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Impact of Educational Gardens and Workshop Activities on 8th-Grade Student's Perception and Knowledge of Plant Biology

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Abstract: Educational gardens can be a significant resource in the promotion of environmental education, engaging both the school population and the general public. The main goal of the present study was to implement and assess a hands-on interventional program to promote knowledge and awareness of plant-related topics at a basic school level. We report on a hands-on educational project implemented with 8th-grade Portuguese students (mostly 13–14 years of age), associated with the establishment, on school grounds, of three educational gardens representing distinct Portuguese ecosystems. This was a collaborative project and encompassed several activities and subjects, including garden creation, plant propagation and plant care, plant identification, the study of form–function relationships, and lectures by plant researchers. A survey instrument with pre- and post-test assessments demonstrated the effectiveness of the program in raising student knowledge and awareness on topics centered around the native flora. Specifically, we noted that scores increased in all questions addressing different plant biology-related topics in the post-test assessment. This study supports the benefits of incorporating field/laboratory work and educational gardens in educational programs geared toward plant-oriented environmental education.

Keywords: educational gardens; environmental education; native flora; invasive species; plant biodiversity

1. Introduction

Environmental education within schools can be fundamental for intellectual growth. By presenting social alternatives and exposing their advantages and disadvantages, environmental education ultimately enhances awareness of environmental problems, promoting a change in student attitude [1]. Fostering connectedness to nature should be a goal for environmental education programs, and there is an increasing consensus within the scientific community that educational gardens play an important part in this effort. An educational garden is one that, in an appropriate context (e.g., on school grounds), is used mainly for educational purposes and should not be mistaken with other public sites (e.g., outdoor recreational spaces). Educational gardens can be themed toward different subjects, including awareness of the loss of biodiversity, climate change, the proliferation of invasive plant species, or a recognition of the interdependence of people and plants [2,3]. Gardens within the school context also engage students to cultivate an interest in science within a holistic and real-world context [4], but unlike remaining outdoor recreational spaces on school grounds, educational gardens typically cover a variety of subjects relevant to the school's curriculum. Gardens are particularly suited to foster plant-oriented environmental education, and we hypothesized that the implementation of a large educational program anchored on novel educational gardens would increase student knowledge on three plant-oriented topics (native vs. invasive species, plant species identification, and plant adaptability). The present study was motivated by a specific research hypothesis: are educational gardens focused on Portuguese native flora effective for increasing plant-oriented environmental knowledge and awareness when students are involved in field/experimental work on school grounds?

1.1. Benefits of Educational Gardens

At present, there is a strong theoretical framework to support the multiple advantages of educational gardens. Young students tend to define and visualize a good and healthy environment as being outside in a safe, clean, green, and inhabitable space [5]. Research has shown that environmental gardens may enhance student learning by incorporating a hands-on approach to experiential learning, impacting both personal and educational levels [6]. Additionally, these gardens can lead to improved performance and well-being as a result of student engagement [7,8]. Many educators are re-discovering the value of gardens as places for learning in educational institutions, including school and university communities [9–12]. Teachers trust that gardens encourage academic instruction, and it was demonstrated that school gardening can improve students' test scores and school behavior [13]. According to Strgar [14], when appropriate methods are used, teacher involvement can significantly increase the interest in less attractive subjects. The specialized knowledge, enthusiasm, and interest of the teacher or of an informal science educator can greatly enhance the student's interest. As such, the extent of teacher perception of the significance of educational gardens has also been recently studied [3]. Gardens are naturally suited toward the exploitation of plant-oriented topics, but their impact can be extended outside this scope. For instance, with didactic farms, children and young people come into contact with domesticated animals and perceive the reality behind the animals that provide various functions, such as clothing or food. Working with living organisms as a whole is an effective way to improve the quality of biological education since it provides information/experiences that are not accessible via reading, viewing pictures, or examining models [15,16]. Additionally, these gardens provide opportunities for field courses, which improve integrative learning, resulting in learning gains that are recognized and appreciated by students [17].

1.2. Plant-Oriented Environmental Education

As stated, the natural calling of educational gardens is the deployment of plant-oriented topics. We wished to amplify the existing body of literature regarding the interdependence of educational gardens and plant-oriented environmental education, favoring environmental rather than biological science education. We identified three topics around the concept of native flora that are of timely interest: native vs. invasive species, plant species identification, and plant adaptability to climatic variables. For theoretical support, it has been acknowledged that botanical gardens have become important settings for the development of educational programs that increase awareness of the interdependence of people and plants and promote an individual's willingness to protect the environment [18]. The fruition of an educational garden can promote motivation toward the protection of the environment. Gardens can address issues such as native plant species [2], and in this regard, we hypothesize that knowledge of the existing flora and the capacity to identify species can have a motivational role. However, due to the changes in vegetation in urban and peri-urban environments, it is often difficult for children and young people to have contact with forests dominated by native trees since the peripheral areas of large cities are dominated by forest plantations of exotic species that were introduced to areas from outside its native range [19]. As such, educational gardens have an added intrinsic value within the urban environment. This interconnects with the issue of non-native species. A work involving students aged 13 to 15 confirmed the effectiveness of a workshop on invasive plants to raise awareness of this matter [20]. In it, researchers emphasized the identification and management of invasive species and investigated the relationship between native/invasive species, clearly demonstrating the success of the strategy to raise students' knowledge and information retention [20]. The presence of exotic plants in ecosystems does not necessarily represent a significant problem unless these species display the potential for invasion, triggered by advantages such as the absence of pathogens, greater resistance/adaptation, or rapid growth [21]. Under these circumstances, invasive species can spread over large regions and at a considerable distance from the parental specimens [22]. Human beings are potential carriers regarding the introduction and spread of these species, and their deliberate or accidental introduction in ecosystems determines important changes, such as biodiversity reduction [2]. Pimentel and co-workers estimated that the economic cost associated with invasive species impact and control exceeds USD 120 billion per year in the United States, and in this sense, the most adequate strategy is to prevent their introduction [23,24]. According to the Portuguese legislation (Decreto-Lei nº 92/2019, Ministério do Ambiente, 2019), 200+ plants are considered invasive in Portugal. Almeida and Freitas [25] state that more than 15% of the Portuguese flora is composed of exotic plants. Given this reality, public awareness regarding the danger of exotic plants and the significance of Portuguese native flora is important. However, the majority of the population is not conscious of this problem, and in order to increase awareness, environmental/scientific education must be a priority.

