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Assessing Learning in School-Based Citizen Science: Self-Efficacy, Knowledge, and Skills

Avaliação de Aprendizagens em Ciência Cidadã Escolar: Autoeficácia, Conhecimentos e Habilidades

Evaluación de Aprendizajes en Ciencia Ciudadana Escolar: Autoeficacia, Conocimientos y Habilidades

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Abstract

Participation in citizen science projects focused on observing biodiversity in school gardens can provide significant learning experiences about scientific practices. This study evaluated individual learning outcomes in citizen science and biodiversity, based on the following indicators: knowledge of scientific concepts, self-efficacy, and scientific investigation skills (biodiversity observation). The research involved 96 third-year elementary students who participated in a co-created citizen science teaching-learning sequence in the school context. Using a mixed-methods approach, the field research included participant observation in a full-time school in the ABC region of São Paulo. Data were collected through a quasi-experimental design, with pre- and post-intervention questionnaires, as well as students' Research Diaries and the teacher-researcher's Field Diary, and analyzed through content analysis. The results indicate that the school-based citizen science proposal was effective in enhancing students' knowledge of scientific concepts, perception of self-efficacy in science, and scientific investigation skills (observation). These findings have significant implications for science education, highlighting the importance of pedagogical strategies that actively engage students in citizen science experiences, promoting their empowerment through a deeper and broader understanding of the scientific process.

Keywords: engagement of youth in science, participatory monitoring, scientific literacy, formal education, active learning

Resumo

A participação em projetos de ciência cidadã focados na observação da biodiversidade em jardins escolares pode proporcionar aprendizagens significativas sobre práticas científicas. Este estudo avaliou resultados de aprendizagem individual em ciência cidadã e biodiversidade, com base nos indicadores: conhecimento de conceitos científicos, percepção de autoeficácia e habilidades de investigação científica (observação de biodiversidade). A pesquisa envolveu 96 estudantes do 3º ano do Ensino Fundamental que participaram de uma sequência de ensino-aprendizagem com ciência cidadã cocriada no contexto escolar. Utilizando uma abordagem quali-quantitativa, a pesquisa de campo incluiu observação participante em uma escola de tempo integral na região do ABC paulista. Os dados foram coletados a partir de um desenho de semi-experimento, com a aplicação de questionários pré e pós intervenção, além dos Diários de Pesquisa dos estudantes e Diário de Campo da professora-pesquisadora, e analisados por meio de análise de conteúdo. Os resultados indicam que a ciência cidadã escolar foi eficaz em aumentar o conhecimento de conceitos científicos, a percepção de autoeficácia em ciência e as habilidades de investigação científica (observação) dos estudantes. Esses achados têm implicações significativas para a educação em Ciências, ressaltando a importância de estratégias pedagógicas que envolvam ativamente os estudantes em experiências de ciência cidadã, promovendo sua emancipação através de uma compreensão mais profunda e abrangente do processo científico.

Palavras-chave: engajamento de jovens em ciência, monitoramento participativo, alfabetização científica, ensino formal, aprendizagem ativa

Resumen

La participación en proyectos de ciencia ciudadana enfocados en la observación de la biodiversidad en los jardines escolares puede proporcionar experiencias de aprendizaje significativas sobre las prácticas científicas. Este estudio evaluó los resultados de aprendizaje individuales en ciencia ciudadana y biodiversidad, basado en los siguientes indicadores: conocimiento de conceptos científicos, percepción de autoeficacia y habilidades de investigación científica (observación de la biodiversidad). La investigación involucró a 96 estudiantes de tercer grado de primaria que participaron en una secuencia de enseñanza-aprendizaje con ciencia ciudadana cocreada en el contexto escolar. Utilizando un enfoque mixto, la investigación de campo incluyó observación participante en una escuela de tiempo completo en la región del ABC de São Paulo. Los datos se recopilaron a través de un diseño cuasi-experimental, con cuestionarios antes y después de la intervención, así como los Diarios de Investigación de los estudiantes y el Diario de Campo del profesor-investigador, y se analizaron mediante análisis de contenido. Los resultados indican que la ciencia ciudadana escolar fue eficaz para mejorar el conocimiento de conceptos científicos, la percepción de autoeficacia en ciencia y las habilidades de investigación científica (observación) de los estudiantes. Estos hallazgos tienen implicaciones significativas para la educación en ciencias, resaltando la importancia de estrategias pedagógicas que involucren activamente a los estudiantes en experiencias de ciencia ciudadana, promoviendo su empoderamiento a través de una comprensión más profunda y amplia del proceso científico.

