education sciences

Article

Education for Environmental Sustainability Component: Innovative Strategies for Experiential Learning in Natural Contexts

Ana Cano-Ortiz [1,*], José Carlos Piñar-Fuentes [2], Carmelo Maria Musarella [3] and Juan Peña-Martínez [1]

[1] Department of Didactics of Experimental, Social and Matematical Sciences, University Complutense of Madrid, 28040 Madrid, Spain; jpe01@ucm.es
[2] Department of Animal and Plant Biology and Ecology, Section of Botany, Universidad de Jaén, 23071 Jaén, Spain; jpinar@ujaen.es
[3] Department of AGRARIA, "Mediterranea" University of Reggio Calabria, 89122 Reggio Calabria, Italy; carmelo.musarella@unirc.it
* Correspondence: acano07@ucm.es

Abstract: This article examines the role of biosphere reserves (BRs) in science education, with a particular focus on teaching for sustainable development. A case study conducted at the Complutense University of Madrid is presented, analyzing 36 of the 53 Spanish BRs to evaluate their conservation activities and educational uses. Using a pre-test–post-test experimental design and a specifically developed questionnaire, the impact of inquiry-based teaching was measured. The results reveal significant differences in students' knowledge levels before and after the teaching, highlighting the effectiveness of informational and educational strategies in enhancing environmental awareness. The study underscores the relevance of BRs not only as conservation spaces but also as valuable educational resources for promoting environmental sustainability through education for sustainable development. It further emphasizes the importance of training future teachers in sustainable practices and employing teaching methodologies that integrate inquiry-based learning. Additionally, the role of BRs in advancing the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda is highlighted. The article concludes that BRs can serve as effective learning laboratories to foster greater environmental awareness and commitment to the environmental sustainability component among educators and their future students.

Keywords: conservation strategies; environmental education; inquiry-based learning; sustainable practices; teacher training

Academic Editors: Tsung-Hau Jen and Jack F. Eichler

Received: 28 February 2025
Revised: 19 May 2025
Accepted: 23 May 2025
Published: 4 June 2025

Citation: Cano-Ortiz, A., Piñar-Fuentes, J. C., Musarella, C. M., & Peña-Martínez, J. (2025). Education for Environmental Sustainability Component: Innovative Strategies for Experiential Learning in Natural Contexts. *Education Sciences*, *15*(6), 697. https://doi.org/10.3390/educsci15060697

1. Introduction

Due to the irrational and unlimited use of natural resources (Haro, 1983) and the exploitation of ecosystem services to the point of exhaustion, as well as strong environmental and ecosystemic deterioration, it is essential to protect those habitats and natural and cultural landscapes of great ecological and heritage value (Burkhard et al., 2010). Throughout history, protective measures have been crucial in conserving biodiversity and mitigating human destruction. However, threats to ecosystems continue to grow, highlighting the need to find true harmony between humans and the environment to achieve conservation and sustainable development (Ishwaran et al., 2008). Biosphere reserves are areas that allow a balanced coexistence between humans and nature, representing minimally altered ecosystems. They integrate territorial development and the sustainable exploitation of resources with natural conservation. These reserves, of high biological value, encompass terrestrial, coastal, and marine habitats, and aim to conserve biological and cultural diversity, as well as to promote economic and social development through environmentally friendly actions (RERB, 2024). It is especially important because it allows direct contact with nature, as well as the development of learning in situ, for those who wish to do so. In addition, other functions such as educational, scientific, and cultural studies are established within its limits (Crespo Castellanos et al., 2018).

Numerous recent studies have highlighted the pedagogical value of natural environments to promote meaningful learning about sustainability, ecological thinking, and environmental literacy (Fägerstam & Blom, 2013; Dillon et al., 2006; Ballantyne & Packer, 2009). Biosphere reserves, as protected areas recognized by UNESCO for their integrated approach to conservation and sustainable development, represent a privileged context for the development of transformative educational experiences (UNESCO, 2017).

In this sense, several international studies have documented educational experiences in biosphere reserves (BRs) that connect the school curriculum with local ecological knowledge and the active participation of students (Heras & Tàbara, 2014). For example, in the Araucanía Andina Biosphere Reserve (Chile), Schüttler et al. (2023) describe how implementing environmental education activities linked to biocultural heritage has strengthened territorial identity and promoted meaningful learning of scientific content related to mountain ecosystems. Similarly, in Sweden, Fägerstam and Blom (2013) analyzed the impact of outdoor learning in secondary school contexts, observing improvements in the understanding of biology and mathematics concepts, as well as higher levels of student motivation. These experiences confirm that didactic work in natural settings supports not only the acquisition of scientific knowledge but also the development of responsible attitudes toward the environment.

Likewise, the work of Ferreira et al. (2012) in the Australian context illustrates how protected natural areas can function as "living classrooms", enabling experiential, interdisciplinary, and affective learning that transcends the limits of traditional environmental education. Other studies, such as that of Beames et al. (2012), highlight the positive impact of outdoor learning on the development of key competencies for sustainability, such as systems thinking, participatory action, and ethical reflection.

Despite these contributions, the international literature still reveals certain gaps. First, studies that systematically analyze the educational use of biosphere reserves (BRs) within the framework of formal education remain scarce and fragmented, particularly regarding the long-term monitoring of learning outcomes and their impact on curricular and social transformation. Most available research consists of case studies with a strong contextual component, which limits the transferability of models and the comparability of experiences (Sauvé, 2005; Bentsen et al., 2009).

Secondly, there is a limited presence of explicit didactic frameworks to guide the planning, implementation, and evaluation of educational initiatives in protected natural contexts. In this regard, studies such as those by Reid et al. (2008) and Monroe et al. (2017) underscore the need to articulate educational proposals grounded in robust pedagogical principles that integrate community participation, scientific inquiry, and transformative action.

Finally, it should be noted that biosphere reserves (BRs) have traditionally been approached from ecological or environmental management perspectives, often overlooking their potential as spaces for pedagogical innovation and teacher education. This lack of attention from the field of science education represents a significant gap that this study seeks to begin addressing.

The distinctive value of this proposal lies in the integration of three key dimensions:

(1) The use of protected natural areas as socio-ecological laboratories;
(2) The application of active didactic approaches based on inquiry;
(3) An explicit orientation toward education for sustainability (EfS), understood not merely as environmental education, but as a transformative process that fosters critical thinking, social justice, and participatory action (UNESCO, 2017; Reid et al., 2008).

Education for sustainability (EfS) has evolved from content transmission approaches to proposals that emphasize situated action, local engagement, and the interrelation between scientific and community knowledge (Monroe et al., 2017; Sterling, 2010). Biosphere reserves, by integrating conservation, sustainable development, and education, provide an ideal context for implementing this approach (UNESCO, 2017). In this sense, the present study aligns with an emerging line of research that seeks to move beyond merely naturalistic or recreational views of learning in nature, aiming instead to develop educational models oriented toward ecosocial transformation (Heras & Tàbara, 2014; Sauvé, 2005).

The research aims not only to analyze the impact of classroom learning but also to emphasize the importance of direct contact with the natural environment as a means to enhance the understanding of conservation principles. This approach reinforces the idea that biosphere reserves serve as experimental spaces for sustainable development (UNESCO, 2022b). In this context, the ecological literacy of future teachers plays a central role, as their training will influence future generations (Ärlemalm-Hagsér & Sandberg, 2011), thereby reinforcing the significance of this line of work.

This research is based on the use of an inquiry-based methodology as a key tool for assessing students' prior knowledge and their ability to relate ecological concepts to the sustainable management of natural resources. The objective is to foster critical thinking and active student participation in knowledge construction, aligning with the most innovative trends in science education (Bybee, 2014; Lederman et al., 2019).

Critical Thinking in Science Education and Its Link to Education for Sustainable Development (ESD)

Critical thinking is a key competence in science education, particularly within the context of education for sustainable development (ESD). This skill, understood as the ability to analyze, evaluate, and argue reflectively about complex issues, is essential for promoting active citizenship capable of making informed and ethically responsible decisions (Rieckmann, 2012).

From the perspective of science didactics, fostering critical thinking involves moving beyond the simple transmission of concepts, to instead promote inquiry processes, evidence-based argumentation, and metacognitive reflection (Lederman et al., 2019). Thus, science learning becomes a means not only to develop scientific knowledge but also to enhance the competencies needed to address contemporary socio-environmental challenges.

Education for sustainable development (ESD), as stated by UNESCO (2017), aims to empower students to act for a sustainable future, which necessitates equipping them with higher-order cognitive competencies, with critical thinking occupying a central role. In fact, SDG 4, and specifically its target 4.7, highlights the need for education systems to promote skills such as critical thinking, problem-solving, and responsible decision making in the context of sustainable development.

In this regard, innovative trends in science education, such as the inquiry-based teaching model and the Next Generation Science Standards (NGSS) approach, also emphasize the importance of integrating critical thinking as a key objective in teaching (Bybee, 2014). Through didactic strategies that encourage the formulation of questions, the evaluation of data, and the construction of evidence-based explanations, these strategies simultaneously contribute to scientific literacy and the development of competencies for sustainability.

Therefore, within the framework of science education oriented toward sustainable development, it is essential to design learning experiences that intentionally and explicitly integrate critical thinking as a transversal element of the educational process.

ESD, as stated by UNESCO (2017), seeks to empower students to act for a sustainable future, which requires equipping them with higher-order cognitive competencies, among which critical thinking occupies a central place. In fact, SDG 4, and more specifically its target 4.7, points to the need for education systems to promote skills such as critical thinking, problem solving and responsible decision making in the context of sustainable development.

In this sense, innovative trends in science education, such as the inquiry-based teaching model or the NGSS (Next Generation Science Standards) approach, also underline the importance of integrating critical thinking as an explicit objective in teaching (Bybee, 2014). Through didactic strategies that promote the formulation of questions, the evaluation of data and the construction of grounded explanations, a simultaneous contribution is made to scientific literacy and the development of competencies for sustainability.

Therefore, within the framework of a science education oriented to sustainable development, it is essential to design learning experiences that intentionally and explicitly integrate critical thinking as a transversal axis of the educational process.

In the 1970s, an international movement was born that proposed the search for a balance between man and nature, which became part of the United Nations Educational, Scientific, and Cultural Organisation's Man and the Biosphere (MAB) program (UNESCO, 2012). This program established three premises: the conservation of natural ecosystems and their genetic wealth, ecological and environmental research, and education. To implement them, the figure of the biosphere reserve was created. Currently, there is a world network of biosphere reserves that promotes the exchange of knowledge, research for development, monitoring, conservation, education, training, and decision making. In this respect, the Intergovernmental Conference on Environmental Education organized by UNESCO in cooperation with the United Nations Environment Programme (PENUMA, 1977) reads as follows: "Environmental education should be provided to people of all ages, at all levels and within the framework of formal and non-formal education. The media have a great responsibility to put their enormous resources at the service of this educational mission. Environmental specialists, as well as those whose actions and decisions may have a perceptible impact on the environment, need to be provided in the course of their training with the necessary knowledge and skills and to acquire a full sense of their responsibilities in this regard".

Biosphere reserves essentially aim to reconcile the conservation of biological diversity, the pursuit of economic and social development, and the maintenance of associated cultural values, leaving behind the traditional sense of protected areas (UNESCO, 1995).

As of 17 June 2022, there are a total of 738 biosphere reserves in 134 countries (Ferreira et al., 2012). For more than 52 years, UNESCO has worked to reconcile sustainable development with the conservation and sustainable use of natural resources through the Man and the Biosphere Program, which includes the Spanish Network of Biosphere Reserves (Ärlemalm-Hagsér & Sandberg, 2011). This international network of wilderness areas covers more than 1.3 million km^2 worldwide. These areas are crucial not only for research, but also for raising public awareness of the importance of implementing sustainable practices and promoting appreciation and understanding of biodiversity, the conservation of which is vital for humanity (UNESCO, 2022b).

The Millennium Ecosystem Assessment shows that this environmental degradation has deteriorated the health of ecosystems, negatively affecting humanity (Stephens, 2023).

Nature education is postulated as a tool for sustainable management, as interactions with nature benefit the mental well-being of the population (Tillmann et al., 2018). This is because in analyzing the benefits of the human–nature connection, it has been found to contribute to the overall development of the individual and to natural preservation by linking the human being to the environment in which his or her brain was configured to develop (Rodríguez & Quintanilla, 2019; Van Quyen, 2023).

The Strategic Plan for Biological Diversity 2011–2020 integrates a new perspective of coexistence, although it has not yet been achieved in an efficient and effective manner; however, numerous international initiatives have not mitigated the increasing environmental changes related to the destruction of ecosystems.

Along these lines is the Kunming–Montreal Global Framework for Biodiversity (Millennium Ecosystem Assessment, 2005). Adopted at the fifteenth meeting of the Conference of the Parties to the Convention on Biological Diversity in December 2022, targets were set with a deadline of 2050 to achieve harmonious coexistence between humans and nature.

In the framework of biodiversity conservation, an international treaty, the Convention on Biological Diversity (CBD), has been established (Millennium Ecosystem Assessment, 2005); the text sets out three main objectives: the conservation of biological diversity, the sustainable use of its components, and the equitable sharing of the benefits of genetic resources. The overall objective is to promote a sustainable future, encompassing levels of biodiversity in development, science, policy, and education, all under the concept of biosphere reserves.

Environmental conservation is established as one of the main functions of this type of protection. Through these actions, we are advancing towards the achievement of the Sustainable Development Goals, established in the 2030 Agenda for Sustainable Development, as well as towards the pursuit of the achievement of this term (United Nations, 2021).

The 2030 Agenda for Sustainable Development, adopted by the 193 member states of the United Nations, underlines the importance of protecting the environment to sustain life and the global economy and establishes the roadmap for achieving the 17 goals set by the UN. Conserving nature is essential both from a conservation perspective and for human livelihoods, as biodiversity supports daily and future needs, with projections for a population of 9.8 billion by 2050.

The Sustainable Development Goals (SDGs), to which UNESCO contributes, address environmental and social challenges such as climate change, pollution, and ecosystem degradation. This study focuses on Goals 4, 13, 14, and 15 (Table 1) (United Nations, 2021).

Table 1. Description of the Sustainable Development Goals.