1.3. Target Group and Methodology

Considering that educational programs targeting young people contribute to a future generation of scientifically literate and environmentally conscious citizens, the main driver of the present study was to implement and assess a hands-on interventional program to promote knowledge and awareness on plant-related topics at a basic school level (8th-grade, mostly 13–14 years of age). This target group was selected considering that the Portuguese 8th-grade biology teaching curriculum includes global issues such as ecosystem management, Earth's sustainability, and spatial planning. Further, 8th-grade students are still at a vital age where they are well attuned to becoming familiar with environmental education [26]. Additionally, we engaged all of the school community in the promotion of environmental protection. The project included socio-cultural and scientific activities that encouraged the presence of parents in the school and promoted interactions between students, parents, and teachers. We applied a pre-validated survey instrument before and after the activities to quantify the effectiveness of our approach to raising awareness of plant-based topics and used a control group from a different school to provide statistical support to our findings. Ultimately, we demonstrate the usefulness of educational gardens in increasing knowledge of different aspects of Portuguese native flora.

2. Materials and Methods

2.1. Research Design

The main objective of the present study was to address the following research question: can a multi-tier educational program on Portuguese native flora, anchored on the creation of educational gardens and fostering direct interplay with plant researchers, increase plant-oriented environmental knowledge and awareness in 8th-grade students? The research design (Figure 1) consisted of the implementation of a comprehensive educational program in one school anchored on the creation of educational gardens on school grounds. A second school was deprived of the educational program and served as the control ecosystem. The instrument chosen for the quantitative analysis of the program's effectiveness was a pre-validated questionnaire coupled with a pre- and post-test assessment strategy (Figure 1). The sampling strategy consisted of convenience sampling across eight 8th-grade classes. The questionnaire addressed three variables/topics, namely Invasive, exotic and native plant species (five items), Plant species identification (three items), and Plant adaptability to climatic variables (three items).

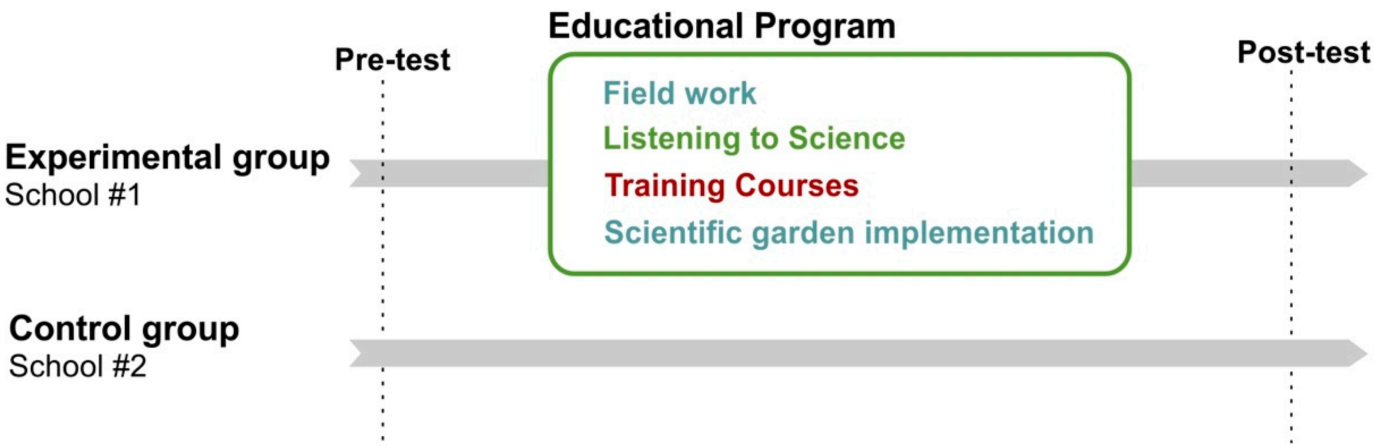

Figure 1. Research design of the study.

2.2. Participants

The activities took place between May 2013 and July 2014. This study involved two public schools: EB 2/3 D. Maria II (experimental group; n = 92) and Escola Básica Conde de Arnoso (control group; n = 58), both belonging to the School Cluster D. Maria II, V.N. Famalicão, in northern Portugal. The EB 2/3 D. Maria II School is located on the outskirts of the city of Vila Nova de Famalicão and Escola Básica Conde de Arnoso (Arnoso Sta. Maria) is located 6 km from the city of Vila Nova de Famalicão. For the present work, we used a convenience sample, detailed in Table 1. The participants consisted of students from eight 8th-grade classes of both these schools. The majority of the students were between 13 and 14 years of age, which is the standard for 8th-grade students in Portugal. Some students started school earlier and were 12, while others were held back one or more years and were 15 and 16 years old (Table 1). The control group was composed of students from Escola Básica Conde de Arnoso. This school was not subjected to any intervention or educational garden implementation; therefore, the students did not attend any of the activities. Even though the impact of demographic variables was not addressed in the present work, experimental and control groups share the same age and educational background (Table 1), come from schools of the same periurban area (distance between schools = 6 Km), and are expected to have comparable socio-demographic background, academic achievement, and science education experience.

Table 1. Depiction of the experimental and control groups.