Palabras clave: compromiso de los jóvenes en la ciencia, monitoreo participativo, alfabetización científica, educación formal, aprendizaje activo

Introduction

In light of the various skills expected to be developed in science classes, those related to scientific inquiry stand out. According to Phillips et al. (2018), these skills encompass observable practices applicable to everyday life, such as formulating and answering questions, collecting data, developing and using models, planning and conducting investigations, reasoning, analyzing and interpreting data, constructing explanations, communicating information, and using evidence in argumentation.

Based on this understanding, citizen science (CS) initiatives gain relevance in the school environment, as they offer authentic investigative experiences and contribute to scientific literacy from the early years of elementary education (Bonney et al., 2009; Gray et al., 2012; Lüsse et al., 2022; Roche et al., 2020; Shah & Martinez, 2016). We recognize that the term "citizen science" is polysemous, acquiring different definitions depending on the context in which it is analyzed (Haklay, 2021). For this study, we adopt the contributions of Bonney et al. (2009) and Ceccaroni et al. (2017), understanding CS as a process that involves public participation in science. In this same direction, and in accordance with the Brazilian Citizen Science Network (RBCC, 2024), we understand that CS can foster public engagement at different stages of the scientific process, as well as promote scientific and technological education and the co-creation of public policies.

Given the wide range of thematic possibilities for developing CS initiatives linked to education, those focused on biodiversity conservation stand out (Chandler et al., 2017; Forti, 2023; Stevenson et al., 2021). Aware of the environmental issues resulting from human activities, we understand that biodiversity conservation is crucial for maintaining environmental balance (Mittermeier, 2005; Venturini, 2008).

In this context, the present study aimed to investigate evidence of learning among students in the early years of elementary education based on their participation in a school-based proposal with a co-created citizen science approach, focused on the study of biodiversity in the school garden. The specific objectives were to analyze: (1) changes in students' conceptions of citizen science and their understanding of guiding principles of its practices; (2) changes in students' perception of self-efficacy in science; and (3) indicators related to biodiversity observation skills present in their productions throughout the proposal.

Citizen Science, Biodiversity, and Learning in the School Context

Duschl (2008) and Stroupe (2014) argue that science education should balance four types of objectives: conceptual, epistemic, material, and social. Conceptual objectives involve the knowledge required to formulate hypotheses, choose investigative strategies, and interpret data. Epistemic objectives refer to the understanding of the criteria that guide data collection and analysis. Material objectives concern the tools used in investigations. Social objectives, in turn, involve the collective construction of knowledge through dialogue among students, who share, question, and reformulate ideas (Silva & Sasseron, 2021). In this same direction, Jiménez-Aleixandre & Crujeiras (2017) highlight that epistemic objectives relate to understanding the processes of scientific knowledge construction, which can be fostered in learning contexts that value scientific practices.

This set of contributions allows us to understand that science education involves not only the appropriation of concepts but also students' engagement in practices of production, interpretation, and circulation of knowledge. Within this framework, citizen science proves particularly relevant in the school context, as it enables forms of public participation in science that bring students closer to the ways in which scientific knowledge is constructed and socially shared.

Beyond contributing to the production of scientific data and results, citizen science involves forms of public participation in the processes of construction, interpretation, circulation, and dissemination of knowledge. Its scientific dimension, therefore, is not limited to the final product of research but also encompasses the ways in which knowledge is produced and socially shared. In the educational field, this perspective promotes learning experiences that bring participants closer to the practices and modes of scientific knowledge production (Roche et al., 2020).