Sustainable Development Goals (SDGs)	Description
4	Ensure inclusive, equitable, and quality education and promote lifelong learning opportunities for all.
13	Adopt urgent measures to mitigate climate change and its impacts.
14	Conserve and sustainably manage the oceans, seas, and marine resources for sustainable development.
15	Protect, restore, and promote the sustainable use of terrestrial ecosystems; sustainably manage forests; combat desertification; halt and reverse land degradation; and prevent biodiversity loss.

Numerous protected areas currently exist with specific administrative and management approaches. However, biosphere reserves differentiate themselves by establishing a constructive and meaningful role for local populations within their zoning. Despite the negative social perception of protected areas as limiting economic activity, biosphere reserves are considered the most appropriate form of protection to conserve the cultural activities of the surrounding social enclaves, as well as traditional agricultural and livestock practices (Charles et al., 2018).

Research and conservation are central activities in biosphere reserves, highlighting their multifunctional role in fostering quality human–nature relationships. It is evident that the human approach to the environment promotes effective conservation strategies (McCormick, 2017; Dudley, 2008).

The International Union for Conservation of Nature (IUCN) defines biosphere reserves as protected terrestrial or marine landscapes that serve as model regions, where practices in harmony with the capacity of natural systems are implemented to address specific environmental problems (UNESCO, 2008). It is essential to implement specific zoning for these protected areas, determining concrete zones to define the activities to be carried out, and a global program is necessary to establish the actions to be taken.

The zoning was established in accordance with the Statutory Framework of the World Network of Biosphere Reserves (UNESCO, 1995), where three well-differentiated zones are established:

- Core Zone: Primarily focused on natural habitat conservation, with minimal human intervention. Often legally designated as national parks or nature reserves.
- Buffer Zone: Surrounds the core zone, providing a protective barrier against human activities. Allows for controlled activities such as livestock farming, agriculture, forestry, and tourism, as long as they do not impact the core zone.
- Transition Zone: Promotes environmentally sustainable economic activities that support the development of local populations and human settlements.

In relation to this zoning, the three main functions of biosphere reserves are established: the conservation of biodiversity and ecosystems, the development of local populations, and the functions of research, training, education, and communication (RERB, 2024).

In Spain, there are a total of 53 biosphere reserves, covering 12.4% of the country's land area and distributed across 16 of the 17 autonomous communities. The first, "Sierra de Grazalema 1", was established in 1977 in Andalusia, covering 53,411.27 hectares. The most recent, "La Ribera Sacra", was established in 2021 in Galicia, covering 306,535 hectares (RERB, 2024).

It is essential to implement the environmental sustainability component in protected areas to conserve nature and enhance the quality of life and economic development of local communities. Biodiversity is maintained only when the protection of natural resources goes hand in hand with social development, as established at the Biosphere Conference in Paris in 1968, which led to the creation of the Man and the Biosphere (MAB) program (UNESCO, 2008). The SDG objectives mention three types of sustainability: social, economic, and environmental.

The latter should explicitly include the component of environmental sustainability, distinguishing it from biological sustainability. Students should be able to differentiate between environmental sustainability and biological sustainability, as the two are not synonymous. Environmental sustainability encompasses both biotic and abiotic elements, whereas biological sustainability pertains exclusively to biotic components.

Biosphere reserves are centers for experimentation and training, where sustainable development experiences are applied. In November 2000, the Sevilla+5 meeting was held in Seville, where the integration of populations with the natural environment was assessed (UNESCO, 2002). All these implications have been considered and translated into educational practices through place-based education (Smith, 2002), in which the environment becomes a central element of the learning process.

This approach benefits knowledge acquisition and connects new generations with nature, fostering emotional behaviors oriented towards ecological preservation (Bruchner, 2012; Chawla, 2020).

Biosphere reserves are considered "real models" within the Seville strategy, integrating environmental conservation actions and sustainable development, taking into account the social, economic, cultural, and natural realities of the territories. They are established as territorial management enclaves, in line with the objectives of the Seville strategy (Ferreira et al., 2012). In addition, these sites are important as experimentation sites for sustainable development, promoting activities compatible with nature conservation (IUCN).

Subsequently, due to new environmental challenges such as uncontrolled urban development or climate change, new objectives were established and taken into account in the updating of the MaB program (UNESCO, 2008, 2012), and specifically in the Madrid Action Plan 2008–2013, which promotes actions to mitigate climate change in these regions, as well as actions aimed at eco-responsible education in search of the territorial component of environmental sustainability (UNESCO, 2008; OCDE, 2019). Biosphere reserves stand out as centers of excellence for promoting coexistence between local communities and nature within the limits of sustainable development. This is achieved through dialogue, knowledge exchange, and participation, always respecting regional culture and promoting social and economic development, with the aim of poverty alleviation and progress towards the Millennium Development Goals (Hedden-Dunkhorst & Schmitt, 2020; Sivaperuman & Banerjee, 2023).

Biosphere reserves are model regions for respectful and sustainable interaction between humans and nature, where conservation and environmental exploitation activities are carried out responsibly. There is a growing global concern for the conservation of the planet to preserve life (Dong & Huang, 2023). This is reflected in global policies for the better management of natural resources, such as the goals of the 2030 Agenda of the United Nations (United Nations, 2021).

This study aims to determine the level of prior knowledge regarding the "biosphere reserve" protection figure, verifying whether it meets one of its fundamental pillars. The third main objective (logistic support function) emphasizes the need to contribute to scientific research, training, environmental education, and the application of sustainable development models (Figure 1). Derived objectives include raising awareness about the conservation and development premises of UNESCO's Man and the Biosphere (MAB) program, promoting experimentation and research to achieve UNESCO's current goals, and establishing social literacy measures through eco-education. Therefore, this article seeks to revalue the natural environment as an educational space (UNESCO, 2022a).

The third main objective of biosphere reserves, known as the logistic support function, is an essential component of UNESCO's "Man and the Biosphere" (MAB) program. This objective not only strengthens environmental conservation and sustainable development but also provides a comprehensive framework for scientific research, training, environmental education, and the experimentation with sustainable territorial management models.

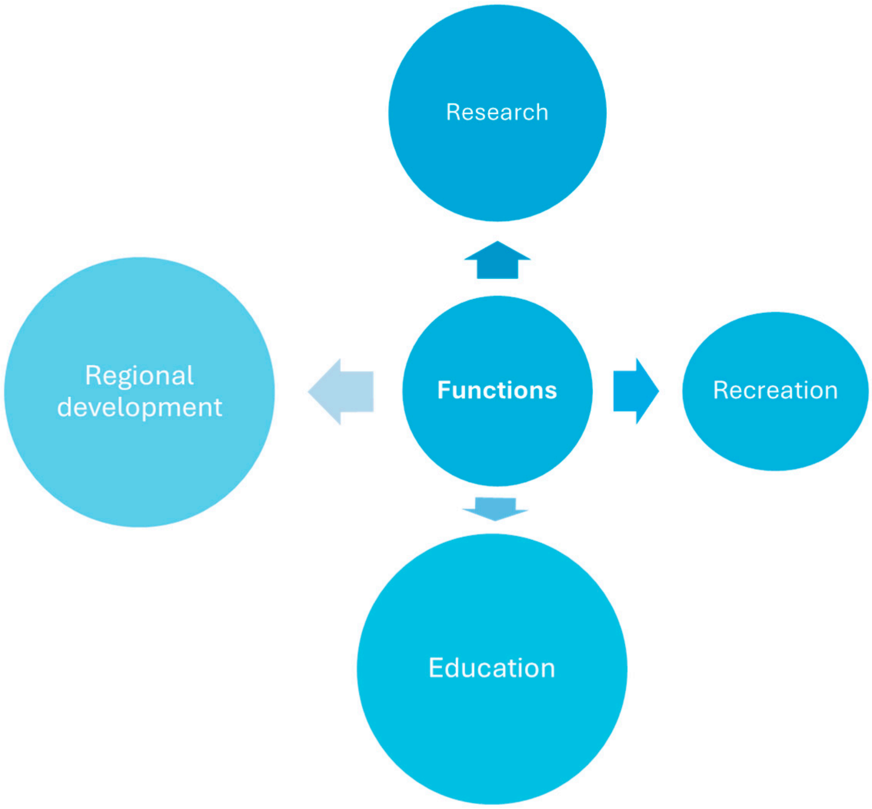


Figure 1. The infographic shows the weight of the functions established within the "biosphere reserve" protection figure. The size of the nodes indicates the weight of each function. Adapted from the Spanish Network of Biosphere Reserves (RERB, 2024).

The objectives to be achieved are as follows:

1. To analyze the didactic value of biosphere reserves as learning environments for science education, specifically in the context of sustainability.
2. To explore how contextualized studies in the natural environment foster critical understanding of ecological and conservation principles.
3. To evaluate the impact of contextualized active methodologies, particularly inquiry-based learning, on the development of scientific and ecosocial competencies in students.

2. Materials and Methods

The experimental group consists of pre-service teachers pursuing a double degree in early childhood and primary education. This group was involved in the study and analysis of 36 out of the 56 existing biosphere reserves in Spain. The research aimed to investigate and assess the various activities conducted in each reserve, focusing particularly on those related to education, which was one of the main objectives.

In each selected reserve, a teaching–learning system based on a heuristic model was established, employing an inquiry-based didactic methodology. The university students (future teachers) took an active role, engaging in problem-solving activities to learn about the biosphere reserves, their functions, and objectives. This inquiry-based methodology, endorsed by several authors, is considered highly appropriate for the study of natural sciences (Artigue et al., 2013; Rocard et al., 2007) (Table 2).

Table 2. Activities conducted in five biosphere reserves.

Biosphere Reserve	Details	Reflections and Importance
Biosphere Reserve of the Sierras de Béjar and Francia	(i-bejar.com, 2024) Students from the Sierras de Béjar and Francia participate in an environmental education program. Link. "Revitalization of the RBSBF: Development of the Strategic Plan" and "Consolidation of the Identity of the RBSBF: A Participatory Model"—A new rural development model based on public participation in biodiversity and landscape management (UNESCO). Creation of the management entity and development of the Management Plan (2008–2013). Public participation initiatives: workshops, forums, "Spring in the Sierras" program, photography and painting contests, music and dance festivals, website, land bank, and land stewardship. Green Homes Program (DERSOS)—Energy efficiency project for 250 households, working with schools, local governments, and communities. Analysis of environmental quality and tourism management.	This work has made me aware of the importance of protecting natural areas, as they are home to many living beings. I have visited the Sierras de Francia and Béjar before, and this project helped me recall what I already knew while learning new things. Conservation of flora, fauna, and traditions is essential. Awareness is necessary because, without it, people will not recognize the risks of ecosystem loss, making solutions impossible.
Biosphere Reserve of Babia	Cantabrian Ecology School Project: Study of over 200 species (including the endangered brown bear), forestry and livestock training, environmental observatory, education programs, sustainable tourism, and a Babia Biosphere Reserve sustainability brand.	The biosphere sustains life on Earth and is home to humans, animals, and plants. Protecting it is our responsibility.
Biosphere Reserve of El Hierro	Observatory. Virtual tour. Eco-school guide. Nature classroom. Educational materials for students. Geopark information center. Ecomuseum of Guinea.	Undoubtedly a positive impact. A role model for education and conservation.
Biosphere Reserve of Monfragüe	Educational Project "MABMonfragüe"—Supports student education through interactive maps, a virtual escape room, educational trips, workshops, and lectures. Collaborations with ENGIE (promoting girls in Earth sciences) and Zurbatravel (heritage studies). Guided tours and activities. "Get to Know Your Monfragüe National Park" (I.E.S. Dr. Fernández Santana students). "Tracks and Traces" Workshop—Identifying animal species and tracking techniques.	Children must understand the importance of conservation from an early age, as flora and fauna are vital for survival. Raising awareness about environmental impacts is urgent.

Table 2. *Cont.*

Biosphere Reserve	Details	Reflections and Importance
Biosphere Reserve of La Mancha Húmeda	Awareness Talk—Organized by Mancha Norte Association to promote wetland conservation. Field visits. Visit to "El Pueblo" lagoons in Pedro Muñoz and "La Veguilla"—Birdwatching, fauna observation, water sampling. Guided tour of Ruidera Lagoons. Children's activities at Las Tablas de Daimiel—Guided tour with field journals for learning about wetland flora, bird species, and ecosystems. Interpretive route in the Manjavacas Lagoons, Mota del Cuervo.	La Mancha Húmeda is Spain's third most important wetland and a vital inland habitat for waterfowl. Wetlands store water, sustain wildlife, and support human activities, making their protection essential.

2.1. Data Collection and Analysis Procedure

A concurrent study was conducted using mixed methods, involving the simultaneous collection of quantitative and qualitative data (Sampieri et al., 2014). The mixed-methods approach entails a systematic set of research processes, followed by their integration and joint discussion, to achieve a more complete understanding of the phenomenon under study (Sampieri & Mendoza, 2018). The choice of this method aligns with the research objectives, allowing for a more holistic response and enhancing the explanatory power of the results. Specifically, the combination of both methods will enable us to compare students' knowledge assimilation about natural spaces and biosphere reserves before and after completing the course. Additionally, it will enrich the interpretation of these results through the creation of a scientific poster by the students, addressing concepts related to biosphere reserves using an inquiry-based methodology. The study was conducted within the context of the course "Fundamentals and Didactics of Biology Education" in the dual degree program of Early Childhood and Primary Education at the Complutense University of Madrid (Madrid, Spain). The research design followed methodological recommendations on mixed methods (Teddlie & Tashakkori, 2011). The following describes the process followed and identifies the two approaches (Figure 2).

As we have indicated, the methodological approach was concurrent and mixed methods, which involved the simultaneous collection of quantitative and qualitative data on the impact of the inquiry-based teaching model applied in the context of biosphere reserves.

Data collection was carried out using the following tools:

- Google Forms: Specific forms were designed to administer both a pre-test and a post-test to participating students.

The pre-test allowed for an initial assessment of students' knowledge and perceptions regarding the conservation of biosphere reserves and the principles of sustainable development.

The post-test was administered after the completion of the teaching intervention to assess changes in the level of understanding, attitudes, and acquired skills.

A heuristic teaching–learning model based on the inquiry-based methodology was designed, in which students took an active role in researching a selected biosphere reserve. Each student conducted a detailed analysis of a specific biosphere reserve, addressing three key dimensions: the environmental dimension, the zoning of the protected area, and the research and educational activities carried out within it, linking the social dimension to sustainable development through these aspects. Particular emphasis was placed on the inquiry process related to the use of the reserve as a space for learning and environmental awareness.