Class	No. of Students	Age	Male	Female
Experimental group				
8ºA	19	12–15	7	12
8ºB	20	13–15	13	7
8ºC	18	13–14	14	4
8ºD	19	13–15	13	6
8ºE	16	13–15	11	5
Control group				
8ºF	20	13–14	9	11
8ºG	19	12–16	7	12
8ºH	19	13–16	6	13
Total	**150**	**12–16**	**80**	**70**

2.3. Educational Program

A team composed of plant biologists, teachers, the Parents Association (EB 2/3 D. Maria II School), and City officials (Vila Nova de Famalicão) implemented the project "Jardins com(s)Ciência" (word pun meaning both Gardens with Science and Gardens with a Conscience). Project development took place within the scope of a Ciência Viva/CONFAP call designated Pais com a Ciência. Ciência Viva is the Portuguese state agency for the promotion of scientific and technological culture (www.cienciaviva.pt). The project's activities encompassed various aspects of plant biology and included the establishment, on school grounds, of three educational gardens. Additionally, we engaged all of the school community in the promotion of plant-oriented environmental protection. The project included socio-cultural and scientific activities that encouraged the presence of parents in the school and promoted interactions between students, parents, and teachers.

2.3.1. Educational Garden Implementation

The focus of activities was the construction within the grounds of School EB 2/3 D. Maria II of the three educational gardens, each with an area of approximately 100 m^2 (Figure 2A). The gardens were designed to incorporate species that represent the Atlantic, Lowland Mediterranean and Mountain Mediterranean ecosystems, which are all typical of the Portuguese vegetation (Figure 2B–D; Supplementary Figure S1). The selection of the different climatic areas that determine the type of vegetation present in Portugal was based on the environmental, climatic stratification of Europe [27]. There are four main environmental zones in the Portuguese continental territory (Lusitanian, Mediterranean Mountains, Mediterranean North, and Mediterranean South). The environmental zone Mediterranean Mountains only occurs in a small part of northern Portugal, and the vegetation present there is similar to the Mediterranean North. For that reason, the Mountain Mediterranean garden represents both of these environments. The Atlantic garden represents the Lusitanian environmental zone, with its relatively humid Atlantic climate and Mediterranean-like distribution of precipitation. The Lowland Mediterranean garden represents the Mediterranean South environmental zone, which occupies plains and uplands in southern Mediterranean areas. Species choice involved two criteria, (1) representativeness of the species in each environmental zone and (2) greater ease in acquiring plant specimens in a nursery or by collection in nature. Figure 2B–D depicts the array and spatial distribution of the selected native species for each ecosystem. Teachers and plant biology researchers planned the garden design and chose and acquired the species introduced in the educational gardens. Students and parents conducted the landscaping effort that implemented the gardens on school grounds, with support from plant researchers. Specimen plantation implicated several landscaping activities, including delimiting of specimens with maritime pine bark, placing of plant label plates, and installation of fences to protect against unauthorized intrusion (Supplementary Figure S1A–D).

2.3.2. Additional Practical Activities

As part of a multi-tier plant-oriented program, students carried out a series of laboratory/practical activities, such as the creation of a plant nursery and different training courses addressing plant propagation, flora identification and the study of the relationship between form and function in plant organs (Figure 3A). One activity consisted of flora identification in the newly implemented educational gardens. The goal of this activity was to engage students in the identification of the species introduced in the educational gardens, and it involved the design of dichotomous keys specifically for each of these gardens (Supplementary Data S1–S3). According to the literature, dichotomous keys have long been considered the most important way of learning how to identify new species and were shown to develop differentiation skills such as diagnostic abilities [28]. The present, purposefully built dichotomous keys can now become a useful teaching tool in the forthcoming school years. A second activity saw the creation of a plant nursery within the school (Figure 3A). This activity involved: (a) workshops on plant propagation with the participation of students and their parents; (b) the creation of a plant nursery with native plants in the classroom; (c) transplanting the native plants, after growth for four months in the nursery, into the school gardens and subsequent monitoring of the setting in process; (d) teacher training in nursery implementation and plant propagation techniques. A third activity consisted of understanding form–function relationships in plant leaves. The goal of this activity was to complement ecological data by providing a more in-depth discussion on leaf morphology, form–function relationships, their importance for plant functioning, and their usefulness during plant species identification via a hands-on workshop and custom-generated PowerPoint presentations. An important feature of these activities was the presence of plant researchers within the project team (Figure 3B). This collaboration allowed the development of state-of-the-art scientific content, particularly concerning aspects that might elude schoolteachers, such as plant identification at species level, generation of dichotomous trees, hands-on plant manipulation, or study of plant form–function relationships. During the three activities, workshops and hands-on field work promoted practical knowledge, which is useful for day-to-day, easy-to-implement practices while simultaneously raising the standards of scientific knowledge (Figure 3B).

A final activity consisted of a set of 1-h lectures, evenly distributed throughout the project, discussing the work of the invited plant researchers (Figure 3A). The goal of this activity was to allow direct contact between students and plant specialists, followed by active discussion within an informal setting. Members from all of the educational community (school board, teachers, educational aids, and parents) attended and participated in these lectures. Here, students listened to topics that included landscaping, native, exotic and invasive plants, plant and fungal symbiotic relationships, and plant morphological and physiological diversity.

During all activities, both teachers and researchers guided the students by asking questions, pointing out interesting plant features, and encouraging students to reflect on what they saw and experienced. This study was a collaborative learning effort between teachers, researchers, parents, and students (Figure 3B). All participants were actively engaged in creative discussions that took into account their different backgrounds and knowledge base. Teacher's knowledge in conducting educational programs, the technical know-how of the researchers, the involvement of parents, and the development of a significant set of activities and contents around plants collectively led to the extensive exposure of 8th-grade students of the experimental group to various topics in plant biology (Figure 3B).