Due to its articulation with the open science movement (Albagli & Rocha, 2021; Santos, 2022; Heinz, 2024), citizen science also engages with discussions on the democratization of scientific knowledge and the expansion of public access to science (Delizoicov et al., 2002). From this perspective, the openness of science is not limited to making results available but also involves strengthening more collaborative, participatory, and socially shared forms of production, circulation, and appropriation of scientific knowledge.

This discussion becomes even more relevant in the educational field when considering, from the perspective of Chassot (2003), that science can be understood as a language that enables a more critical reading of the world. In the school context, this approach is pertinent, as it allows students' participation in scientific activities to be understood not merely as a teaching strategy but as an opportunity for engagement in social practices of knowledge production and sharing. Thus, school-based citizen science initiatives can contribute both to science education and to strengthening more participatory relationships between science and other sectors of society. Moreover, these initiatives can contribute to students' scientific literacy, reinforcing their relevance in Basic Education (Roche et al., 2020).

Citizen science projects can assume different purposes and levels of participation (Wiggins & Crowston, 2011). Although they were initially conceived for informal learning contexts, they have been gaining recognition in formal education, highlighting their potential for science education (Lüsse et al., 2022). Regarding the participation of citizen scientists, such projects can be classified as contributory, when participation is mainly focused on data collection and/or analysis; collaborative, when there is more significant involvement in different stages of the investigation; and co-created, when participants engage in multiple phases of the scientific process, from formulating the research question to disseminating the results (Bonney et al., 2009; Shirk et al., 2012).

In this study, we understand school-based citizen science as a proposal developed in partnership among professional scientists, the teacher-researcher, and students, in which students' participation is not limited to task execution but involves dialogue, negotiation of meanings, and shared responsibilities throughout the investigative process. This understanding aligns with perspectives that conceive public participation in scientific research at different levels and formats, ranging from more limited contributions to more intensive forms of involvement and co-creation (Haklay, 2013; Shirk et al., 2012). In this sense, we consider the quality of participation to be central in distinguishing initiatives that merely mobilize students to fulfill pre-defined tasks from those that genuinely promote students' engagement in scientific practices with formative and investigative meaning.

Considering the characteristics of the developed proposal, we understand that it aligns with the co-created citizen science model, since students participated in different stages of the investigative process within the school context. In the present study, this typology is used not only to classify the proposal but also to make explicit how student participation was conceived. By characterizing it as co-created, we seek to emphasize that students took part in conceptual discussions, question formulation, data production and interpretation, and the dissemination of results, rather than merely executing the data collection stage, as is common in contributory and collaborative citizen science initiatives (Shirk et al., 2012).

In this context, citizen science proposals focused on biodiversity represent relevant possibilities, both due to their potential scientific contribution and their formative strength in the field of science and environmental education. By bringing participants closer to issues related to conservation, monitoring, and environmental interpretation, these initiatives foster the articulation between scientific practices and reflections on concrete socio-environmental problems.

Understanding the importance of biodiversity for ecosystem conservation and socio-environmental balance constitutes what Dias (2000) defines as environmental literacy and, as highlighted by the Brazilian National Common Core Curriculum (BNCC), this understanding enables students to evaluate practices essential for sustaining life on the planet (Ministério da Educação, 2018). In this study, we understand biodiversity as the diversity of organisms at various levels, including genetic diversity, the diversity of taxonomic groups, and ecosystem diversity (Wilson, 1996; Lévêque, 1999).

Marín (2017) emphasizes the importance of teaching biodiversity in Biology, a perspective we extend to science education, in line with Garcia & Franzolin (2021). In this sense, citizen science projects in the school context constitute a relevant strategy for introducing this concept and its implications. Studies such as those by Forti (2023), Greving (2023), Kelemen-Finan et al. (2018), and Stevenson et al. (2021) support this perspective by pointing to positive outcomes, such as increased interest in science, expansion of scientific knowledge, improvement in motivation and self-efficacy, changes in behavior and attitudes, greater engagement with science and the environment, and the production of high-quality data. These studies indicate that such initiatives can contribute both to the generation of scientific data on species monitoring, richness, and distribution, and to strengthening participants' pro-environmental engagement. Therefore, we consider it pertinent to develop school-based citizen science proposals focused on biodiversity.