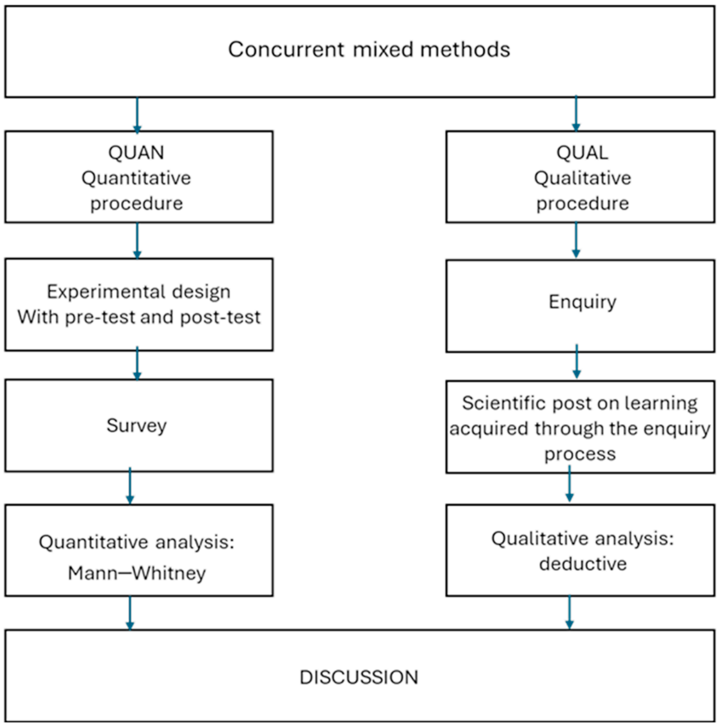


Figure 2. Methodological scheme used.

The didactic methodology employed emphasized experiential learning, following an inquiry-based approach supported by previous studies in science education (Bybee, 2014; Lederman et al., 2019).

During the inquiry process, students participated in activities structured around guiding questions designed to foster critical thinking and reflective analysis. These questions included the following:

- How does the biosphere reserve contribute to biodiversity conservation?
- How do local communities interact with the protected area?
- What educational strategies are implemented in this natural space?

Based on these questions, students gathered information from various sources. Through this process, they not only strengthened their research skills but also developed a holistic understanding of the sustainable management of biosphere reserves.

Specifically, the activities were structured around an inquiry-based learning model, in which students, organized into small groups, analyzed official information available on Spanish biosphere reserves (institutional websites, management reports, scientific and informational publications). Based on the guiding questions formulated, each group prepared brief reports in which they evaluated the following:

- The specific contribution of the reserves to the conservation of local species and ecosystems, as well as their zoning.
- The conservation actions developed in the reserves and related projects.
- The environmental education programs developed in the reserves (workshops, educational routes, visitor centers, etc.).

The application of inquiry as a didactic strategy has been extensively validated in the educational field, as it enables active knowledge construction and fosters scientific research skills in real-world scenarios (Creswell & Plano Clark, 2017). In this context, the research conducted not only assessed the knowledge acquired but also enhanced students' ecological literacy through an interdisciplinary approach.

At the conclusion of the teaching–learning process based on the inquiry methodology and the heuristic model, a key pedagogical strategy oriented to the consolidation of learning was implemented: the cooperative elaboration of a scientific poster as a final product of the research process. During this phase, students organized their work in small groups, which fostered a cooperative learning environment characterized by positive inter-dependence, individual responsibility, and peer collaboration (Gillies, 2016; Johnson & Johnson, 2017). This group dynamic was designed to enhance specific competencies, such as scientific argumentation, shared decision making, effective communication, and critical reflection.

The design and presentation of the posters allowed students to structure their scientific thinking and strengthen their communication skills in formats accessible to the educational community. In addition, this experience facilitated the integration of scientific knowledge with educational, environmental, and social dimensions, promoting deep and meaningful learning in accordance with the principles of education for sustainable development (UNESCO, 2020). Likewise, cooperative learning contributed to the development of transversal competencies and prosocial attitudes, as well as to the internalization of values linked to sustainability, such as co-responsibility, respect for the environment, and collective action, in line with contemporary educational objectives (Slavin, 2014).

The use of scientific posters as a didactic tool has been widely supported in previous studies, as it fosters the development of scientific communication skills, enhances the understanding of concepts in natural sciences, promotes information synthesis and evidence-based argumentation, and improves students' attitudes toward research. This strategy also facilitates cooperative learning and critical discussion among peers, promoting an active learning environment (Osborne & Dillon, 2010).

The scientific poster served as the final product of the students' research on their respective biosphere reserves. This resource not only allowed them to structure their findings but also functioned as a teaching–learning strategy to encourage scientific argumentation and the development of effective oral communication skills in science.

Each poster included the following:

- The research context, highlighting the analyzed biosphere reserve, its zoning, location, and territorial characteristics.
- Scientific research and educational actions carried out within the studied biosphere reserve.
- Results and conclusions, as well as potential applications of their findings in environmental education and sustainable management, presented in visual formats (graphs, diagrams, and tables) to facilitate their interpretation.

Specifically, the rubric was designed ad hoc by the research team with the objective of holistically evaluating the students' productions—in this case, scientific posters—at the end of their participation in the didactic activities carried out in the biosphere reserve. The instrument was structured around three key dimensions—(1) scientific content, (2) communicative quality, and (3) ecosocial and sustainability approach—with descriptors graded on a scale from 1 to 4. To ensure the content validity of the rubric, it was subjected to a review process by three experts in science didactics and environmental education from two Spanish universities. The experts evaluated the relevance, clarity, and adequacy of each descriptor and provided suggestions that were incorporated into the final version of the instrument (Jonsson & Svingby, 2007). Regarding inter-rater reliability, a double independent evaluation process was applied to a random sample of 30% of the posters, conducted by two researchers from the team. Cohen's Kappa concordance index was calculated, yielding a value of $\kappa = 0.81$, indicating a very high degree of agreement according to the established standards (Landis & Koch, 1977). Regarding the previous use of the rubric, it is an original instrument, adapted to the specific context of the research, though inspired by previous work that has addressed the assessment of scientific competencies in experiential learning and sustainability contexts (Bybee et al., 2006).

To analyze the data contained in the posters, a qualitative evaluation rubric was applied, structured around the following criteria:

- Scientific accuracy: Correct use of ecological and educational concepts (dimension 1).
- Argumentative capacity: Critical reasoning in the interpretation of results (dimension 2).

- ▪ Expository clarity: Visual organization, language, and presentation (dimension 2).
- ▪ The post shows the conclusions and possible applications of its results to environmental education and sustainable management (dimension 3).

The analysis of the posters allowed for the identification of trends in the understanding of biosphere reserves, an assessment of the impact of the inquiry-based approach, and the detection of potential challenges in scientific knowledge construction.

Regarding the inquiry-based methodology, a guided inquiry approach was used, where students explored environmental and educational issues within the biosphere reserves.

This methodology, supported by previous studies in science education (Bybee, 2014; Lederman et al., 2019), enabled students to actively engage in knowledge construction rather than passively receiving information.

Throughout the research process, problem-solving was promoted by applying the acquired knowledge to biosphere reserves. Students analyzed issues such as the following:

- What sustainable development strategies can be implemented in the community?
- How can educational initiatives in these protected areas be improved?

These issues were addressed using active learning strategies, in which students conducted research, contrasted information, and formulated proposals based on scientific and pedagogical principles (Table 3).

Table 3. Evaluation rubric.

Dimension	Evaluation Criteria	Level 1 (Insufficient)	Level 2 (Acceptable)	Level 3 (Good)	Level 4 (Excellent)
1. Scientific content	Accuracy, depth, and appropriateness of content on natural processes, conservation, and education Argumentative capacity	Content imprecise, disorganized, or unconnected to the concepts covered	General content, with occasional errors and limited connection to the natural context.	Correct content, with clear explanations and adequate examples	Rigorous, well-articulated, and contextualized content with ecological depth
2. Communication and design	Expository clarity, expository quality (visual structure, graphic quality, and adequacy of language)	Disorganized design; poor language; difficult to read or understand	Simple but understandable design; basic use of scientific language	Clear and structured presentation; good use of images and scientific terms	Attractive, coherent, and creative design; excellent communicative and visual usage
3. Ecosocial approach	Ability to relate learning to real environmental and social challenges	No relationships are identified between what is learned and its application in real life	Vague references to environmental or social problems with no deepening of the information	Explicit connection to real problems; relevant personal proposals or reflections	Sound critical perspective; argued and innovative proposals towards sustainability

In the described teaching–learning process, both before and after the intervention (once the content was covered with the students), an ad hoc questionnaire was administered at two different time intervals. This questionnaire consisted of two content blocks: identification data, conceptions about natural spaces and protection figures, and conceptions about biosphere reserves. Initially, data were collected from the experimental group (pre-test): the pre-teachers responded according to their prior conceptions about the different types of protected natural spaces in Spain, as well as concepts related to biosphere reserves. After covering the content related to biosphere reserves, the same knowledge acquisition process was repeated using the post-test. The questions included in the questionnaire can be seen in Table 4.

Table 4. Variables and type of variable in the questionnaire on a priori and a posteriori knowledge of concepts related to biosphere reserves and protected natural areas.

Variable	Categories of Variables
Do you know any National Parks in Spain?	Binary (Yes, No)
How many National Parks are there in Spain?	Factor (Text)
What is/are the function(s) of a Nature Park?	Factor (Multivaluated)
Do you know the difference between a Natural Park and a Rural Park?	Binary (Yes, No)
If so, please indicate concisely the differences between the two figures.	Factor (Text)
Who is responsible for the management of the National Parks?	Factor (Multivaluated)
Do you know what biosphere reserves are?	Binary (Yes, No)
If so, define what a biosphere reserve is.	Factor (Text)
Do you know the Man and the Biosphere (MaB) program?	Binary (Yes, No)
What is the role of the MaB program?	Factor (Multivaluated)
Do you know the zoning of biosphere reserves?	Binary (Yes, No)
If yes, indicate the areas that make up the biosphere reserve.	Factor (Multivaluated)
Are there urban centers within the territory of a biosphere reserve?	Binary (Yes, No)
How many biosphere reserves are there in Spain?	Factor (Multivaluated)
How many biosphere reserves are there worldwide?	Factor (Multivaluated)
On the following scale, indicate the extent to which you are familiar with the functions of biosphere reserves.	Factor (Multivaluated)
Do you think that citizen participation is allowed in the management of biosphere reserves?	Binary (Yes, No)
A biosphere reserve is proposed for creation by . . .	Factor (Multivaluated)
Do you know what SAMSAR sites are?	Binary (Yes, No)
Do you know the different types of environmental protection that exist in Spain?	Binary (Yes, No)
In addition to conservation, can you tell me about any other function of the protection figures?	Factor (Text)
Do you consider National Parks to be accessible to the population?	Factor (Yes, No, I don't know)
Do you know what the Natura 2000 Network is?	Binary (Yes, No)
What is an ecosystem?	Factor (Multivaluated)
Other inferred variables	

Table 4. *Cont.*

Variable	Categories of Variables
Number of correct National Parks	Numeric
Number of incorrect National Parks	Numeric
% Correct/Incorrect	Numeric
Do you know any National Parks in Spain?	Binary (Yes, No)

The questionnaire was administered through the Google Forms platform, ensuring greater accessibility and flexibility for students, allowing them to respond at different times and in various settings. Additionally, this tool facilitated the structured collection of data by combining both quantitative and qualitative questions. The automation of the process also streamlined both the organization and analysis of the collected information.

Prior to its implementation, the questionnaire was reviewed and validated by three experts in science education to ensure that each item was relevant and comprehensible.

The open-ended questions were specifically designed for this study, following methodological criteria that support the assessment of meaningful learning and the development of scientific thinking. Their design considered three key aspects.

2.2. Databases and Their Relevance to Educational Research

The use of databases in education has become increasingly relevant in recent decades, particularly as a tool to support research, evaluation, and evidence-based decision-making processes. In general terms, a database is defined as a structured information storage and management system that allows the efficient access, organization, and retrieval of data (Elmasri & Navathe, 2016). In education, its use has transcended the administrative level to become a key resource in the design, monitoring, and analysis of educational policies, pedagogical practices, and learning processes.

The potential of databases in educational research is evident, among other aspects, in the possibility of conducting longitudinal analyses, identifying patterns in student performance, and establishing relationships between individual, institutional, and contextual variables (Means et al., 2010). This data-driven approach helps to overcome intuitive or anecdotal models, enabling progress towards evidence-based education.

The availability of large-scale databases, promoted by organizations such as the OCDE (2019), has facilitated access to systematized information on educational indicators at the international level, strengthening comparisons between systems and the identification of best practices. At a more localized level, information management systems in educational institutions have also become primary data sources for research, especially in analyzing the use of technologies and digital resources in the classroom (Zhao & Frank, 2003).

In the specific field of the didactics of experimental sciences, databases provide the opportunity to observe in greater depth how scientific concepts are learned, the difficulties students face, and the strategies that are most effective at various educational levels. For example, studies focusing on scientific argumentation in the classroom have used systematized performance records to assess the quality of reasoning constructed by students (Archila, 2012).

Thus, databases are a strategic resource for the continuous improvement of education. Their responsible and critical use, particularly in science education, not only documents the current state of learning but also facilitates the design of didactic interventions that respond to the real needs of students and the demands of the contemporary educational context (Lederman et al., 2019; Creswell & Plano Clark, 2017):

- Identifying potential misconceptions or incorrect interpretations among students (Osborne & Dillon, 2010).
- Enhancing metacognitive skills, allowing participants to organize their ideas and develop well-founded arguments (Zohar & Dori, 2003).
- Enabling a deeper analysis of learning, in contrast to closed-ended questions, which often limit the exploration of complex concepts (Yin, 2016).

The sample group was randomly selected. The study sample consisted of accessible subjects enrolled in the "Fundamentals and Didactics of Biology" course of the double degree in Early Childhood and Primary Education at UCM. All participants were volunteers and were informed about the research objectives. A total of 41 students participated, of whom 92.7% were women and 7.3% men. Most students were between 19 and 20 years old (80.5%), followed by those aged 21 years (4.9%). Only 14.6% were older than 21 years.