Figure 2. Design and construction of three educational gardens within the grounds of School EB 2/3 D. Maria II. (**A**) Aerial picture of the school grounds (dashed line), depicting the implementation site of the Atlantic (1), Mountain Mediterranean (2), and Lowland Mediterranean (3) gardens; image was retrieved from Maps (Apple). (**B**–**D**) Species spatial distribution in the Atlantic (**B**), Mountain Mediterranean (**C**), and Lowland Mediterranean (**D**) gardens. Am, *Armeria maritima*; Ap, *Acer pseudoplatanus*; Au, *Arbutus unedo*; Ba, *Betula alba*; Ca, *Corylus avellana*; Cm, *Crataegus monogyna*; Cp, *Cistus populifolius*; Cv, *Calluna vulgaris*; Da, *Dianthus lusitanicus*; Dc, *Daboecia cantábrica*; Dp, *Digitalis purpurea*; Dt, *Digitalis thapsi*; Ear, *Erica arborea*; Eau, *Erica australis*; Fv, *Fragaria vesca*; Hs, *Helichrysum stoechos*; Lp, *Lavandula pedunculata*; Np, *Narcissus pseudonarcissus*; Ov, *Origanum vulgare*; Po, *Polygonatum odoratum*; Qf, *Quercus faginea*; Qp, *Quercus pyrenaica*; Qrb, *Quercus robur*; Qro, *Quercus rotundifolia*; Qs, *Quercus suber*; Rc, *Rosa canina*; Tm, *Thymus mastichina;* Tp, *Thymus pulegioides*; Vr, *Viola riviniana*.

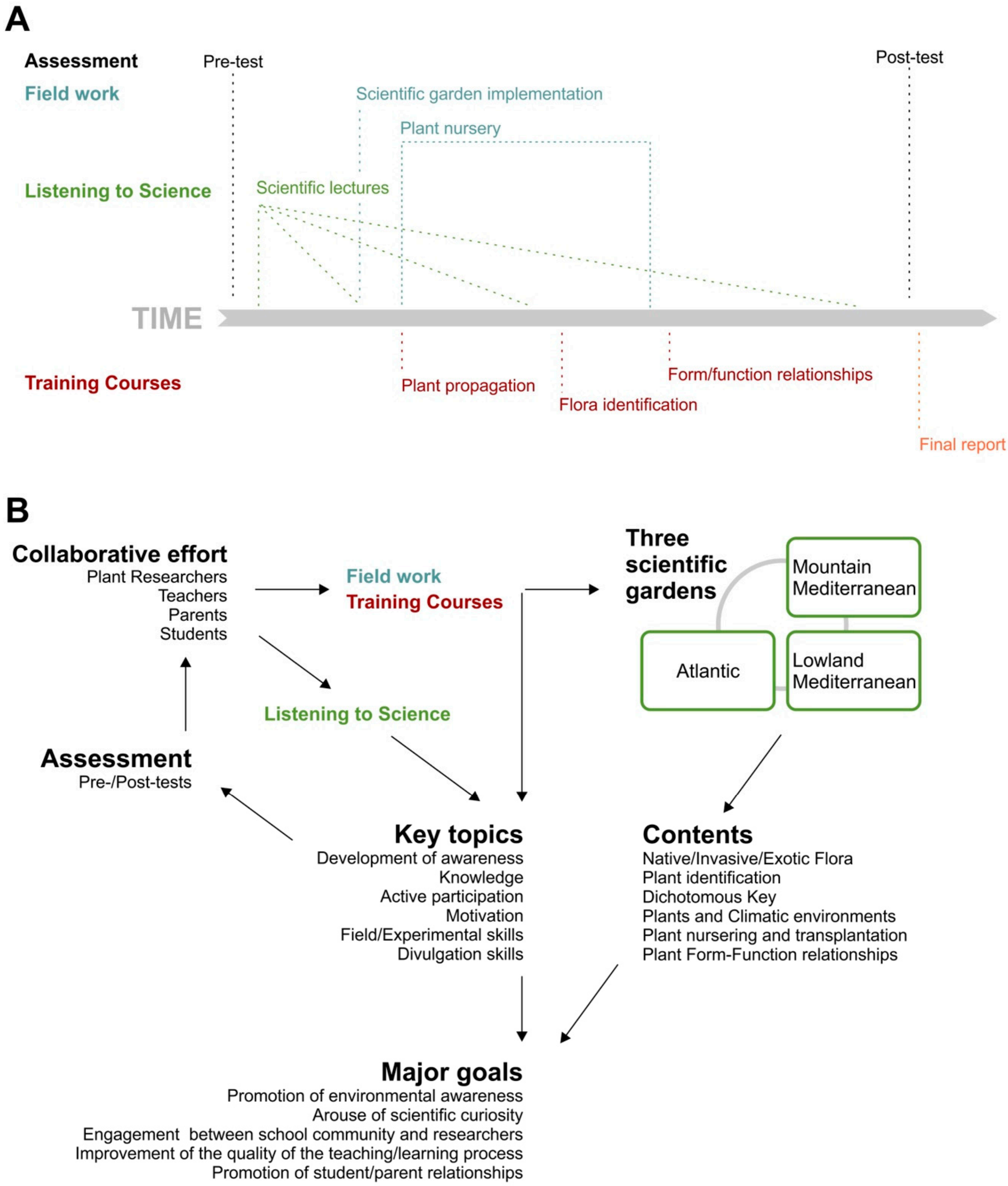

Figure 3. Timeline and outline of the project. (**A**) Timeline depicting the major events that took place during the project's duration. (**B**) Outline of the project, based on the creation of three scientific gardens, and including project intervenients, contents, key topics and major goals.