Albagli & Rocha (2021) highlight that citizen science initiatives in Brazil are still at an early stage, although they have been receiving increasing attention, as also evidenced by Queiroz-Souza et al. (2023), who report the creation of the Brazilian Citizen Science Network as a milestone in consolidating this field in the country. As citizen science expands into different spaces, including schools, it becomes essential to assess participants' learning, although this practice is not yet frequent (Barbieri et al., 2023). In this regard, Phillips et al. (2018) propose six learning indicators in citizen science projects (interest, self-efficacy, behavior and attitudes, motivation, knowledge, and scientific inquiry skills), which can support both impact assessment and the development of new initiatives. In this study, we focus on three of these indicators due to their direct relationship with the research objectives: knowledge, self-efficacy, and scientific inquiry skills, with an emphasis on observation (Phillips et al., 2018).

Based on Phillips et al. (2018), we understand knowledge as the understanding of a given subject, fact, or scientific concept. This indicator relates to the conceptual domain of scientific knowledge proposed by Duschl (2008), although the author emphasizes that conceptual and epistemic learning should occur in an articulated manner. In this sense, its analysis involves both the participants' initial repertoire and the conceptual advances enabled by the experienced proposal.

Self-efficacy, in turn, refers to individuals' beliefs about their ability to learn content or perform specific behaviors. Understanding this indicator in participants of such initiatives is relevant, as self-efficacy is directly related to motivation and initial engagement in scientific practices (Hiller & Kitsantas, 2022), and may also foster sustained involvement throughout citizen science proposals.

Regarding scientific inquiry skills, we understand them as observable practices related to scientific processes, such as formulating and answering questions, collecting data, observing, and investigating (Phillips et al., 2018). In this study, we specifically focus on biodiversity observation. According to Bizzo (2009), observation fosters the development of recording skills, enabling the construction of progressively more complex models and explanations. Furthermore, observing brings students closer to the scientific context, giving concreteness to teaching and learning processes (Marandino et al., 2009). We also consider that this indicator aligns with the epistemic domain of scientific knowledge (Duschl, 2008), as observation integrates scientific practices that contribute to the development of epistemic practices (Jiménez-Aleixandre & Crujeiras, 2017).

Methodological Procedures

Research Characterization

This study is characterized as field research, developed within the school context, combining participant observation and both qualitative and quantitative procedures. From the perspective of Gatti (2006), the integration of quantitative and qualitative data broadens the possibilities for understanding events, facts, and processes, which underpins the approach adopted in this study. According to Gonçalves (2001), field research requires the direct presence of the researcher at the site where the investigated phenomenon occurs, thus favoring data production in real-life situations. In this regard, participant observation—understood as a process in which the researcher is immersed in a social setting for the purpose of scientific investigation (Minayo, 2011)—was conducted by the teacher-researcher, who was directly involved with the participants throughout the development of the proposal.

The research design was based on a quasi-experimental study, with the application of a questionnaire before and after the intervention (Gopalan, Rosinger, & Ahn, 2020), aiming to identify evidence of learning associated with the implementation of a teaching-learning sequence involving co-created citizen science in the school context (Gonzalez & Ghilardi-Lopes, 2024).

This study adopts both qualitative and quantitative approaches. The quantitative dimension derives from the treatment and analysis of part of the data produced in the pre- and post-intervention questionnaires and in the Technical Sheets. For some closed-ended questions, responses from the pre- and post-intervention questionnaires were statistically compared, allowing for the identification of significant differences between these two stages of the students' learning process. In the case of categories identified in open-ended responses and in the Technical Sheets, the quantification of occurrences was used as a complementary resource to qualitative interpretation, enabling the identification of frequency and recurrence patterns in the analyzed materials. Thus, the quantitative approach in this study is not limited to simple data counting but constitutes an analytical strategy articulated with the qualitative interpretation of the results (see the "Data Analysis" section).