2.3. Experimental Design

The design of this research, focused on analyzing biosphere reserves (BRs) as educational resources, effectively acknowledges the importance of contact with nature as a fundamental component of environmental and scientific education. While the educational intervention was based on activities involving analysis, inquiry, and reflection on BRs, some of which utilized digital materials and specific documentation, it is important to note that field trips or in-person visits to these spaces were not systematically incorporated during the course of the experiment.

The didactic proposal was framed within the place-based education methodology, aiming, as suggested by (Smith, 2002), to foster affective connections with the environment, facilitate meaningful learning, and promote responsible attitudes toward sustainability through the contextualization of educational activities in natural settings.

Nevertheless, the theoretical framework and didactic rationale of the study underscore the significance of experiential learning and direct contact with natural environments as a critical strategy for enhancing the understanding of conservation principles (UNESCO, 2017; Rickinson, 2001). From these perspectives, direct experience in natural settings not only deepens current knowledge but also fosters pro-environmental attitudes and an emotional connection to the environment—key elements of education for sustainable development (UNESCO, 2017).

To statistically compare changes in responses after the educational intervention, the data were analyzed considering two factors: a priori and a posteriori data. The Shapiro–Wilk normality test was applied (Shapiro & Wilk, 1965). The normality test indicated that the variables did not follow a normal probability distribution, primarily due to their qualitative nominal nature.

The questionnaire design was based on two key assumptions: first, the anonymous nature of the surveys, which implies that the responses were not paired; and second, the mix of variable types (Table 4). These factors influenced the choice of statistical analyses.

Initially, an exploratory data analysis was conducted to verify standard assumptions regarding normality and variance distribution. The Shapiro–Wilk test confirmed that most variables did not follow a normal distribution. This violation of parametric test assumptions made it more appropriate to use robust statistical techniques suited for non-normal data distributions. Consequently, non-parametric tests were employed.

Among the various non-parametric tools available, the present study's variables included nominal categorical, ordinal categorical, genuine binary, and numerical (discrete or continuous) variables. This classification determined the statistical tests used: for categorical and nominal variables, the Chi-square test was applied, whereas for the remaining variables, options such as Wilcoxon or Mann–Whitney were considered appropriate.

Due to the anonymous nature of the questionnaires, the "a priori" and "a posteriori" treatments were considered as independent samples, as they were not paired. This led to the use of the Mann–Whitney U test and the Chi-square test for analysis.

Moreover, the Mann–Whitney test effectively addressed the issue of requiring equal sample sizes. In the experimental design, some students who were unable to complete the pre-test later participated in the post-test. On the other hand, the Wilcoxon test performs better when variables contain numerous categories or options. However, since many variables in this study had only three categories, applying the Wilcoxon test could yield misleading results. Although the sign test could address this issue for certain variables, many responses remained unchanged between pre-test and post-test, preventing the sign test from detecting significant differences.

For these reasons, to ensure a standardized analytical approach across all variables, the most suitable tests, albeit not necessarily optimal for every variable, were the Mann–Whitney U test and the Chi-square test.

With the pre-test and post-test questions and answers of the students, an Excel table is generated, which is subjected to statistical analysis with the Past.exe program. The linear correlation for each item and the average of this correlation is obtained in order to apply Cronbach's alpha coefficient to determine the internal consistency and obtain the degree of reliability (Oviedo & Campo-Arias, 2005), for which we use the following formula:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma_i^2}{\sigma_T^2}\right)$$

α = Cronbach's alpha coefficient, k = number of items, ${\sigma_i}^2$ = variance of each item, and ${\sigma_t}^2$ = total variance of the scale. Among the two available methods for calculating this statistic, this approach was chosen due to the different nature of the variables, which required applying different types of correlations depending on the variable type. The Cronbach's alpha coefficient obtained was 0.838, indicating good reliability, as the variables were well correlated.

Subsequently, various measures were conducted to assess the adequacy of the variables for multivariate analyses, such as principal component analysis (PCA) or exploratory and confirmatory factor analysis. To this end, Bartlett's sphericity test (Table 5) and the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy were performed. The sphericity test was significant, with a p-value < 0.0001.

Table 5. Bartlett's sphericity test statistics. Significant values imply that at least one of the correlations between variables is different from 0.

Statistics	Values
Chi-square (observed value):	1,696,298
Chi-square (critical value):	395,688
Degrees of freedom (GL):	351
p-value (two-tailed):	<0.0001
Alpha level (α):	0.05

The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy is generally greater than 0.6. The overall KMO for these variables is 0.771, indicating that PCA can be used to reduce the dimensionality of the data. Although some variables have very low KMO values and are not suitable for analysis, these variables may be excluded in subsequent analyses.

Based on these premises, an exploratory and confirmatory factor analysis is proposed to confirm the model. The questionnaire is designed to explore students' knowledge regarding various natural spaces, protection figures, and conceptions about biosphere reserves. Therefore, a satisfactory exploratory factor analysis with four factors is expected. The parameters for the exploratory factor analysis are as follows:

- Correlation: Spearman;
- Extraction method: principal factor analysis;
- Number of factors: automatic;
- Initial communalities: random;
- Rotation: oblimin (Kaiser normalization);
- Number of factors = 4;
- Tau = 0.

To evaluate the data obtained from the questionnaires, data preprocessing was performed to normalize and transform the different types of responses into a numerical format for subsequent comparative analysis. Contingency tables were created for further analysis using the Chi-square test.

Consequently, non-parametric comparison tests were performed. Initially, a principal component analysis (PCA) was conducted to observe the distribution, significance, and relationships among the different variables, as well as their correlation with the treatments before (a priori) and after (a posteriori) the intervention for each questionnaire question. In this exploratory factor analysis, to better visualize the most relevant variables, an oblimin rotation was used, projecting the variables onto the first two axes (F1 and F2). The initial model parameters followed these premises: initial communities were set to random, and the model was constrained to converge within 10,000 iterations or when the convergence rate reached 0.0001. Subsequently, under the same model premises, another PCA was performed to explore the distribution and correlation of responses in both treatments. The procedure for conducting the PCA is summarized in Figure 3.

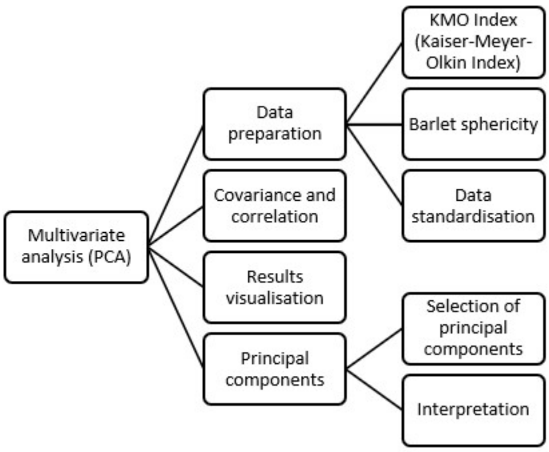


Figure 3. Diagram of the statistical procedures used during data analysis.

To make comparisons between the means of the variables, taking into account the two factors, the Mann–Whitney U test was used (Mann & Whitney, 1947). A non-parametric test was used, given the semi-quantitative nature of the data and the chosen sample universe. The premises of normality and heteroscedasticity are not met for the probability distribution of all the analyzed variables. The Shapiro–Wilk test was employed to verify the distribution of the variables.

To analyze the qualitative responses, an inductive categorization strategy was applied, developed a posteriori, once the data had been collected. This method allowed the categories to emerge directly from the data, avoiding the imposition of predetermined schemes and respecting the conceptual freedom of the participants. In this way, a rigorous and open analysis was guaranteed, capable of capturing the diversity and richness of the students' knowledge of the topic under study. This methodological decision was based on the need to preserve the spontaneity and authenticity of the students' productions, avoiding prior conditioning through closed categories. In this way, it was possible to explore in greater depth the students' prior knowledge, intuitive ideas, and conceptual representations of the topic.

The procedure consisted of an exhaustive reading of all the responses, identifying relevant units of meaning. Subsequently, an open coding was carried out that allowed grouping of the statements around common meanings, thus generating emerging categories. The responses were grouped into categories and the ascription to each of them was based on the grouping of the statements by semantic similarity. This approach follows the principles of qualitative analysis proposed by Miles et al. (2014), who highlight the usefulness of inductive categorization to detect conceptual patterns in educational contexts. Likewise, the criteria of clarity, completeness, and exclusivity recommended by Bardin (2011) in content analysis were followed.

To ensure the reliability of the analysis, the category system was subjected to a process of inter-subjective validation among the team's researchers, discussing divergences and reaching a consensus on the final classification. This procedure guaranteed interpretative coherence and strengthened the consistency of the analysis.

This study does not need the endorsement of an ethics committee due to the irreversible anonymized treatment of the data used, according to the Organic Law 3/2018, of December 5, on the Protection of Personal Data and Guarantee of Digital Rights (Ley Orgánica, 2018). For the application of the regulations, the Basic Guide to Anonymization of the Spanish Data Protection Agency (Agencia Española de Protección de Datos, 2022) has been followed.

However, the research has been submitted for approval to the Ethics Committee of the Complutense University of Madrid, and was approved with the reference code: 115_CE20241212_17_SOC.

The study participants took part voluntarily. Upon agreeing to participate, they were provided with a hard copy of an "informed consent" document prior to completing the survey. This document informed them that all collected data would remain confidential and be used exclusively for a scientific study conducted by researchers from the Complutense University of Madrid (Spain). To eliminate any potential coercion, the survey administrators emphasized that participation was voluntary and that participants could withdraw at any time. These instructions, along with the email address of the principal investigator (author), were made available to participants who wished to receive the study results or had additional questions. This information was included in the "informed consent" document provided in paper format. Prior to starting the survey, participants were again encouraged to ask any questions they might have regarding the process. Similarly, during and after the survey, the researchers were available to address any questions or concerns that arose during its completion.

3. Results

In this study, nearly 68% of the territory protected under the biosphere reserve designation in Spain was analyzed (see Figure 4). This percentage includes reserves located in 13 of the 17 autonomous communities, ensuring a broad representation of the national territory. In terms of area, the analysis covers a total of 3,656,642 hectares of terrestrial ecosystems and 797,829 hectares of marine spaces, which are part of the Spanish Network of Biosphere Reserves.

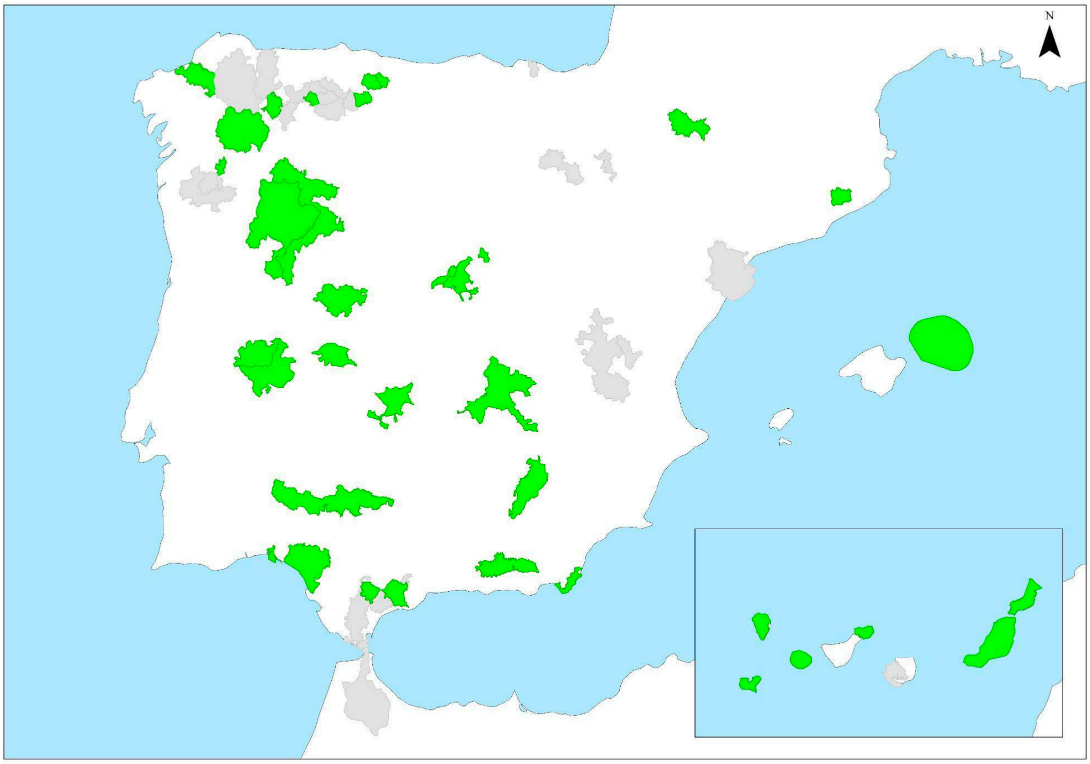


Figure 4. Biosphere reserves in Spain and neighboring countries that share areas with this protected status. The biosphere reserves studied and worked on by the students are shown shaded in green.

The linear correlation analysis, denoted as r, yields a result of 0.1993. When applying Cronbach's alpha coefficient, the formula is as follows:

$$\alpha = 25 \times 0.1993/1 + 0.1993\ (25 - 1) = 0.8615$$

The exploratory analysis through the conducted tests shows that the variability of the 27 involved variables can be explained by the first four factors, using the criterion of selecting factors with eigenvalues greater than 1 (Table 6). The factor analysis allows us to define two major blocks of questions in the questionnaires, based on the different responses given both a priori and a posteriori. As seen in Table 4, questions Q10–Q24, Q26, and Q27 are significantly correlated with factor 1 (F1) of the exploratory factor analysis. The factors are latent variables derived from a set of observed variables (Figure 5).

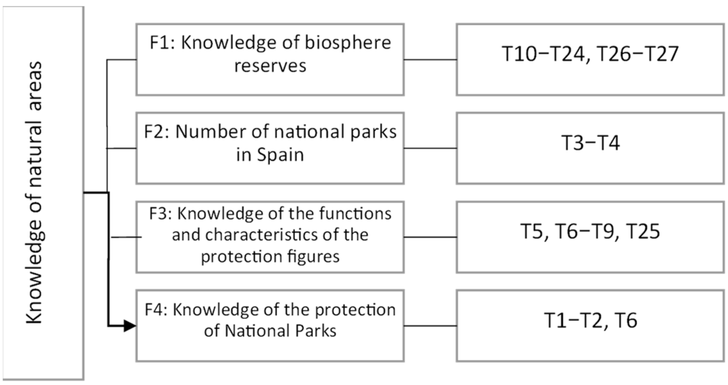


Figure 5. General model for measuring the questionnaire according to factor analysis.