2.4. Instrument, Data Collection and Analysis

The instrument selected to quantify the effectiveness of the project's activities and assess students' knowledge gains consisted of a pre-validated questionnaire containing 11 informative items, given to students at the beginning and at the end of the intervention (pre- and post-test) (Figures 1 and 3A). The same procedure was implemented in the control school group, where no gardens or activities were developed (school Escola Básica Conde de Arnoso). The survey instrument was previously validated by a group of six students from the same grade belonging to the experimental group school. No doubts were raised during the process. The survey instrument emphasized Portuguese native flora and specifically three topics pertaining to student familiarity with the terms exotic, invasive, and autochthonous plants, identification of native species, and plant adaptability to climatic variables (Table 2). The native species included in the questionnaire were *Acer pseudoplatanus*, *Arbutus unedo*, *Crataegus monogyna*, *Pinus pinaster*, *Quercus rotundifolia*, *Quercus suber*, *Quercus robur*, *Quercus faginea*, and *Quercus pyrenaica*, and the exotic/invasive were *Acacia dealbata*, *Acacia longifolia*, *Carpobrotus edulis*, and *Eucalyptus globulus*. The time between the implementation of the first activity (implementation of the school gardens) and the application of the post-test was seven months. Supplementary Data S4 contains the full questionnaire, whereas Table 2 summarizes the items and topics. Students completed the questionnaire during the course of a regular natural sciences class, with a time limit of 40 min. Student participation was anonymous and voluntary. Teachers informed students that their participation and questionnaire performance would have no implication in their curricular evaluation. Data obtained in the pre- and post-tests from the experimental and control groups (matched case-control study) was statistically resolved through a McNemar's test, using GraphPad's web-based statistics platform (http://graphpad.com/quickcalcs/mcNemar2/; accessed on 10 July 2020) with significance set at $p < 0.05$.

Table 2. Items incorporated into the survey instrument, addressing three separate topics, and used to assess students' knowledge.

Invasive, Exotic, and Native Plant Species
Q5 Identification of synonyms within terms concerning native/invasive plants
Q6 Meaning of invasive plants
Q7 Typical features of invasive plants
Q8 Recognition of invasive species in Portugal
Q9 Species abundance in the region prior to human modification of the landscape
Plant species identification
Q10 Identification of the common name of several species given their scientific name and a representative picture
Q11 Identifying deciduous trees
Q12 Correct use of dichotomous key
Plant adaptability to climatic variables
Q13 Matching between species and climatic environments/forest ecosystems
Q14 Ideal time for the transplantation of plant species
Q15 Cautions with the transplantation of plant species

3. Results

This project Jardins com(s)Ciência consisted of a series of activities designed to promote environmental awareness toward plant biology and native plant protection in 8th-grade Portuguese students (Figure 3). The activities had a broad scope and included: (a) the implementation of three educational gardens representing different Portuguese forest ecosystems; (b) the creation of a plant nursery; (c) different training courses addressing plant propagation, flora identification, and the study of the relationship between form and function in plant organs; (d) scientific lectures by active plant researchers (Figure 3A). To estimate the impact of this project on students' plant-oriented environmental awareness, we used a survey instrument with pre- and post-test comparisons of the performance of both experimental and control groups. For statistical support, we tested the Chi-square and McNemar tests. Here, we observed that the McNemar test out-performed the Chi-square analysis of statistical differences (data not shown), with the latter providing biased (extremely low) *p*-values due to the fairly high number of test subjects, whereas the McNemar test provided a *p*-value resolution within the range of the *p*-value cut-off (0.05). The McNemar suits this form of paired comparison as it determines the statistical significance of the difference between two correlated proportions (2 × 2 contingency table), in this case, pre-test vs. post-test × control group vs. experimental group.

To assess performance, we developed 11 items associated with Portuguese native flora and centered around three topics: Invasive, exotic and native plant species; Plant species identification; Plant adaptability to climatic variables (Table 2). Figure 4 and Supplementary Data S5 reports the overall performance in the pre and post-tests of the experimental and control groups, displaying the percentage of correct answers and the statistical significance of results between tests, while Supplementary Data S6 contains the bulk data. The experimental group's scores increased in all questions when comparing the pre-test to the post-test (Figure 4A). Conversely, the control group often displayed marginal increases or even a decrease in scores, with only three questions showing a marked increase (Q5, Q7, Q13; Figure 4A). The average accuracy in the pre-test was similar between the experimental group (32.6 ± 18.9) and the control group (30.9 ± 20.6), highlighting the robustness of the study population (Figure 4B). Following the implementation of the educational program, average accuracy increased in the experimental group by over two-fold (71.2 ± 17.0) but not in the control group (34.3 ± 16.0). Figure 4C scrutinizes this information by depicting the variation in response success from the pre- to the post-test in both groups for each specific question. By far, the largest increase (94.5%) was observed in Q7, regarding the typical features of invasive plants. This was followed by three questions with improvements in the ~45% range, one within the same topic of invasive species (Q9) and two within the topic of Plant adaptability to climatic variables (Q14 and Q15). Broadly, the topic of Plant species identification was the worst performer in this analysis. We observed the existence of statistical support for these claims in every question present in the questionnaire (p-values < 0.05; Supplementary Data S5). Collectively, the results provide very strong support that the implementation of our educational program increased student awareness across all topics.

In each topic, we incorporated questions that involved knowledge of multiple forest species, with broadly positive results in the experimental group (Figure 5). For the topic of Invasive, exotic and native plant species, students were asked to recognize the name of invasive species (Q8). Here, a positive increase in the acknowledgment that *Acacia* sp. are invasive was observed in the experimental group (Figure 5A). For the topic of Plant species identification, students were asked to name a forest species common in the Portuguese flora based on a provided image (Q10; Figure 5B). Interestingly, for *Pinus pinaster* and *Eucalyptus globulus*, the most abundant forest species in Northwest Portugal, score variation was very low for both the control and experimental groups because initial (pre-test) results were high to begin with (Supplementary Data S6). Still, on this topic, a consistent improvement across all species was observed in Q11, which addressed the concept of deciduous species (Figure 5C), suggesting a generalized lack of knowledge and a beneficial effect of the educational program. Finally, with regards to Plant adaptability to climatic variables, students were asked to match a species to one of the three Portuguese climatic environments/forest ecosystems (Q13; Figure 5D). Here, the most effective progress was associated with two oaks species (*Q. robur* and *Q. rotundifolia*) and the strawberry tree (*Arbutus unedo*).