Study Context

The intervention was carried out throughout the 2022 academic year, from March to November, with third-grade elementary school students in a full-time public municipal school in the ABC region of São Paulo. A total of 96 children participated, organized into four classes, each subdivided into five groups of 5 or 6 students throughout all stages of the study. The research took place during Scientific Initiation workshop classes, whose curriculum is compatible with the development of investigative activities. The teacher-researcher, who holds a degree in Biological Sciences, conducted the workshop with the support of four generalist teachers with pedagogical training, each responsible for one class. At certain moments, they worked collaboratively in the development of the activities. This workshop is part of the curriculum of full-time public schools in the municipality.

Teaching-Learning Sequence with Citizen Science (TLSCS)

In this study, we chose to use the expression teaching-learning because we understand that teaching and learning, although not identical processes, constitute interdependent dimensions of educational practice. From this perspective, teaching is not limited to the transmission of content but involves the intentional organization of conditions, mediations, and sequences that promote students' learning (Zabala, 1998; Libâneo, 2013). Thus, the articulated use of the term seeks to emphasize that the developed proposal was conceived both from the standpoint of instructional organization and from the learning outcomes intended within the investigated context.

The TLSCS followed thirteen stages (Figure 1), according to Gonzalez & Ghilardi-Lopes (2024). The interval between the pre-test and post-test corresponded to the period of implementation of the proposal, during which students co-created a citizen science project focused on the biodiversity of the school garden. Throughout this process, students recorded their observations in individual Research Diaries, while the teacher-researcher used a Field Diary. According to Yin (2010), field notes capture real-life events and enrich data collection. Thus, in addition to the questionnaires, the diaries were also included in the corpus of analysis and contributed to the discussions.

Figure 1

Stages of the TLSCS and their respective learning objectives.

Stages	Learning Objectives
1	• Explore the concept of individual and biological group • Recognize plants as a broad category of living beings • Differentiate individuals belonging to various biological groups
2	• Understand the concept of biodiversity
3	• Analyze images of scientists in different research environments • Formulate possible research questions based on the analyzed images • Understand the concept of science and the role played by scientists • Relate scientific work to research questioning
4	• **Explore the concept of citizen science and its various initiatives** • **Become familiar with the iNaturalist application**
5	• Conduct a guided visit to the school garden • Develop scientific research questions about the school garden
6	• **Prepare Technical Sheets** • **Improve the ability to observe living organisms** • **Consult an Identification Guide to research groups of living beings**
7	• Relate the work of scientists to research questions • Formulate scientific research questions to investigate the school's biodiversity
8	• Define research questions, by group, for the investigation • Promote research strategies
9	• Conduct the investigation in the school garden • Collect data for each group's research
10	• Analyze the data obtained during the investigation of the school garden • Discuss the results with peers • Contribute data to the iNaturalist platform • Synthesize the data obtained
11	• Create posters to disseminate research results • Collaborate with information for the development of an e-book on the school garden investigation
12	• Publish the scientific production developed by the groups
13	• Reach a conclusion based on the analysis of the data obtained throughout the entire investigative process

Note. The learning objectives highlighted in bold correspond to the stages analyzed in the present study.

Source: Prepared by the authors (2024).

In Stage 4, the class explored the concept of citizen science (CS) through a group discussion, during which different initiatives related to the study of biodiversity were presented. Subsequently, they collectively developed a definition of citizen science, recording their understandings in their Research Diaries. At this stage, students were informed that they would participate in a project to investigate the school's biodiversity, emphasizing the role they would play as citizen scientists. The iNaturalist platform (https://www.inaturalist.org) was introduced as the virtual space for submitting project data. iNaturalist is a citizen science platform that functions as a social network for recording and mapping global biodiversity. Registered users share records (photos, videos, or audio) of living organisms, which can be identified by specialists and professional scientists.