Table 6. Variables under study and their "Cod" coding (Q1–Q27) included in the survey. The factors (F1–F4) are correlated with the variables studied using Spearman's correlation coefficient, with those correlations that are significant at a confidence level of 95%. (*) indicate significant differences at 95% confidence level.

Cod	Variables	F1	F2	F3	F4
	Eigenvalue	9.446	2.158	1.811	1.339
	Variability (%)	34.984	7.993	6.706	4.958
	Cumulative %	34.984	42.977	49.683	54.641
Q1	Do you know any National Parks in Spain?	−0.114	0.116	−0.008	0.845 *
Q2	Number of correct National Parks	0.232	−0.265	0.122	0.613 *
Q3	Number of incorrect National Parks	−0.036	0.966 *	−0.103	0.325
Q4	% Correct/Incorrect	−0.030	−0.826 *	0.036	0.460
Q5	How many National Parks are there in Spain?	0.162	0.119	0.401 *	0.014
Q6	What is/are the function(s) of a Nature Park?	0.087	0.027	0.086	0.093 *
Q7	Do you know the difference between a Natural Park and a Rural Park?	−0.012	−0.065	0.910 *	0.033
Q8	If so, please indicate concisely the differences between the two figures.	−0.037	0.005	0.882 *	0.013
Q9	Who is responsible for the management of the National Parks?	0.030	0.001	0.276 *	0.199
Q10	Do you know what biosphere reserves are?	0.896 *	0.073	0.080	−0.188
Q11	If so, define what a biosphere reserve is.	0.672 *	0.103	0.167	−0.126
Q12	Do you know the Man and the Biosphere (MaB) program?	0.964 *	−0.080	−0.066	−0.019
Q13	What is the role of the MaB program?	0.906 *	−0,.71	0.000	−0.085
Q14	Do you know the zoning of biosphere reserves?	0.965 *	−0.053	−0.059	−0.053
Q15	If yes, indicate the areas that make up the biosphere reserve.	0.957 *	−0.015	−0.047	−0.057
Q16	Are there urban centers within the territory of a biosphere reserve?	−0.776 *	−0.018	−0.071	0.197
Q17	How many biosphere reserves are there in Spain?	0.738 *	0.072	0.054	−0.048
Q18	How many biosphere reserves are there worldwide?	0.767 *	0.047	−0.042	0.127
Q19	On the following scale, indicate the extent to which you are familiar with the functions of biosphere reserves.	0.915 *	0.033	−0.102	−0.014
Q20	Do you think that citizen participation is allowed in the management of biosphere reserves?	−0.488 *	0.055	−0.035	−0.088
Q21	A biosphere reserve is proposed for creation by . . .	0.645 *	−0.028	−0.046	0.189
Q23	Do you know what SAMSAR sites are?	0.720 *	−0.021	0.114	0.068
Q24	Do you know the different types of environmental protection that exist in Spain?	0.359 *	0.028	0.304	−0.074
Q25	In addition to conservation, can you tell me about any other function of the protection figures?	−0.021	−0.021	0.099 *	−0.010
Q26	Do you consider National Parks to be accessible to the population?	0.442 *	0.131	0.129	0.051
Q27	Do you know what the Natura 2000 Network is?	0.254 *	−0.012	−0.107	0.064

In this factor analysis (Table 6), the four factors (F1–F4) highlighted by the exploratory model are summarized. Each factor represents a latent variable that cannot be measured directly, summarizing a series of items. Factor 1 (F1) should be interpreted as the latent variable "Knowledge about Biosphere Reserves" because the significant questions in F1 are related to this concept. Factor 2 (F2) highlights the items related to the lack of knowledge about national parks. Factor 3 (F3) concerns the characteristics and functions of national parks, while Factor 4 (F4) pertains to knowledge of these protective designations of national parks.

These latent variables are theoretical constructs that cannot be directly measured but are inferred from the correlations between observed variables. The factors represent the underlying dimensions that explain the interrelationships among the measured variables in the analysis. To more clearly determine these possible groups of variables, the principal component analysis (PCA) grouped the questions related to the students' a priori and a posteriori knowledge about biosphere reserves, their functions, social implications, and the MaB (Man and the Biosphere) program (Figure 6). Therefore, factor F1 represents the questionnaire questions related to biosphere reserves. The remaining factors (F2–F4) summarize the rest of the variables corresponding to questions related to general aspects of different protected areas in Spain, their number, management, functions, etc. Similarly, the first two principal components (D1 and D2) clearly confirmed these two groups, combining 44.43% of the total variability in these first two components.

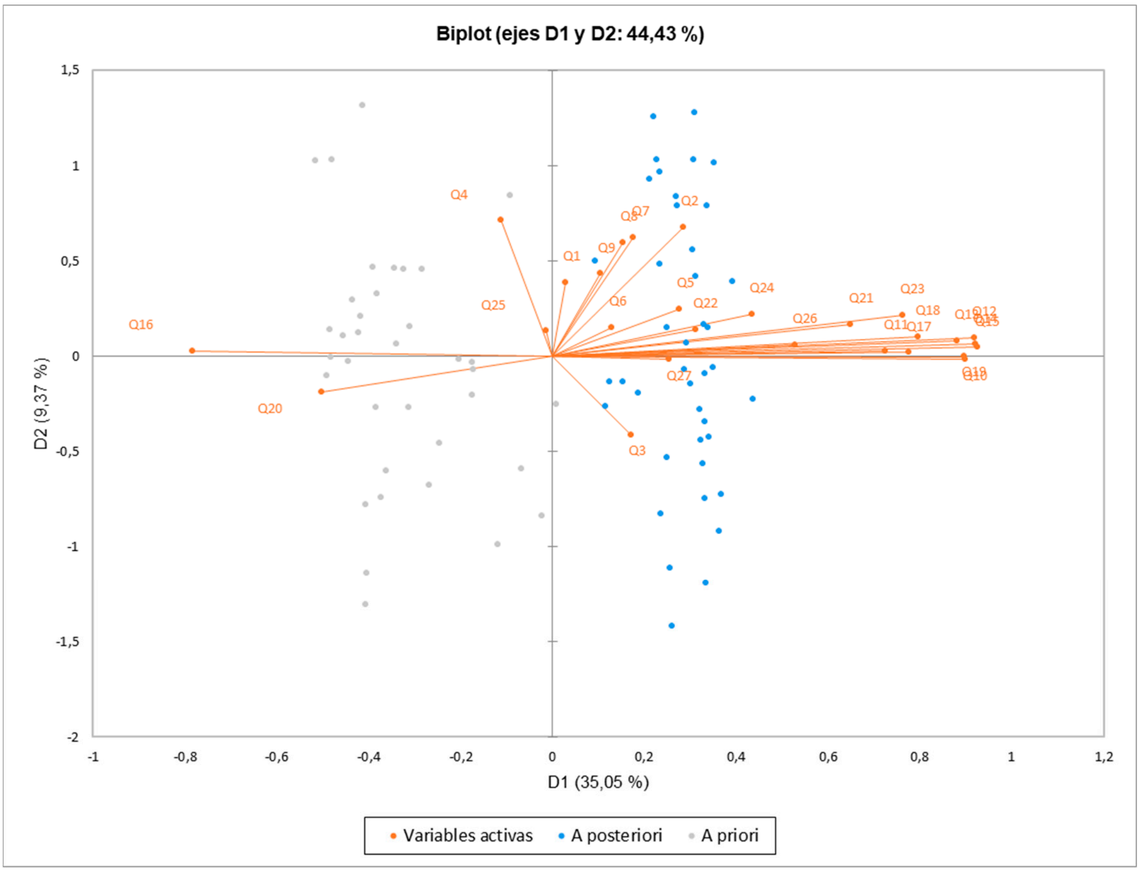


Figure 6. Principal component analysis of the different variables corresponding to each of the questions answered in the questionnaire. The orange ellipse shows variables directly related to specific knowledge about biosphere reserves, while the green ellipse encompasses questions related to general knowledge about protected natural areas.

The use of an initial exploratory factor analysis reduces the studied variables to a few factors in a multivariate analysis, improving data comprehension. Subsequently, the use of a PCA more reliably establishes which groups of variables form based on the responses given. These exploratory analyses have clearly identified two sets of questions: control questions regarding knowledge of protected areas, and questions assessing whether classroom work on the content of biosphere reserves in Spain has resulted in significant knowledge acquisition (Figure 7).

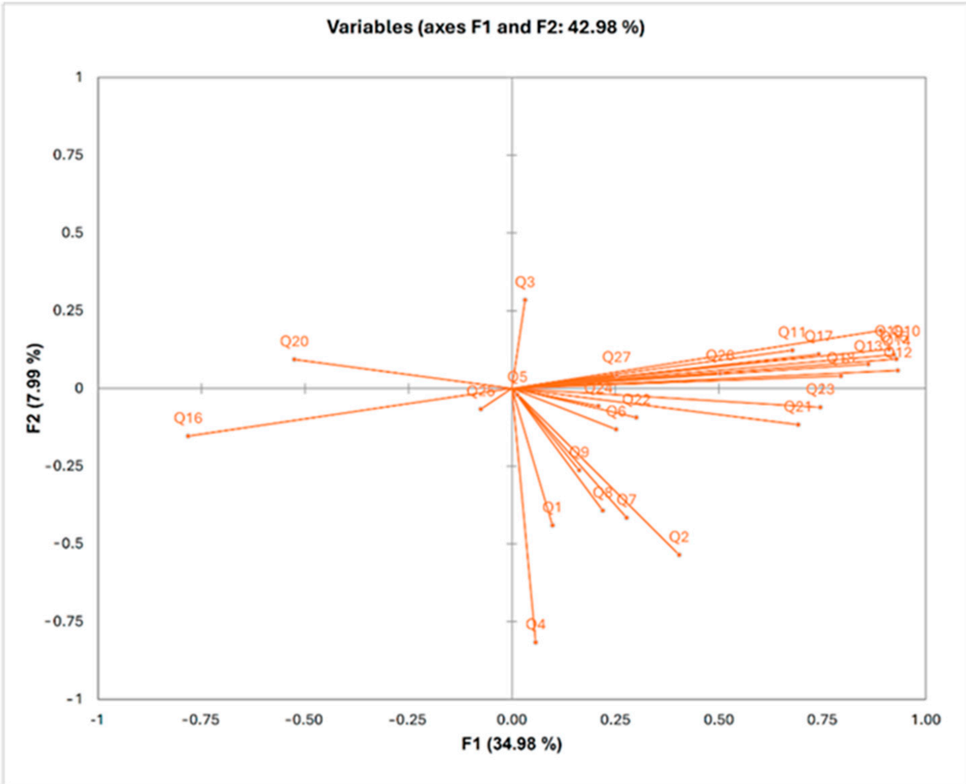


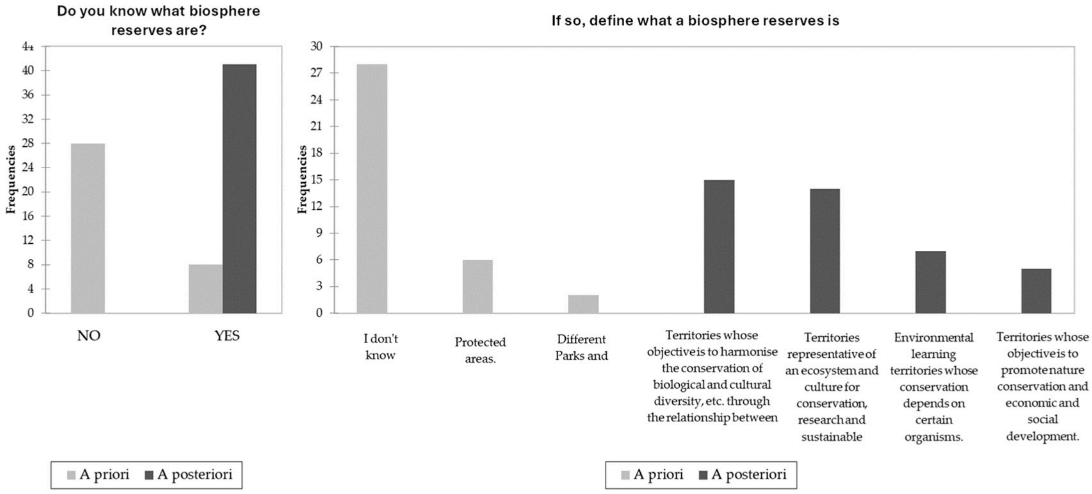
Figure 7. Factor analysis of the different variables corresponding to each of the questions answered in the questionnaire.

In relation to knowledge about the functions and implications of biosphere reserves, it is observed that students do not have a priori a formed idea of what biosphere reserves are (Figure 8a,b), so we must focus on the two questions that directly seek to clarify this fact.