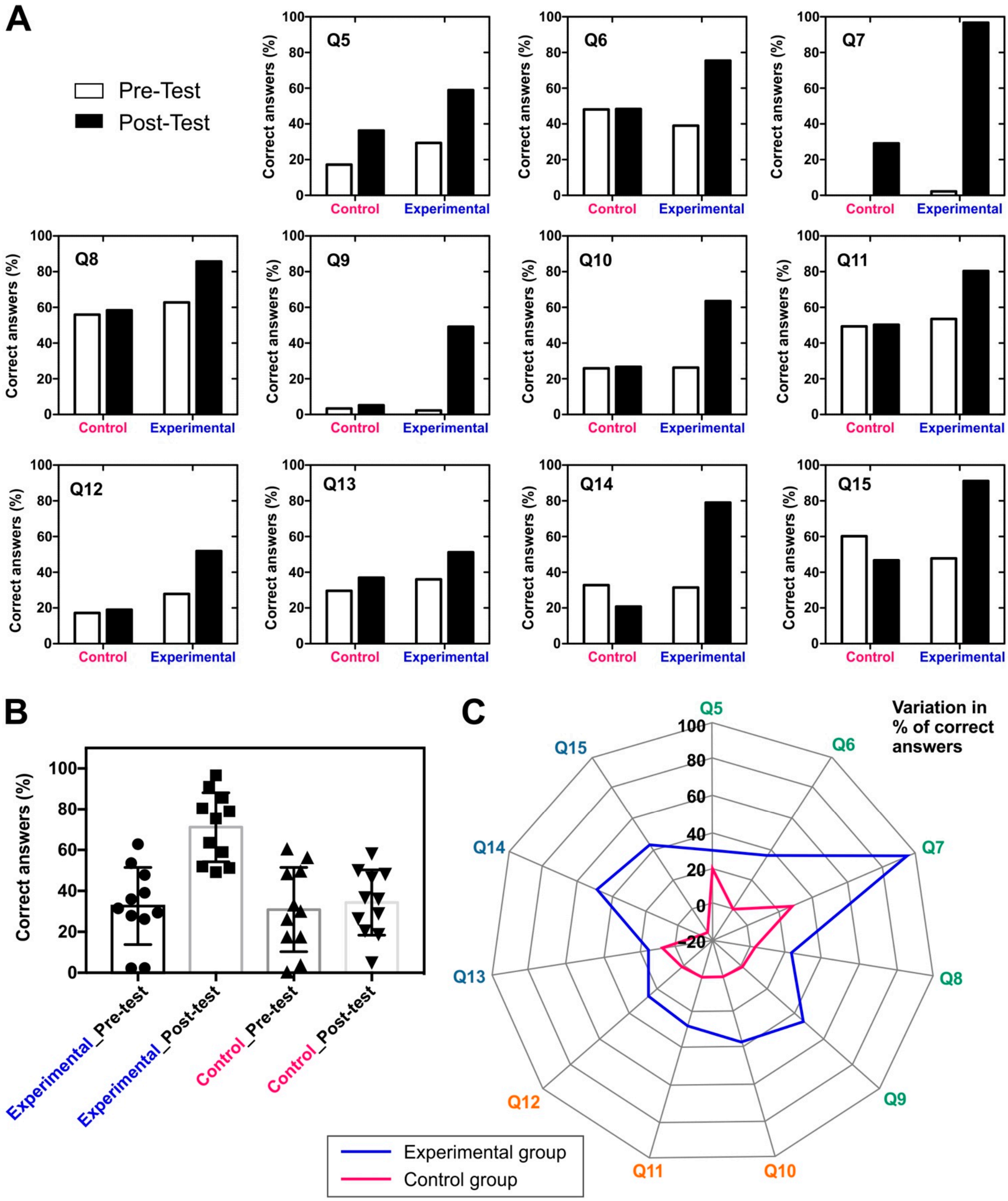

Figure 4. Results of the student questionnaire in the pre- and post-test assessment of the Experimental and Control groups. (**A**) Percentage of correct answers (accuracy) in each group for each question. (**B**) Variation in accuracy between the four different test populations. (**C**) Radar map showing the variation in the percentage of correct answers between pre- and post-test for the control and experimental groups.