In Stage 6, the living organisms found in the school garden were recorded on iNaturalist. Subsequently, each group received some examples for analysis. Based on direct observation, students completed Technical Sheets without the need for additional research. An Identification Guide, without scientific names, was used as support. In addition, the Technical Sheets required a drawing and a name for each organism, which could be created by the student if they did not know the common name of that living being.

We recognize that observation skills are crucial for the study of local biodiversity within the perspective of citizen science, as they provide valuable information for monitoring ecological processes, anthropogenic effects, species abundance and occurrence, as well as contributing to environmental monitoring (Chandler et al., 2017; Forti, 2023). In order to assess students' biodiversity observation skills, we developed three models of Technical Sheets (for the study of animals, terrestrial plants, and lichens and fungi), allowing students to record morphological aspects of the organisms observed in the school garden (Figure 2).

Figure 2

Items required for completion in the three Technical Sheet models based on the observation of organisms found in the school garden

Animals	Terrestrial Plants	Lichens and Fungi
Drawing Name Classification Number of legs Locomotion Presence of wings Presence of antennae Lives in the Garden or is a visitor Curiosities	Drawing Name Classification Presence of flowers Presence of spores Presence de fruits Stem characteristics Root characteristics Leaf characteristics Curiosities	Drawing Name Classification Coloration Location Size Morphology Curiosities

Source: Prepared by the authors (2024).

Ethical Aspects

The analyzed data refer to the work produced by 96 students whose participation was authorized by their legal guardians (Informed Consent Form) and confirmed by the students themselves (Assent Form), in accordance with the guidelines of the Research Ethics Committee of Universidade Federal do ABC (CAAE 54478321.5.0000.5594). Students without the required documentation were invited to participate in the activities and complete the questionnaires to ensure inclusion and avoid embarrassment; however, their productions were not considered in the analysis.

Data Collection

Students initially completed a pre-test questionnaire consisting of 19 questions addressing scientific concepts, perception of self-efficacy, motivation, and interest in science. For this article, only the questions related to understanding of citizen science (CS) and perception of self-efficacy were analyzed (Figure 3), in alignment with the study objectives. After the intervention, students completed a post-test containing the same 19 original questions along with five additional ones. Four questions equivalent to those in the pre-test and two exclusive to the post-test, all related to self-efficacy, were analyzed, totaling six questions. According to Gil (1999), questionnaires are a useful technique for investigating opinions, beliefs, and expectations. DiBenedetto & Schunk (2022) highlight their use in assessing self-efficacy, considered a measurable dimension of learning, especially through Likert scales. Both questionnaires provided a basis for evaluating possible changes in students' knowledge about CS and their perception of self-efficacy.

During Stage 4 of the intervention, students also recorded their conceptions of CS in their Research Diaries. These records were selected for analysis and compared with responses from the pre- and post-test questionnaires to the question: "What is citizen science?". The Technical Sheets from Stage 6 were also collected, with the aim of assessing students' scientific observation skills, focused on identifying biodiversity.

Figure 3

Evaluated indicators and the respective questions selected for analysis in the pre- and post-test questionnaires administered to students

Evaluated Indicator(s)	Description of Questions	Description of Response Options
Knowledge	1. What is citizen science?	Open-ended question (no response options)
Self-efficacy	2. Do you feel prepared to participate in a scientific project at school?	Scale from 1 to 10 (the higher the score, the greater the perception of being prepared)
Self-efficacy	3. Do you believe it is possible to collaborate on a scientific project?	Definitely yes; Probably yes; I don't know; Probably not; Definitely not
Self-efficacy	4. Do you think it is possible to do science at school?	Definitely yes; Probably yes; I don't know; Probably not; Definitely not
Self-efficacy	5. Do you feel confident and prepared to create your own scientific project?*	Definitely yes; Probably yes; I don't know; Probably not; Definitely not
Self-efficacy	6. How do you evaluate your participation in the school biodiversity project?*	Scale from 1 to 10 (the higher the score, the greater the perception of good performance in the project)

Note. *Questions marked with an asterisk were included only in the post-test.
Source: Prepared by the authors (2024).

