for external use - Relaxing baths or baths for rheumatism - Steam inhalation for colds
Stem	Infusion to relieve stomach pain, fever, colds, cramps, or to cleanse the blood	- Stomach disorders - Fever and respiratory ailments - Muscle and dental pain	- Stem decoction for healing washes and baths - Infusion for stomach and muscle pain - Mouthwash for dental pain

Table 5 sets out the principal traditional medicinal uses attributed to Schinus terebinthifolius. Incorporating this information extended student learning beyond the ecological dimension, fostering an appreciation of the species' cultural and biocultural value. By examining this traditional knowledge, students came to understand the relationship among biodiversity, health, and cultural heritage, reinforcing a more integrated view of environmental conservation and the sustainable use of natural resources.

Figure 1
Shaded area generated by each Schinus terebinthifolius plant

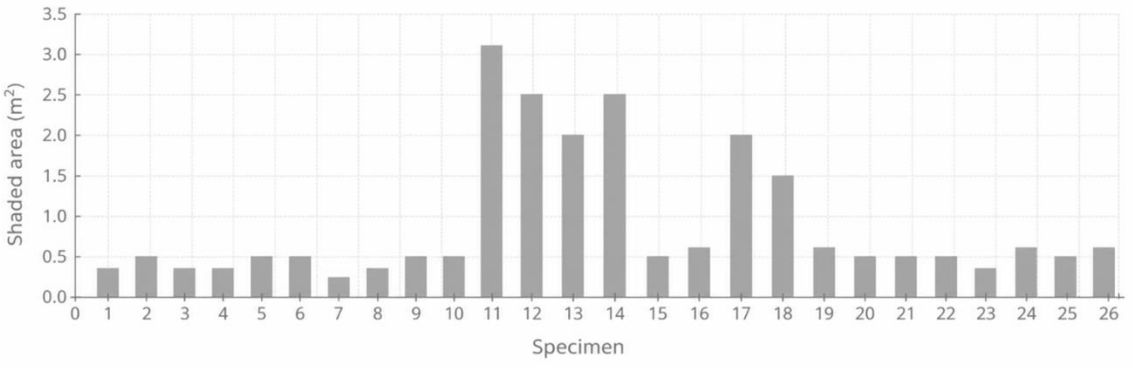


Figure 1 shows that the shaded area generated by Schinus terebinthifolius varied considerably across the 26 specimens assessed. Most produced relatively little shade, around 0.5 m², while a few individuals exceeded 2 to 3 m², pointing to the species' potential for canopy expansion. This uneven distribution suggests that only a small subset of specimens contribute substantially to canopy cover, underscoring the importance of management practices that support canopy growth and structural stability within the school environment.

Figure 2
Distribution of the shaded area generated by the Schinus terebinthifolius plants

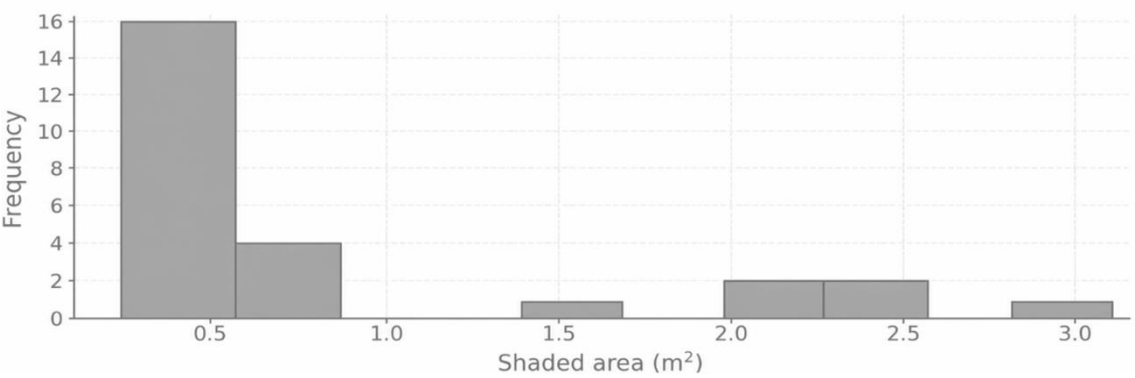


Figure 2 shows that shade production in Schinus terebinthifolius skews toward small values, with most specimens clustered around 0.5 m² and only a few exceeding 2 m². This confirms that canopy cover is not uniform across individuals and that a small number of plants account disproportionately for the total shaded area. The results point to the need for management practices that encourage more balanced canopy development within the school environment.