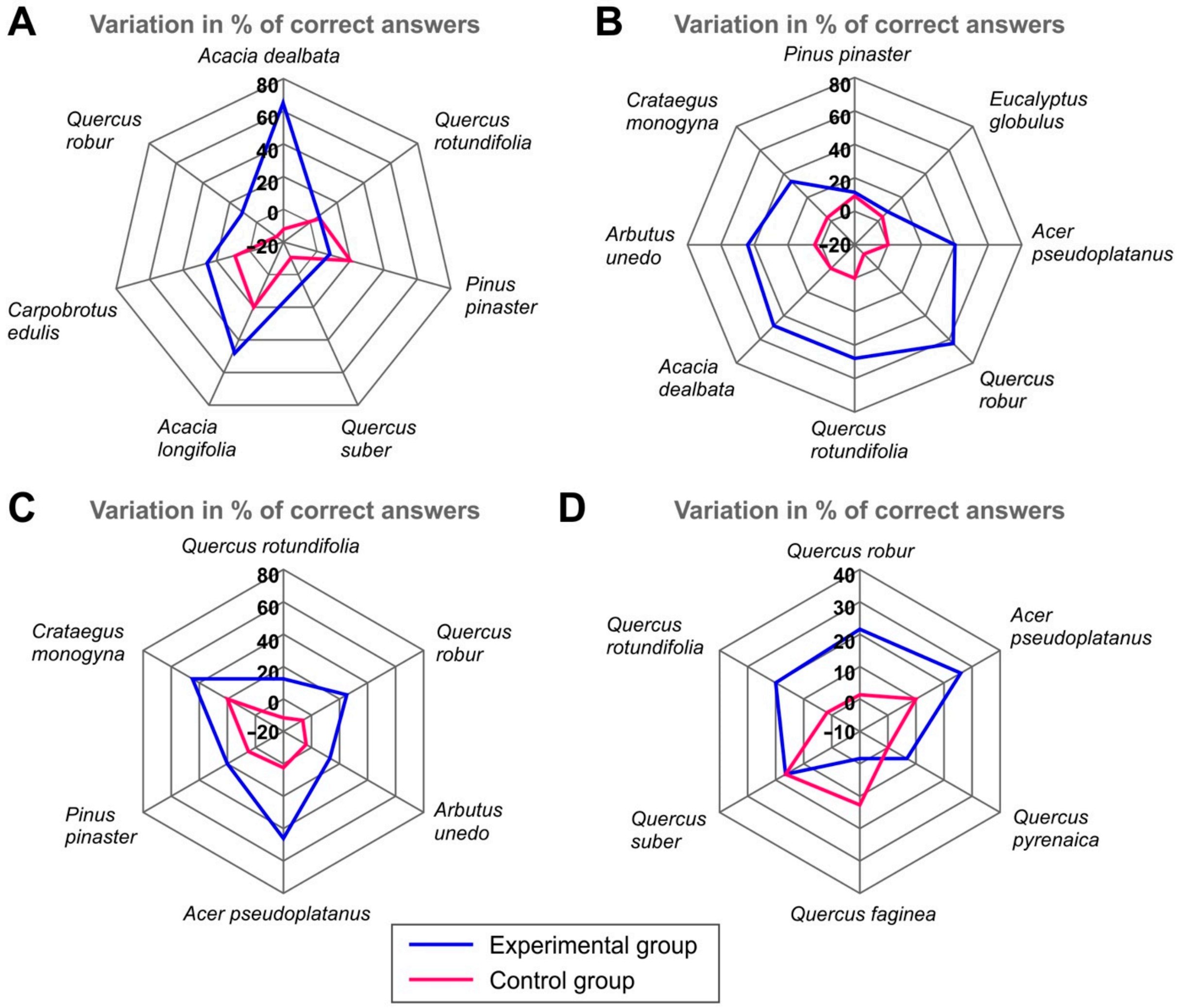

Figure 5. Radar map showing the variation in the accuracy, i.e., the percentage of correct answers between pre- and post-test, for the control and experimental groups, in questions tackling different species. Discrimination of answers at the species level for question 8 (**A**), question 10 (**B**), question 11 (**C**), and question 13 (**D**).

4. Discussion

Presently, there is an urgent need to educate people effectively so that current and future actions and decisions are made in educated and informed ways [3]. In this regard, outdoor education is considered an important tool for improving student attitudes and clearly influencing students' knowledge of plants [29]. In order to increase plant-oriented environmental awareness and scientific literacy in general, we designed a project named Jardins com(s)Ciência (Gardens with Science/Conscience). This environmental program is in line with recent strategies adopted by educators, which are re-discovering the value of gardens as spaces for learning in educational institutions [30]. It was also geared toward students at an age where they begin to lose environmental attitude and behavior [26]. Thus, we structured the program's contents vertically, ranging from organ structure/function to species to ecosystem levels. It was a hands-on program, including various field activities designed to enhance the participants' understanding of autochthonous/invasive plants, plant identification, plant features, the correct use of dichotomous keys, the relationship between species/climatic environment, and plant nurturing (germination, growth and transplantation).

With a 25 h/week contact time between students and teachers, Portuguese 8th-graders spend a significant part of their time at school (http://www.dge.mec.pt/matriz-curricular-do-3o-ciclo; accessed on 9 November 2021). We hypothesized that field and laboratory motivational activities within the school context could be an important additional recourse for academic success and most importantly, a good instrument to raise awareness to plant-related topics. In support, various studies have shown that intrinsic motivation is linked to active and engaged behaviors [31]. Further, hands-on, laboratory and out-of-class education activities improve students' interests, scientific inquiry skills, autonomy, and understanding of scientific concepts [15,32–34]. Finally, providing students with autonomy is an additional factor toward an increase in their motivation [35]. Results showed that the present work was successful in increasing student knowledge across a series of plant topics centered around the native Portuguese flora and its contrast with invasive species. For questions focused on invasive plants (Q5–8), there was an overall improvement. The student's preexisting knowledge was high for the definition of an invasive plant (Q6 ~50%) and identification of invasive plant species (Q8 ~60%). Improvements were more noticeable in the identification of the characteristics of invasive plants, where the variation in the experimental groups was close to 100% (Q7). The positive performance of the students on this subject may be related to the knowledge acquired during the lectures given by plant researchers on native, exotic, and invasive plants (where active discussions were promoted) and the fact that this topic was emphasized during garden implementation and flora identification activities. Likewise, this emphasis may explain why scores in the post-test increased significantly when addressing the identification of plant species (using both their common and scientific names) and the correct use of a dichotomous key. This hands-on approach also contributed to the knowledge increase observed in the more practical aspects of the questionnaire, which focused on plant transplantation (Q14 and Q15). In support, previous studies corroborate the positive impacts of gardening, leading to increased academic learning, environmental attitudes and interpersonal skills [8]. Garden-based learning experiences develop students' environmental knowledge, improve environmental attitudes, encourage their sense of environmental responsibility, and motivate related positive actions [30]. Teaching in school gardens has been shown to enhance student's academic learning and skills acquisition across the curriculum, as well as foster the development of students' social, affective, and physical skills [36]. Other studies have emphasized the importance of outdoor programs in significantly relieving 'plant blindness', making this biology topic more attractive to students [29].