Data Analysis

Data analysis was organized according to the nature of the materials produced by the students. Open-ended responses to the question "What is citizen science?", present in the pre- and post-test questionnaires and in the Research Diaries, were subjected to content analysis based on Bardin (2011). Closed-ended questions related to the perception of self-efficacy were analyzed through the organization of response frequencies and the assignment of scores to the alternatives, allowing for comparisons between the mean scores obtained before and after the intervention. Responses to questions 3, 4 and 5 (Figure 3) were converted into scores ranging from 1 to 5 (1 = definitely not; 2 = probably not; 3 = I don't know; 4 = probably yes; 5 = definitely yes). The Technical Sheets, in turn, were analyzed based on previously defined indicators, encompassing general aspects of completion, written production, and drawings.

To address the first research objective, we conducted content analysis (Bardin, 2011) of the responses to the open-ended question "What is citizen science?" across the three selected data collection instruments: pre- and post-test questionnaires and the Research Diary. The categories used in this analysis were defined a priori, based on three principles of citizen science selected due to their direct relationship with the developed proposal, namely: (1) citizen science projects actively engage citizens in scientific activities, generating new knowledge and understanding; (4) citizen scientists may, if they wish, participate in multiple stages of the scientific process; and (7) data and metadata generated by citizen science projects are publicly shared in open-access formats (ECSA, 2015; Robinson et al., 2018).

These principles were not treated as ready-made responses to be merely identified in the empirical material, but rather as a theoretical reference for the construction of analytical categories and for the interpretation of the units of meaning produced by the students. Thus, within the framework of the adopted content analysis, they are considered a priori categories, constructed based on the theoretical framework and used to interpret students' responses.

In the final classification of responses, we analyzed units of meaning related to the three selected principles. Responses that mentioned public participation in scientific activities were associated with the first principle; those addressing stages of the scientific process, such as formulating questions, researching, and seeking answers, with the fourth; and mentions of the dissemination of scientific results with the seventh. As many responses articulated more than one idea within the same statement, we chose to analyze the different units of meaning present rather than classifying each response entirely into a single category. Thus, a single response could be associated with more than one principle whenever it presented elements semantically linked to distinct categories. The excerpts presented in the results were coded according to the corpus of analysis, indicating the data collection instrument and the corresponding student: pre-test questionnaire (PTQ), post-test questionnaire (POQ), and Research Diary (RD), followed by the letter S and the student number (e.g., S01).

Complementing this approach and addressing the second research objective, responses to the closed-ended questions related to self-efficacy were organized based on the frequency of alternatives selected by students in the pre- and post-test questionnaires. The scores (Likert scale from 1 to 10) of question 2 were considered. For questions 3, 4 and 5, responses were converted into numerical scores on a 5-point Likert scale, ranging from 1 ("definitely not") to 5 ("definitely yes"). Based on these scores, means and standard deviations were calculated for the group of students who participated in the TLSCS activities. As one student left question 2 unanswered, this variable was analyzed with 95 valid paired observations, while questions 3 and 4 were analyzed with 96 valid pairs. Comparisons between pre- and post-test were performed using the paired t-test (Zar, 2010), considering the dependence between observations, since the same students responded to the instrument at both stages.

Although Likert-scale items are formally ordinal, methodological literature indicates that parametric tests can demonstrate satisfactory robustness in this context, especially in moderate to large samples and in repeated-measures comparisons (Norman, 2010). A significance level of 5% was adopted in a two-tailed test. Thus, p-values lower than 0.05 were interpreted as evidence of statistically significant differences between pre and post-intervention moments, suggesting changes associated with the educational experience.

The two questions exclusive to the post-test (5 and 6) were analyzed descriptively, based on the distribution of the most frequent responses.