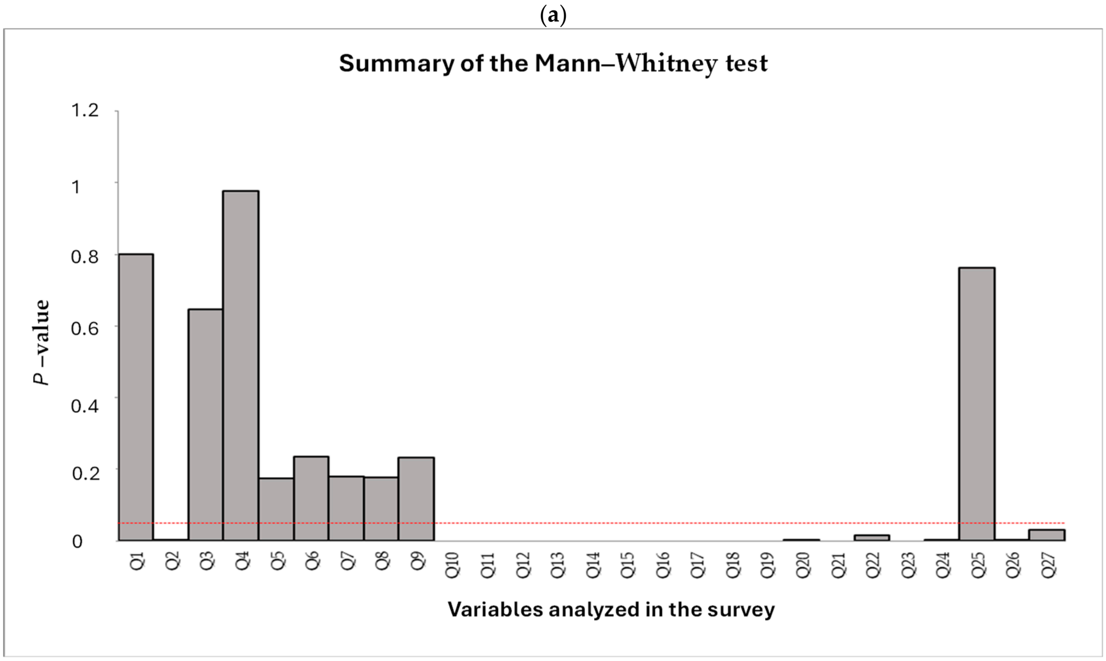
As observed in Figure 6, once the students had worked on and acquired knowledge about biosphere reserves, their post-intervention responses changed significantly compared to their pre-intervention responses. Initially, although most students (28 out of 41) did not know what these protected areas were, those who answered affirmatively limited their definitions to "protected areas" or "various parks and reserves". This demonstrates the general lack of knowledge among future primary school teachers in Spain about this type of protection. However, after the intervention, 100% of the students became familiar with the concept of a "biosphere reserve", providing several responses related to the concept, such as the following:

- "Territories aimed at harmonizing the conservation of biological, cultural diversity, etc., through the relationship between people and nature".
- "Territories representative of an ecosystem and a culture for conservation, research, and sustainable development".
- "Environmental learning territories whose conservation depends on specific organizations".

- “Territories aimed at promoting nature conservation and economic and social development”.



(**a**)



(**b**)

Figure 8. (**a**) Responses on knowledge of biosphere reserves, as well as the definition of biosphere reserves, before and after working on the concepts. Chi^2 test shows differences between a priori and a posteriori responses on both questions with a p-value < 0.00001. (**b**) p-values corresponding to the comparative analysis of means of the Mann–Whitney test for each of the questions considered. Values below the line indicate that there were significant differences between the responses in the pre-test and post-test with a p-value < 0.05.

The Mann–Whitney comparative analysis allows for the determination of differences between responses given before and after the educational intervention on biosphere reserves. As shown in Figure 6, there are variables with significant differences. The comparison of mean scores for various factors before and after the intervention reveals that the questions corresponding to F1 (see Table 6), which are related to students’ direct knowledge of biosphere reserves, show significant changes in responses. In contrast, the general questions about various protected areas in Spain do not show differences. Therefore, the work on biosphere reserves concepts has had a significant and relevant impact on students’ knowledge levels, as illustrated in Figure 9. Additionally, the knowledge gained about biosphere reserves has enabled students to respond more accurately to broader ecological concepts, influencing their future perception of conservation. For instance, in questions P26, "Do you know what the Natura 2000 Network is?", and P27, "What is an ecosystem?", the most common post-intervention response was "the relationship between living organisms and their environment (biotic and abiotic)" (see Tables 6–8).

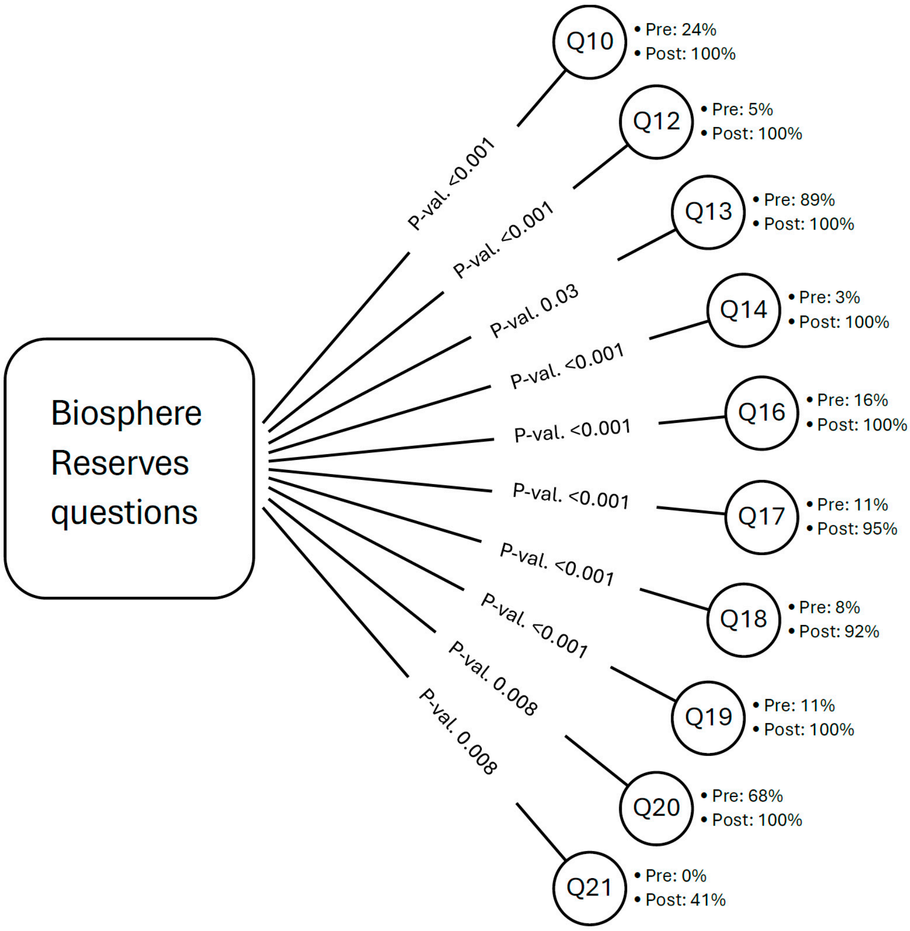


Figure 9. Percentage of correct answers in the pre-test (pre) and post-test (post) in the questions directly related to the conceptual field of biosphere reserves. *p*-val. represents the *p*-value of the statistical significance of the difference in means between the correct answers given without working on the contents (pre-test) and after working on the conceptual field of biosphere reserves (post-test).

Table 7. Effect size analysis using Cohen's d categorized into small, moderate, and large.

Variable	Cohen's d	Interpretation
Do you know any National Parks in Spain?	−0.04	Small (<0.2)
Number of correct National Parks	−0.8	Large (>0.8)
Number of incorrect National Parks	0.07	Small (<0.2)
% Correct/Incorrect	−0.12	Small (<0.2)
How many National Parks are there in Spain?	0.27	Moderate (0.2–0.5)
What is/are the function(s) of a Nature Park?	−0.44	Moderate (0.2–0.5)
Do you know the difference between a Natural Park and a Rural Park?	−0.33	Moderate (0.2–0.5)
If so, please indicate concisely the differences between the two figures.	−0.28	Moderate (0.2–0.5)

Table 7. *Cont.*

Variable	Cohen's d	Interpretation
Who is responsible for the management of the National Parks?	−0.29	Moderate (0.2–0.5)
Do you know what biosphere reserves are?	−2.7	Large (>0.8)
If so, define what a biosphere reserve is.	−1.36	Large (>0.8)
Do you know the Man and the Biosphere (MaB) program?	−8.54	Large (>0.8)
What is the role of the MaB program?	−3.41	Large (>0.8)
Do you know the zoning of biosphere reserves?	−5.97	Large (>0.8)
If yes, indicate the areas that make up the biosphere reserve.	−5.99	Large (>0.8)
Are there urban centers within the territory of a biosphere reserve?	1.93	Large (>0.8)
How many biosphere reserves are there in Spain?	−1.83	Large (>0.8)
How many biosphere reserves are there worldwide?	−2.41	Large (>0.8)
On the following scale, indicate the extent to which you are familiar with the functions of biosphere reserves.	−3.86	Large (>0.8)
Do you think that citizen participation is allowed in the management of biosphere reserves?	1.04	Large (>0.8)
A biosphere reserve is proposed for creation by . . .	−1.59	Large (>0.8)
Do you know what SAMSAR sites are?	−0.56	Medium (0.5–0.8)
Do you know the different types of environmental protection that exist in Spain?	−2.13	Large (>0.8)
In addition to conservation, can you tell me about any other function of the protection figures?	−0.27	Moderate (0.2–0.5)
Do you consider National Parks to be accessible to the population?	0.14	Small (<0.2)
Do you know what the Natura 2000 Network is?	−0.86	Large (>0.8)

Table 8. Chi-square analysis of the items, *p*-values followed by (*) indicate significant differences at 95% confidence level.

Item	Chi-Square (Observed Value)	Chi-Square (Critical Value)	*p*-Value
Do you know any National Parks in Spain?	0.028	3841	0.868
N.P. Correct	15,802	14,067	0.027 *
P.N. Incorrect	6.65	9488	0.156
% Correct/Incorrect	10,054	18,307	0.436
how many National Parks are there in Spain?	12,544	7815	0.006 *
What are the functions of a Natural Park?	6342	11.07	0.274
Do you know the difference between a Natural Park and a Rural Park?	2089	3841	0.148
If so, indicate concisely the differences between the two figures.	9289	11.07	0.098
Who is responsible for the management of the National Parks?	1736	5991	0.42
Do you know what biosphere reserves are?	50,111	3841	<0.0001 *
If yes, define what a biosphere reserve is.	77	12,592	<0.0001 *
Do you know the Man and the Biosphere (MaB) program?	73,079	3841	<0.0001 *
What is the role of the MaB program?	65,901	9488	<0.0001 *
Do you know the zoning of the biosphere reserves?	69,389	3841	<0.0001 *
If yes, indicate the zones that compose it, separated by commas.	77	11.07	<0.0001 *
Are there urban centers within the territory of a biosphere reserve?	55,269	5991	<0.0001 *
How many biosphere reserves are there in Spain?	59,875	12,592	<0.0001 *
How many biosphere reserves are there worldwide?	49,768	11.07	<0.0001 *

Table 8. *Cont.*

Item	Chi-Square (Observed Value)	Chi-Square (Critical Value)	*p*-Value
On the following scale, indicate to what degree you are familiar with the functions of biosphere reserves.	66,623	9488	<0.0001 *
Do you think that citizen participation is allowed in the management of biosphere reserves?	16,746	5991	0.003 *
A biosphere reserve is proposed for creation by . . .	46.51	9488	<0.0001 *
Do you know what SAMSAR sites are?	5714	3841	0.017 *
Do you know the different figures of environmental protection that exist in Spain?	53,086	9488	<0.0001 *
In addition to conservation, can you tell me any other function of the protection figures?	40,997	14,067	<0.0001 *
Do you consider National Parks to be accessible to the population?	4642	5991	0.098
Do you know what the Natura 2000 Network is?	12.18	3841	0.004 *

In the analysis of the Cohen's Kappa concordance index, a value of $\kappa = 0.81$ was obtained, indicating a high degree of agreement according to the established standards (Landis & Koch, 1977; Cohen et al., 2018). In Cohen's study, three groups were classified based on the effect size: a very small effect when $d < 0.2$; a moderate effect when $0.2 \leq d < 0.5$, with the effect being small but tending towards moderate; moderate when $0.5 \leq d < 0.8$; and finally, a large effect when $d \geq 0.8$, which clearly differentiates between the groups. Regarding the level of knowledge before and after the educational intervention, significant differences were observed in 13 cases with a p-value < 0.0001, in 5 cases with p-values ranging from 0.003 to 0.027, and in 8 cases with no significant differences, with p-values ranging from 0.098 to 0.868 (Table 8). This indicates that, in most cases, students improved their knowledge and motivation regarding Natural Parks and biosphere reserves.

Given these significant differences in learning, it is evident that the educational intervention, through direct engagement with the natural environment, led to a learning success rate exceeding 70%, thus largely achieving the intended objectives.

On the other hand, the work on the aforementioned concepts did not significantly change the issues related to the different types and functions of other protected natural areas contemplated in Spanish legislation, as well as in other aspects of scientific literacy and climate change (Mitchell, 2023) related to their location or name. However, there has been a significant change in the number of nature parks that pupils know correctly (Q2).

4. Discussion

The measure of the reliability of the scale used through Cronbach's alpha coefficient presents a value of 0.8615, which, being between 0.7 and 0.9, demonstrates that there is internal consistency in the scale used.

To achieve an effective change in behavior towards the environmental crisis, numerous publications emphasize the need to use methodologies and learning strategies in educational settings to develop pro-environmental competencies and actions (Molano Niño et al., 2012; Sauvé, 2004; Mendoza-Fernandez et al., 2023; Cano-Ortiz, 2023). The concept of sustainable development emerged as a critique of the model of economic growth without respect for the environment. Thus, in the 1970s (Zarta Ávila, 2018), economic growth was criticized as the basis for development, introducing the concept of ecodevelopment. This highlighted the need for an ethics that values and respects diversity. A new economy and social development based on ecological, moral, and cultural principles should emerge as a condition for the component of environmental sustainability (Leff, 2006). One of the main objectives of the study was to evaluate whether students' prior conceptions were based on scientific knowledge about protected areas, particularly biosphere reserves. The data indicated a lack of such knowledge, reflecting a poor acquisition of information on protected areas and conservation measures. After applying the inquiry-based methodology, a more current understanding of the nature of science was observed, with greater knowledge of sustainable development and conservation proposals, implementing various teaching–learning methodologies (Greca et al., 2017). This is particularly relevant as this need for science education is included as one of the functions of biosphere reserves established by the Madrid Action Plan (UNESCO, 2008). Pre-test results show a low level of knowledge about biosphere reserves and other protected areas, which devalues the sustainable vision these protection figures should embody. It is necessary to promote natural spaces as learning laboratories since unconventional educational environments, such as natural parks and botanical gardens, have traditionally strengthened the formal education curriculum (Angarita, 2017). Based on our results and on the narrative of authors such as Guillén (1996) and Cano-Ortiz et al. (2024), there are only two unequivocal options: continuing with a development model that depletes natural resources or working towards sustainable resource exploitation, for which the participation of the educational system is essential.

Although, in this initial phase of the research, the educational intervention focused on activities involving analysis and documentary research on biosphere reserves (BRs), without incorporating in-person field trips to natural environments, the importance of direct contact with nature is acknowledged as a key component for deepening the understanding of conservation principles. Various studies (Ballantyne & Packer, 2009; Rickinson, 2001) have demonstrated that educational experiences grounded in direct interaction with the natural environment foster not only cognitive learning but also the development of attitudes such as respect, empathy, and a commitment to the environment.