Figure 3
Box plot of the shaded area generated by the Schinus terebinthifolius plants

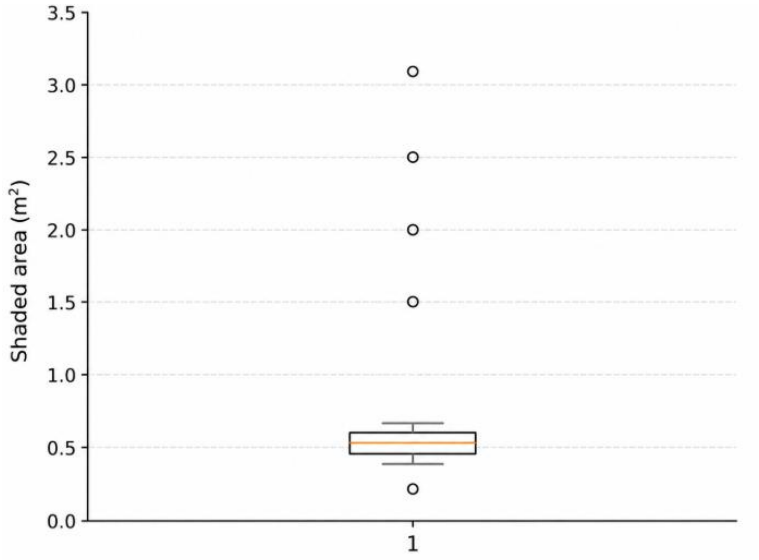


Figure 3 confirms the uneven canopy development observed in Schinus terebinthifolius: most specimens cast relatively modest shade, between 0.4 and 0.7 m², while a small number exceed 1.5 m² and reach beyond 3 m². This further confirms that a handful of individuals account disproportionately for the species' overall shading capacity.

Figure 4
Frequency of key terms identified in the observational records of the Schinus terebinthifolius plants

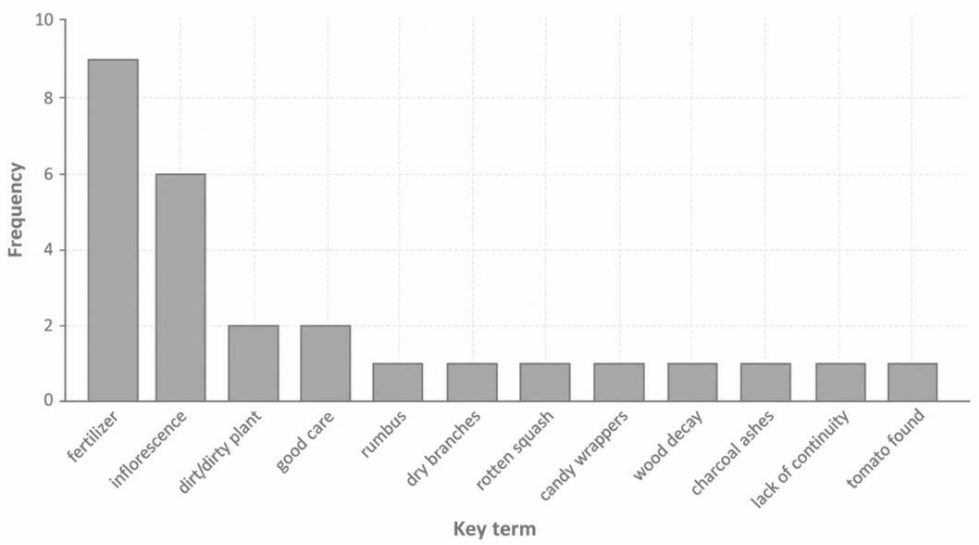


Figure 4 shows that the observational records centered largely on plant management and condition, with fertilizer, inflorescences, fungi, and waste emerging as the most frequently noted terms. These findings allowed students to examine the influence of human practices on plant development and strengthened their skills in observation, recording, and the interpretation of evidence related to environmental care and sustainability.

Figure 5
Perimeter fence of the school planted with Schinus terebinthifolius (Peruvian pepper tree)



Figure 5 illustrates the linear planting of Schinus terebinthifolius along the school perimeter, demonstrating its adaptability to limiting soil conditions and its potential as school green infrastructure. Taken together, the morphological, ecological, and ethnobotanical findings gave students the opportunity to observe, analyze, and explain real environmental phenomena. Variation in growth, shade, associated biodiversity, and management of the species provided concrete evidence for understanding its behavior within the school setting. These findings confirm, then, that Schinus terebinthifolius can serve as a pedagogical resource for strengthening environmental awareness and scientific inquiry skills through contextualized learning experiences.