In the past, environmental education researchers were encouraged to explore alternative models leading to responsible environmental behavior after the publication of Hungerford and Volk's work [37]. As a result, knowledge was no longer considered a unique factor that could lead to behavior change. One of the models that followed this line of thought, the Hines Model [38], is based on behavior change and environmental education literature. However, this model also focuses on additional conditions, including personality factors, knowledge of issues, and possession of skills for taking action. In the current work, the information and messages communicated to students were an important step toward the promotion of future environmentally friendly attitudes. According to the Hines Model, knowledge is a prerequisite to action: before an individual can intentionally act on a particular environmental problem, that individual must be conscious of the existence of that problem [38]. Here, we observed a significant increase in knowledge on various topics in students who participated in the project.

Research has demonstrated that teaching with and about plants is full of misconceptions and is considered a pedagogical challenge [39,40]. The present success in improving student awareness can foremost be attributed to teacher and plant researcher involvement. In support, teacher involvement was shown to increase student interest in subjects, such as plant biology, when appropriate motivational methods were used. Our results effectively add to existing studies, specifically demonstrating that planting trees within the school area in collaboration with experts may have a significant impact on student understanding of the role of plants in nature, building positive attitudes toward plants [29].

A key topic addressed by the present project concerned the issue of autochthonous vs. invasive plant species. Results obtained in the pre-test concerning this specific subject are in agreement with previous reports, indicating that only 1% of the Portuguese population considered invasive species to be the most important threat to biodiversity [41]. Studies have demonstrated the importance of public participation in both environmental conservation initiatives and the improvement of student knowledge of native and exotic plants [42]. Thus, our project's first lecture, open to all of the school community, was used to motivate students toward this issue within Portuguese ecosystems, and later activities in the educational gardens highlighted the native nature of the planted species. A workshop regarding invasive plant species performed at the Botanical Museum of Coimbra University, Portugal, clearly demonstrated the importance of practical and informal education activities similar to our own [20]. Reis and co-workers revealed the effectiveness of their activities in increasing public awareness regarding synonyms of native plants and the meaning of invasive plants, corroborating our results since the percentage of correct answers in both studies was similar [20]. Concerning the recognition of invasive species in Portugal vs. the number of invasive plant species reported in Portugal, the number of correct answers obtained in the post-test (86%) is higher than those registered by Reis and co-workers (39.7% of correct answers). This discrepancy could reside in the fact that the results from Reis and co-workers were obtained one year after the implementation of the activities [20]. In summation, our assessment demonstrates the effectiveness of public education efforts in raising awareness that may help prevent the propagation of invasive species in Portugal.

The results and their subsequent statistical treatment support that this project was successful in raising student knowledge and awareness of various plant biology topics. The results suggest that knowledge improvement is related to the effectiveness of the teaching methodology rather than to the existence of a priori student familiarity with specific topics. We administered the post-test seven months after the start of the field activities. In order to infer the long-term retention of knowledge, it would be interesting to re-apply the test after a longer period. Most significantly, we designed several of the activities and contents of this project to be sustainable and last beyond the project's initial duration. Globally, the developed contents will allow teachers to carry out most of the project's tasks in the upcoming years. This is significant because the consistency of educational messages is known to affect behavior [43].

The importance of motivating learners to physically maintain plants, plant trees, name plants, and identify them using dichotomous keys has already been suggested to improve awareness of the importance of plants in nature [29]. Outdoor programs can, therefore, be considered good supplements to conventional biology settings, providing a better knowledge of living organisms and promoting positive attitudes. Moreover, educational gardens can influence the well-being of the whole school community, including teachers, staff, and parents. Additionally, it is known that families bring valuable resources to informal learning. Building the capacity in families to organize and optimize learning opportunities wherever they arise, therefore, constitutes an important feature [44]. Overall, this project contributed to improving students' knowledge concerning plant biology, with emphasis on autochthones/invasive plants, species identification, ecosystem ecology, and form/function relationships in plant organs. The present garden designs and the dichotomous keys constitute promising tools that can be easily extended toward other school/educational programs within the Mediterranean ecological space. Finally, our findings reinforce the necessity of employing this type of approach to promote environmental education, as the targeting of students contributes to the engagement of future generations of citizens in having a more active and mindful attitude toward sustainable development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci12090619/s1, Supplementary Data S1. Dichotomous key for the Atlantic garden; Supplementary Data S2. Dichotomous key for the Lowland Mediterranean garden; Supplementary Data S3. Dichotomous key for the Mountain Mediterranean garden; Supplementary Data S4. Full pre-validated questionnaire for quantitative assessment of student knowledge gain; Supplementary Data S5. Performance in each question of the experimental and control groups, in both the pre- and post-test questionnaires; Supplementary Data S6. Scores for the pre-test and post-test in both control and experimental groups; Supplementary Figure S1. Construction of three educational gardens within the grounds of School EB 2/3 D. Maria II.

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Institutional Review Board Statement: This study was approved by the School Board of the School EB 2/3 D. Maria II, V. N. Famalicão, after hearing the Pedagogic Council, since there is no ethics committee in the school. Student participation was anonymous and voluntary.

Informed Consent Statement: Informed consent was obtained verbally from the students' guardians on behalf of the students enrolled in our study. This was obtained during a regular meeting, in which the director of the class explained the aims of the project and requested authorization from parents for their children to participate. Verbal consent was the method agreed upon by the School Board, class director, and the students' guardians.

Data Availability Statement: The datasets for this study can be found in the article and its Supplementary Materials.

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

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