Therefore, as a projection of future lines of research, it is proposed to design and implement didactic proposals that incorporate field visits and activities within the biosphere reserves (BRs) themselves. This aims to enhance experiential learning and foster a closer emotional connection between students and natural environments, in alignment with current approaches to education for sustainable development (UNESCO, 2017).

Synthesis of Findings and Educational Implications

The results of this study highlight the educational value of biosphere reserves (BRs) as significant contexts for science teaching and education for sustainable development. Through an inquiry-based intervention and a pre-test–post-test design, a significant improvement was observed in students' understanding of the objectives and functions of these protected areas. Students demonstrated a deeper understanding of key concepts such as biodiversity conservation, zoning, and the balance between development and sustainability.

Additionally, a shift in student perception was observed, with students beginning to view BRs not only as spaces for environmental protection but also as valuable settings for learning and knowledge generation. The inquiry methodology proved effective in facilitating the understanding of complex content, promoting active participation, and strengthening the connection between scientific knowledge and its real-life applications.

Regarding practical implications, the findings suggest a need to more explicitly integrate content related to nature reserves and other protected areas into basic education curricula. This would contribute to developing a more informed and engaged citizenry, better equipped to address current environmental challenges.

From a teacher-training perspective, it is crucial to strengthen the preparation of future educators in active methodologies such as inquiry, as well as in their understanding of protected natural areas and their educational potential. This training can have a direct impact on the quality of environmental education delivered in the classroom.

Furthermore, the results highlight the importance of establishing lasting connections between schools, BR managers, and environmental organizations. Such collaborations would facilitate the design of contextualized educational activities, including field experiences that foster meaningful learning and the development of responsible attitudes toward the environment.

Looking ahead, further research into the impact of various teaching approaches on students' understanding and awareness of sustainability is a priority. This would enable more effective adaptation of pedagogical strategies to address the challenges of contemporary environmental education.

The data obtained in the pre-test show little correlation between the functions of conservation and sustainable development; this reaffirms the lack of social scientific literacy, (Membiela Iglesia, 1997), and the experiments of authors such as Garmendia Mujika and Guisasola Aranzabal (2015), who obtained positive results on scientific literacy through the use of workshops in schools, are interesting. Recently, Guerrero Fernández et al. (2022) in a study on environmental literacy among teachers concluded that, in the pilot experience, teachers had limited socio-environmental knowledge. Consequently, they could not effectively transmit concepts of conservation and sustainable development, leading to a lack of understanding of these fundamental environmental values among their future students in compulsory education. These values are neither transmitted nor acquired by society, as they are not included in the "Boletín Oficial del Estado Español" (B.O.E., 2022). Our results are in line with authors such as Delgado (2005), suggesting that environmental education should be a tool for social awareness and the foundation for environmental knowledge. States must reorient environmental teaching from the early stages of education to higher education.

However, as demonstrated by the results of the educational intervention, future teachers acquire knowledge of fundamental environmental values, enabling them to share this knowledge with their students. The intervention led to significant improvements in learning, with over 70% positive feedback, thereby achieving the proposed objectives.

Authors like Kostøl et al. (2023) consider that developing knowledge about the nature of science is essential to produce scientifically literate citizens. They suggest incorporating Natural Sciences (Biology, Chemistry, and Physics) into curricula, with biosphere reserves serving as ideal laboratories for meaningful learning. It is necessary to increase students' knowledge and motivation regarding protection figures, especially biosphere reserves, as school sensitization is insufficient. This is crucial for achieving the Sustainable Development Goals of the 2030 Agenda. The effectiveness of didactic actions depends on the teachers' willingness and awareness, as they are not formally included in the curriculum. Zarta Ávila (2018), Tilbury (1995), and Solano (2008) indicate that education should be viewed as a social process, detached from a merely curricular approach. Therefore, environmental education must facilitate the involvement of the local population in territorial management. Environmental education for sustainable development should aim to raise social awareness and sensitivity. Linking knowledge to concrete reality helps to solve real, everyday problems and facilitates learning directed at solving developmental issues. This requires clear and well-defined objectives and processes (Jiménez et al., 2022; Caruso, 2022).

One of the main limitations identified is not the diversity of settings, as the educational intervention was carried out in multiple biosphere reserves, allowing for the comparison of different realities. However, it is acknowledged that, at the curricular level, significant structural barriers remain to the systematic integration of these protected areas as teaching resources within formal educational programs. The lack of explicit recognition in the curriculum, limited teacher training in outdoor methodologies, and the perception of protected areas as remote or restricted spaces hinder their continued and widespread use within the educational system (UNESCO, 2017).

Likewise, a limitation related to equitable access to these experiences for the school population has been identified. Factors such as geographic location, logistical resources, and socioeconomic inequalities can limit students' actual contact with these privileged environments, thereby reproducing participation gaps in sustainability education (Reid et al., 2008).

Among future lines of research, the following are proposed:

- Analyze models of institutional collaboration between schools and biosphere reserve managers to facilitate their incorporation into the curriculum and their connection to the Sustainable Development Goals.
- Study teacher-training strategies for using protected natural areas as platforms for interdisciplinary and transformative learning.
- Design and evaluate pilot programs for inclusive outdoor education aimed at overcoming access barriers and promoting equitable participation for the entire school community.

These proposals aim to strengthen the role of BRs as living educational settings, capable of fostering critical ecosocial competencies to address the challenges of the 21st century.

5. Conclusions

This study has revealed significant findings regarding the role of biosphere reserves (BRs) in science education and sustainable development education. Through a pre-test–post-test experimental design, it was observed that the inquiry-based educational intervention had a significant impact on students' knowledge and understanding of BRs and their importance in environmental conservation and sustainable development.

A significant increase in students' knowledge about the functions and objectives of BRs was evidenced after the educational intervention. Students demonstrated a better understanding of concepts related to biodiversity conservation, sustainable development, and BR zoning.

The perception of BRs as vital tools for conservation and education improved markedly. Students recognized the importance of these protected areas not only as sites for environmental preservation but also as living laboratories for education and research.

The inquiry-based learning methodology proved effective in teaching complex concepts related to environmental sciences and components of environmental sustainability. This approach allowed students to actively engage in the learning process, enhancing their comprehension and retention of the content.

It is recommended to include content about BRs and other protected areas in primary and secondary school curricula. This will contribute to greater awareness and knowledge from an early age about the importance of conservation and sustainable development.

Strengthening the training of future educators in the area of sustainability and environmental conservation is crucial. Training in inquiry methodologies and familiarity with BRs can significantly improve the quality of environmental education provided.

Encouraging collaboration between educational institutions, environmental organizations, and BR managers is suggested to develop educational programs and field activities that enrich students' learning experiences.

Continued research is necessary to evaluate the impact of different educational methodologies on understanding and awareness of environmental conservation and sustainable development. This will allow for the adjustment and improvement of the pedagogical strategies used.

These findings, along with their educational implications and strategic recommendations, are summarized in Table 9, which provides a comprehensive overview of the outcomes of the study and proposed actions for educational stakeholders.

Table 9. Summary of findings, implications, and recommendations of the study.

Category	Description	Implications/Recommendations
Finding 1: Improved knowledge	Significant increase in student understanding of BRs and their role in sustainability.	Integrate BR content into basic education curricula.
Finding 2: Change in perception	Recognition of BRs as educational spaces and not just conservation spaces.	Promote BRs as pedagogical resources in curriculum design.
Finding 3: Effectiveness of the inquiry approach	The inquiry-based methodology facilitated the understanding of complex content.	Promote active methodologies in science and sustainability teaching.
Implication in educational policy	Sustainability education must begin at an early stage.	Include environmental education in regulatory frameworks and official curricula.
Implication in teacher training	Specific training in research and knowledge of protected areas is required.	Strengthen initial and continuing teacher-training programs in environmental education.
Inter-institutional collaboration	Partnerships between schools, BR managers, and NGOs enrich the educational experience.	Promote joint programs and field activities between educational centers and environmental entities.
Future line of research	Need to evaluate other methodologies and their effects on environmental awareness.	Develop comparative research on didactic approaches in education for sustainability.

Author Contributions: Conceptualization, A.C.-O. and J.P.-M.; Methodology, A.C.-O.; Software, J.C.P.-F.; Validation, A.C.-O., C.M.M. and J.P.-M.; Formal analysis, A.C.-O.; Investigation, A.C.-O.; Resources, J.P.-M.; Data curation, J.C.P.-F.; Writing – original draft, A.C.-O.; Writing—review & editing, A.C.-O.; Visualization, C.M.M.; Supervision, J.P.-M.; Project administration, A.C.-O.; Funding acquisition, J.P.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Informed consent for participation was obtained from all subjects involved in the study. And the approval of the Ethics Committee of the Complutense University is available with Ref. No. 115_CE20241212_17_SOC. (30 January 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. This research has been submitted for approval to the Ethics Committee of the Complutense University of Madrid and was approved with the reference code: 115_CE20241212_17_SOC.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

Agencia Española de Protección de Datos. (2022). *Guía básica de anonimización*. Available online: https://www.aepd.es/documento/guia-basica-anonimizacion.pdf (accessed on 3 March 2025).

Angarita, T. E. R. (2017). El sentido educativo de los espacios no convencionales de educación (ENCE) tipo jardines botánicos: Un estudio de caso. In *Enseñanza de las ciencias: Revista de investigación y experiencias didácticas, núm* (pp. 3411–3416). Universidad Distrital Francisco José de Caldas.

Archila, P. A. (2012). La investigación en argumentación y sus implicaciones en la formación inicial de profesores de ciencias. *Revista Eureka Sobre Enseñanza y Divulgación de las Ciencias*, *9*(3), 361–375. Available online: https://revistas.uca.es/index.php/eureka/article/view/2783 (accessed on 1 January 2025). [CrossRef]

Artigue, M., Baptist, O., Dillon, J., Harlen, W., & Léna, O. (2013). *The Fibonacci project to science and mathematics education: A systemic approach for sustainable implementation and dissemination of inquiry pedagogy* (W. Harlen, & P. Léna, Eds.). Fondation La Main à la Pâte. Available online: https://fondation-lamap.org/sites/default/files/pdf_res_int/fibonacci_book.pdf (accessed on 13 December 2024).

Ärlemalm-Hagsér, E., & Sandberg, A. (2011). Sustainable development in early childhood education: In-service students' comprehension of the concept. *Environmental Education Research*, *17*(2), 187–200. [CrossRef]

Ballantyne, R., & Packer, J. (2009). Introducing a fifth pedagogy: Experience-based strategies for facilitating learning in natural environments. *Environmental Education Research*, *15*(2), 243–262. [CrossRef]

Bardin, L. (2011). *Análise de Conteúdo* (Vol. 70). Edições.

Beames, S., Higgins, P., & Nicol, R. (2012). *Learning outside the classroom: Theory and guidelines for practice*. Routledge.

Bentsen, P., Jensen, F. S., Mygind, E., & Randrup, T. B. (2009). The extent and dissemination of udeskole in Danish schools. *Urban Forestry & Urban Greening*, *9*(3), 235–243. [CrossRef]

B.O.E. (2022). *Real decreto 217/2022, de 29 de marzo, por el que se establece la ordenación y las enseñanzas mínimas de la educación secundaria obligatoria*. Boletín Oficial del Estado. Available online: https://www.boe.es/buscar/act.php?id=BOE-A-2022-4975 (accessed on 2 November 2024).

Bruchner, P. (2012). Escuelas infantiles al aire libre. *Cuadernos de Pedagogía*, *420*, 26–29.

Burkhard, B., Petrosillo, I., & Costanza, R. (2010). Ecosystem services: Bridging ecology, economy and social sciences. *Ecological Complexity*, *7*(3), 257–259. [CrossRef]

Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education*, *25*(2), 211–221. [CrossRef]

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness*. BSCS.

Cano-Ortiz, A. (2023). Teaching about biodiversity from phytosociology: Evaluation and conservation. *Plant Sociology*, *60*, 25–37. [CrossRef]

Cano-Ortiz, A., Piñar Fuentes, J. C., Rodrigues Meireles, C. I., & Cano, E. (2024). Urban natural spaces as laboratories for learning and social awareness. *Sustainability*, *16*(8), 3232. [CrossRef]

Caruso, G. (2022). Calabrian native project: Botanical education applied to conservation and valorization of autochthonous woody plants. *Research Journal of Ecology and Environmental Sciences*, *2*(2), 47–59. [CrossRef]

Charles, C., Keenleyside, K., Chapple, R., Kilburn, B., Salah van der Leest, P., Allen, D., Richardson, M., Giusti, M., Franklin, L., Harbrow, M., Wilson, R., Moss, A., Metcalf, L., & Camargo, L. (2018). *Home to us all: How connecting with nature helps us care for ourselves and the Earth*. Children & Nature Network. Available online: https://iucn.org/resources/grey-literature/connecting-nature-care-ourselves-and-earth (accessed on 14 January 2025).

Chawla, L. (2020). Childhood nature connection and constructive hope: A review of research on connecting with nature and coping with environmental loss. *People and Nature*, *2*(3), 619–642. [CrossRef]

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge. [CrossRef]

Crespo Castellanos, J. M., Gómez Ruiz, M. L., & Cruz, J. M. (2018). Una aproximación a los parques nacionales y sus paisajes a través de itinerarios didácticos. *Espacio, Tiempo y Forma. Serie VI, Geografía*, *11*, 121–140. Available online: https://revistas.uned.es/index.php/ETFVI/article/view/22359 (accessed on 5 January 2025). [CrossRef]

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research* (3rd ed.). Sage Publications.

Delgado, H. A. M. (2005). La educación ambiental como herramienta social. *Geoenseñanza*, *10*(1), 61–67.

Dillon, J., Rickinson, M., Teamey, K., Morris, M., Choi, M. Y., Sanders, D., & Benefield, P. (2006). The value of outdoor learning: Evidence from research in the UK and elsewhere. *School Science Review*, *87*(320), 107–111.

Dong, L., & Huang, Z. (2023). Some evidence and new insights for feedback loops of human-nature interactions from a holistic Earth perspective. *Journal of Cleaner Production*, *432*, 139667. [CrossRef]

Dudley, N. (Ed.). (2008). *Guidelines for applying protected area management categories* (Best Practice Protected Area Guidelines Series No. 21). IUCN. Available online: https://portals.iucn.org/library/sites/library/files/documents/pag-021.pdf (accessed on 8 October 2024).