Impact of the intervention on environmental awareness and scientific inquiry competencies

The results indicate that monitoring Schinus terebinthifolius strengthened students' environmental awareness, as reflected in gains across knowledge, attitudes, and sustainable practices. This finding speaks directly to the study's objective and confirms that direct engagement with a living resource in the school environment fosters more meaningful environmental learning than approaches centered solely on content transmission. Lu (2021), in a similar vein, argues that environmental education becomes more effective when students take part in experiences connected to their immediate reality, while Jabbar et al. (2022) contend that educational green spaces serve both an ecological and a formative function by strengthening well-being and connection with nature. The decline in low-level awareness and the corresponding rise in high-level awareness also align with Serrano-Jiménez et al. (2025), who show that revegetated spaces encourage the adoption of pro-environmental behaviors. From an inquiry-based standpoint, the variability observed in height, stem diameter, number of branches, and shaded area allowed students to formulate questions, identify patterns, and build evidence-based explanations, consolidating the role of Schinus terebinthifolius as a living laboratory for integrating environmental awareness, experiential learning, and environmental problem-solving.

Schinus terebinthifolius as a living laboratory for environmental learning

Using Schinus terebinthifolius as a living laboratory turned the school's green space into a setting for situated environmental learning, where students observed real ecological phenomena and built explanations grounded in evidence. This outcome resonates with Cuya et al. (2024), who argue that green infrastructure can bridge scientific knowledge with concrete experiences within the educational setting. The morphological heterogeneity observed among the specimens, meanwhile, echoes Razzak et al. (2023) and Maité-Rodríguez-Díaz et al. (2024), both of whom highlight the adaptive capacity of Schinus terebinthifolius across varying environmental conditions. Seen from this angle, differences in growth, management, fungal presence, waste, and associated organisms do more than describe the species' ecological behavior, they enhance its pedagogical value by enabling students to examine the interplay among natural factors, human intervention, and the dynamics of the school ecosystem.

Educational implications, research gaps, and future directions

The findings suggest that Schinus terebinthifolius carries an educational value that extends well beyond its ecological function, serving as a teaching resource that brings together environmental education, scientific inquiry, and an appreciation of biodiversity within the school setting. This aligns with Pérez et al. (2024), who note that plants present in educational spaces foster environmental learning through experiences close to the student's everyday world. The role of school green infrastructure likewise gains relevance for its pedagogical and environmental benefits, consistent with Gebreyesus et al. (2024), who note that tree species can help improve air quality, and with Sarigu et al. (2025), who underscores the importance of resilient species for strengthening urban sustainability in the face of environmental change. That said, the study was conducted at a single institution under a pre-experimental design without a control group; future research should therefore adopt longitudinal designs, incorporate both educational and ecosystem-related variables, and compare native species across different school settings in order to more precisely characterize their environmental and pedagogical contribution.

Conclusions

This research shows that the educational experience built around monitoring Schinus terebinthifolius strengthened environmental awareness among secondary school students, evident in improved knowledge, attitudes, and environmental practices, as well as in the development of scientific inquiry skills through the observation, recording, analysis, and interpretation of evidence in real-world contexts.

Its use as a living laboratory further demonstrated that school green spaces can bring together environmental education, experiential learning, school-based research, and biocultural knowledge, fostering a more comprehensive understanding of sustainability.

These results should nonetheless be interpreted with certain limitations in mind: the study was carried out at a single educational institution, under a pre-experimental design without a control group, assessing only immediate effects and lacking longer-term follow-up or socioemotional and behavioral measures. Future research should therefore incorporate longitudinal designs, control groups, samples drawn from a range of educational contexts, and variables related to environmental behavior, student participation, and critical thinking, so as to build stronger evidence for the pedagogical potential of living laboratories and school green spaces in shaping citizens committed to sustainability.

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APPENDIX

Instrument name: School-Context Environmental Awareness Scale (SCEAS)

Value	Category
1	Strongly disagree
2	**Disagree**
3	Neither agree nor disagree
4	**Agree**
5	Strongly agree

DIMENSIONS AND ITEMS

Dimension 1: Environmental knowledge

1. I understand the importance of green areas for improving air quality.
2. I recognize the role trees play in regulating the local climate.

3. I can identify the relationship between biodiversity and ecological balance.
4. I understand how human actions affect plant growth.
5. I am familiar with appropriate practices for caring for plants in school settings.

Dimension 2: Environmental attitudes

6. I consider it important to care for the green areas of my school.
7. I am concerned about the environmental condition of my school surroundings.
8. I value the presence of trees and plants in my community.
9. I believe everyone should take part in caring for the environment.
10. I am interested in learning more about caring for nature.

Dimension 3: Environmental practices

11. I actively take part in caring for plants or green areas.
12. I avoid polluting the natural spaces at my school.
13. I apply recycling or material-reuse practices.
14. I take part in activities related to environmental care.
15. I encourage environmental care among my peers.