Elmasri, R., & Navathe, S. B. (2016). *Fundamentals of database systems* (7th ed.). Pearson.

Fägerstam, E., & Blom, J. (2013). Learning biology and mathematics outdoors: Effects and attitudes in a Swedish high school context. *Journal of Adventure Education and Outdoor Learning*, *13*(1), 56–75. [CrossRef]

Ferreira, J. A., Ryan, L., & Tilbury, D. (2012). Whole-school approaches to sustainability: A review of models for professional development in pre-service teacher education. *Australian Journal of Environmental Education*, *28*(2), 29–47.

Garmendia Mujika, M., & Guisasola Aranzabal, J. (2015). Alfabetización científica en contextos escolares: El Proyecto Zientzia Live! *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, *12*(2), 294–310. Available online: https://revistas.uca.es/index.php/eureka/article/view/2922 (accessed on 16 October 2024). [CrossRef]

Gillies, R. M. (2016). Cooperative learning: Review of research and practice. *Australian Journal of Teacher Education*, *41*(3), 39–54. [CrossRef]

Greca, I. M., Meneses Villagrá, J. A., & Diez Ojeda, M. (2017). La formación en ciencias de los estudiantes del grado en maestro de Educación Primaria. *Revista Electrónica de Enseñanza de las Ciencias*, *16*(2), 231–256. Available online: http://reec.uvigo.es/volumenes/volumen16/REEC_16_2_4_ex1068.pdf (accessed on 11 November 2024).

Guerrero Fernández, A., Rodríguez Marín, F., López Lozano, L., & Solís Ramírez, E. (2022). Alfabetización ambiental en la formación inicial docente: Diseño y validación de un cuestionario. *Enseñanza de las Ciencias*, *40*(1), 25–46. [CrossRef]

Guillén, F. C. (1996). Educación, medio ambiente y desarrollo sostenible. *Revista Iberoamericana de Educación*, *11*, 103–110. [CrossRef]

Haro, J. (1983). *Calidad y conservación del medio ambiente* (Cuadernos de estudio 10). Cincel.

Hedden-Dunkhorst, B., & Schmitt, F. (2020). Exploring the potential and contribution of UNESCO biosphere reserves for landscape governance and management in Africa. *Land*, *9*(8), 237. [CrossRef]

Heras, M., & Tàbara, J. D. (2014). Let's play transformations! Performative methods for sustainability. *Sustainability Science*, *9*(3), 379–398. [CrossRef]

i-bejar.com. (2024, January 10). *Escolares de las sierras de Béjar y Francia participan en un programa de educación ambiental*. Available online: https://www.i-bejar.com/noticias/bejar/escolares-sierras-bejar-francia-participan-programa-educacion-ambiental-34511.htm (accessed on 1 January 2025).

Ishwaran, N., Persic, A., & Tri, N. H. (2008). Concept and practice: The case of UNESCO biosphere reserves. *International Journal of Environment and Sustainable Development*, *7*(2), 118–131. [CrossRef]

Jiménez, Y. M., Castro Acevedo, G. P., & Cebey Sánchez, J. A. (2022). The Cuabal of Callejón de Los Patos, in Santa Clara: Need for its sustainability. *Research Journal of Ecology and Environmental Sciences*, *2*(2), 23–46. [CrossRef]

Johnson, D. W., & Johnson, R. T. (2017). Cooperative learning and teaching citizenship in democracies. *International Journal of Educational Research*, *82*, 159–168. [CrossRef]

Jonsson, A., & Svingby, G. (2007). The use of scoring rubrics: Reliability, validity and educational consequences. *Educational Research Review*, *2*(2), 130–144. [CrossRef]

Kostøl, K. B., Bøe, M. V., & Skår, A. R. (2023). Nature of science in Norway's recent curricula reform: Analysis of the biology, chemistry, and physics curricula. *Science & Education*, *32*(5), 1561–1581. Available online: https://link.springer.com/article/10.1007/s11191-022-00399-z (accessed on 20 November 2024).

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159–174. [CrossRef] [PubMed]

Lederman, N. G., Lederman, J. S., & Antink, A. (2019). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science and Technology*, *7*(2), 87–102.

Leff, E. (2006). Ética por la vida: Elogio de la voluntad de poder. *Polis, Revista Latinoamericana*, *13*. Available online: https://dialnet.unirioja.es/servlet/articulo?codigo=2225851 (accessed on 17 January 2025).

Ley Orgánica 3/2018, de 5 de Diciembre, de Protección de Datos Personales y Garantía de los Derechos Digitales. (2018). *Boletín Oficial del Estado, núm. 294*. Available online: https://www.boe.es/buscar/act.php?id=BOE-A-2018-16673 (accessed on 17 January 2025).

Mann, H. B., & Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics*, *18*(1), 50–60. [CrossRef]

McCormick, R. (2017). Does access to green space impact the mental well-being of children? A systematic review. *Journal of Pediatric Nursing*, *37*, 3–7. [CrossRef]

Means, B., Padilla, C., & Gallagher, L. (2010). *Use of education data at the local level: From accountability to instructional improvement*. U.S. Department of Education. Available online: https://files.eric.ed.gov/fulltext/ED511656.pdf (accessed on 17 January 2025).

Membiela Iglesia, P. (1997). Alfabetización científica y ciencia para todos en la educación obligatoria. *Alambique: Didáctica de las Ciencias Experimentales*, *13*, 37–44.

Mendoza-Fernandez, A. L., Arnao, L., Carretero, C., Martínez-Hernández, F., & Sánchez Gomez, J. M. (2023). Threatened wildlife for an instructional approach about biodiversity conservation. *Research Journal of Ecology and Environmental Sciences*, *3*(1), 47–60. [CrossRef]

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). SAGE Publications.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Wetlands and water synthesis*. World Resources Institute. Available online: https://www.millenniumassessment.org/documents/document.358.aspx.pdf (accessed on 3 October 2024).

Mitchell, J. T. (2023). Wicked from the start: Educational impediments to teaching about climate change (and how geography education can help). *Education Sciences*, *13*(12), 1174. [CrossRef]

Molano Niño, A. C., Rodríguez Sánchez, I. M., & Lozano-Rivas, W. A. (2012). La complejidad de la educación ambiental: Una mirada desde los siete saberes necesarios para la educación del futuro de Morin. *Revista de Didáctica Ambiental*, *11*, 1–9.

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2017). Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, *25*(6), 791–812. [CrossRef]

OCDE. (2019). *Estrategia de competencias de la OCDE 2019: Competencias para construir un futuro mejor*. OECD Publishing/Fundación Santillana. Available online: https://www.oecd.org/es/publications/2019/05/oecd-skills-strategy-2019_g1g9ff20.html (accessed on 8 October 2024).

Osborne, J., & Dillon, J. (2010). *Good practice in science teaching: What research has to say*. Open University Press.

Oviedo, H. C., & Campo-Arias, A. (2005). Aproximación al uso del coeficiente alfa de Cronbach. *Revista Colombiana de Psiquiatría*, *34*(4), 572–580. Available online: http://www.scielo.org.co/pdf/rcp/v34n4/v34n4a09.pdf (accessed on 8 October 2024).

Programa de las Naciones Unidas para el Medio Ambiente (PENUMA). (1977). *Declaración de la Conferencia Intergubernamental de Tbilisi sobre Educación Ambiental*. UNESCO. Available online: https://www.minam.gob.pe/cidea7/documentos/Declaracion-de-Tbilisi-1977.pdf (accessed on 23 November 2024).

Red Española de Reservas de la Biosfera (RERB). (2024). *El Programa MaB de la UNESCO*. Ministerio para la Transición Ecológica y el Reto Demográfico. Available online: http://www.rerb.oapn.es/el-programa-mab-de-la-unesco/que-es-reserva-de-la-biosfera (accessed on 15 September 2024).

Reid, A., Jensen, B. B., Nikel, J., & Simovska, V. (Eds.). (2008). *Participation and learning: Perspectives on education and the environment, health and sustainability*. Springer.

Rickinson, M. (2001). Learners and learning in environmental education: A critical review of the evidence. *Environmental Education Research*, *7*(3), 207–320. [CrossRef]

Rieckmann, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? *Futures*, *44*(2), 127–135. [CrossRef]

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walwerg-Henriksson, H., & Hemmo, V. (2007). *Science education now: A renewed pedagogy for the future of Europe*. European Commission. Available online: https://www.europeansources.info/record/science-education-now-a-renewed-pedagogy-for-the-future-of-europe/ (accessed on 11 December 2024).

Rodríguez, E., & Quintanilla, A. L. (2019). Relación ser humano-naturaleza: Desarrollo, adaptabilidad y posicionamiento hacia la búsqueda de bienestar subjetivo. *Avances en Investigación Agropecuaria*, *23*(3), 7–22. Available online: https://revistasacademicas.ucol.mx/index.php/agropecuaria/article/view/238 (accessed on 14 December 2024).

Sampieri, R. H., Collado, C. F., & Lucio, P. B. (2014). *Metodología de la investigación*. McGraw-Hill Education.

Sampieri, R. H., & Mendoza, C. (2018). *Metodología de la investigación: Las rutas cuantitativa, cualitativa y mixta*. McGraw-Hill Interamericana.

Sauvé, L. (2004). *Perspectivas curriculares para la formación de formadores en educación ambiental* (pp. 160–162). Carpeta informativa CENEAM. Available online: https://www.miteco.gob.es/content/dam/miteco/es/ceneam/articulos-de-opinion/2004_11sauve_tcm30-163438.pdf (accessed on 8 January 2025).

Sauvé, L. (2005). Currents in environmental education: Mapping a complex and evolving pedagogical field. *Canadian Journal of Environmental Education*, *10*(1), 11–37. Available online: https://cjee.lakeheadu.ca/article/view/328 (accessed on 8 January 2025).

Schüttler, E., Mackenzie, R., & Muñoz-Petersen, L. (2023). Biocultural conservation in biosphere reserves in temperate regions of Chile, Estonia, Germany, and Sweden. In R. Rozzi, A. Tauro, N. Avriel-Avni, T. Wright, & R. H. May Jr. (Eds.), *Field environmental philosophy* (pp. 483–502). Springer. [CrossRef]

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3–4), 591–611. [CrossRef]

Sivaperuman, C., & Banerjee, D. (2023). Great Nicobar Biosphere Reserve: An overview. In C. Sivaperuman, D. Banerjee, B. Tripathy, & K. Chandra (Eds.), *Faunal ecology and conservation of the great nicobar biosphere reserve* (pp. 3–39). Springer Nature. Available online: https://content.e-bookshelf.de/media/reading/L-18553842-0aa219dd94.pdf (accessed on 8 October 2024).

Slavin, R. E. (2014). Cooperative learning and academic achievement: Why does groupwork work? *Anales de Psicología*, *30*(3), 785–791. [CrossRef]

Smith, G. A. (2002). Place-based education: Learning to be where we are. *Phi Delta Kappan*, *83*(8), 584–594. [CrossRef]

Solano, D. (2008). *Estrategias de comunicación y educación para el desarrollo sostenible [Informe]*. UNESCO-United Nations Educational, Scientific and Cultural Organisation. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000159531 (accessed on 8 October 2024).

Stephens, T. (2023). The Kunming-Montreal global biodiversity framework. *International Legal Materials*, *62*(5), 868–887. [CrossRef]

Sterling, S. (2010). Learning for resilience, or the resilient learner? Towards a necessary reconciliation in a paradigm of sustainable education. *Environmental Education Research*, *16*(5–6), 511–528. [CrossRef]

Teddlie, C., & Tashakkori, A. (2011). Mixed methods research. In N. K. Denzin, & Y. S. Lincoln (Eds.), *The SAGE handbook of qualitative research* (4th ed., pp. 285–300). SAGE.

Tilbury, D. (1995). Environmental education for sustainability: Defining the new focus of environmental education in the 1990s. *Environmental Education Research*, *1*(2), 195–212. [CrossRef]

Tillmann, S., Tobin, D., Avison, W., & Gilliland, J. (2018). Mental health benefits of interactions with nature in children and teenagers: A systematic review. *Journal of Epidemiology and Community Health*, *72*, 958–966. [CrossRef]

UNESCO. (1995). The seville strategy for biosphere reserves. *Nature and Resources*, *31*(2), 2–17. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000262500 (accessed on 27 October 2024).

UNESCO. (2002). *Seville+5 recommendations addressed to the Secretariat (of the MAB)*. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000128063 (accessed on 27 October 2024).

UNESCO. (2008). *Madrid action plan for biosphere reserves (2008–2013)*. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000163301 (accessed on 25 October 2024).

UNESCO. (2012). *El programa MaB y su aplicación en España*. Available online: http://rerb.oapn.es/images/PDF_publicaciones/programa_Mab_Espana_Sintesis.pdf (accessed on 24 October 2024).

UNESCO. (2017). *Educación para los objetivos de desarrollo sostenible: Objetivos de aprendizaje*. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000247444 (accessed on 28 October 2024).

UNESCO. (2020). *Education for sustainable development: A roadmap*. United Nations Educational, Scientific and Cultural Organization. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000374802 (accessed on 2 November 2024).

UNESCO. (2022a). *The Man and the Biosphere (MAB) programme*. Available online: https://www.unesco.org/en/mab (accessed on 2 November 2024).

UNESCO. (2022b). *Biosphere reserves*. Available online: https://www.unesco.org/en/mab/wnbr/about (accessed on 2 November 2024).

United Nations. (2021). *Sustainable development goals: Guidelines for the use of the SDG logo including the colour wheel and 17 icons*. Available online: https://nso.gov.mt/wp-content/uploads/SDG-2021.pdf (accessed on 4 November 2024).

Van Quyen, M. L. (2023). *Cerebro y naturaleza* (6th ed.). Plataforma.

Yin, R. K. (2016). *Qualitative research from start to finish* (2nd ed.). Guilford Publications.

Zarta Ávila, P. (2018). A sustentabilidad o sostenibilidad: Un concepto poderoso para la humanidad. *Tabula Rasa*, *28*, 409–423. [CrossRef]

Zhao, Y., & Frank, K. A. (2003). Factors affecting technology uses in schools: An ecological perspective. *American Educational Research Journal*, *40*(4), 807–840. [CrossRef]

Zohar, A., & Dori, Y. J. (2003). Higher order thinking skills and low-achieving students: Are they mutually exclusive? *The Journal of the Learning Sciences*, *12*(2), 145–181. [CrossRef]