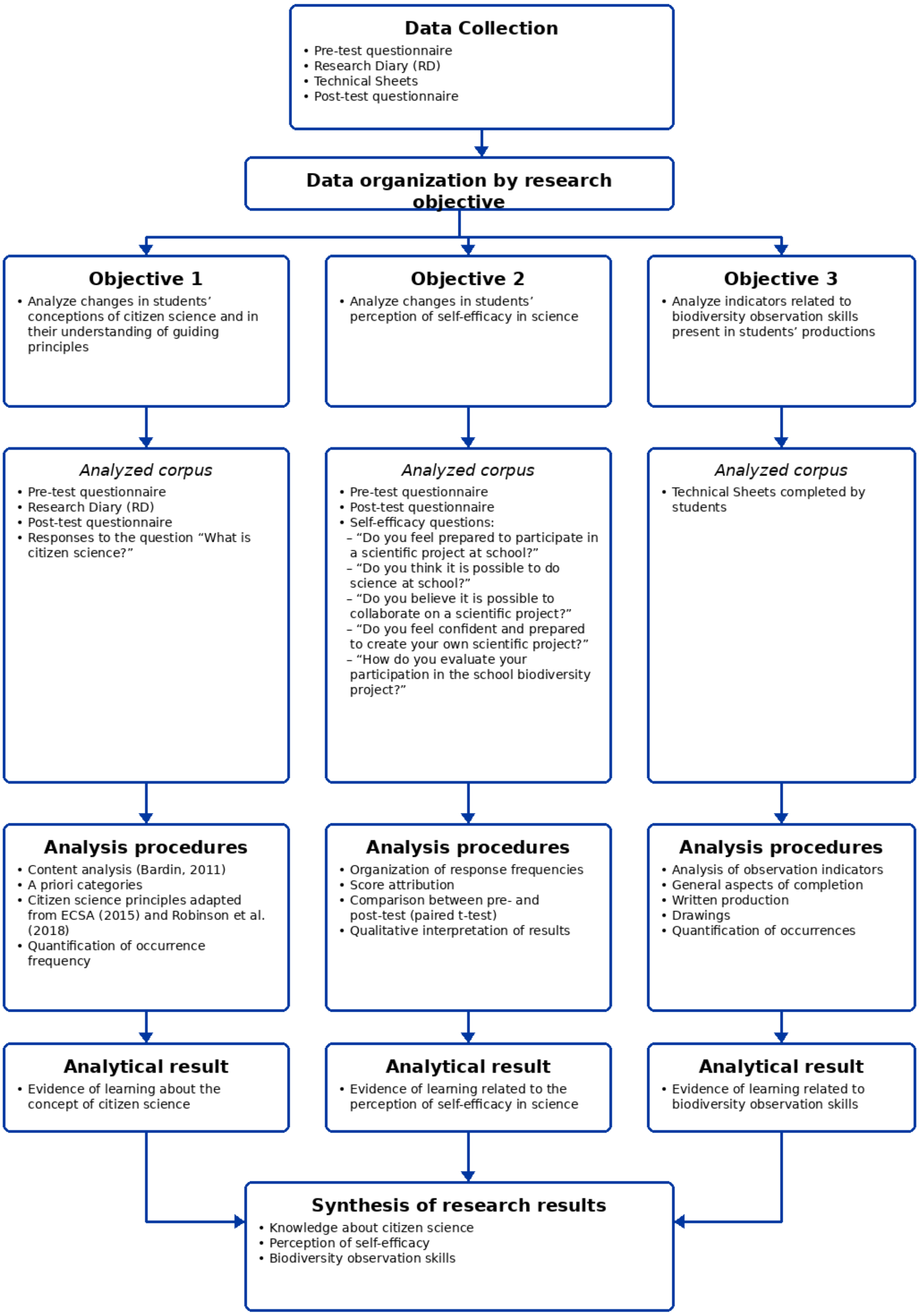
Regarding the analysis of the Technical Sheets, related to the third research objective, we adopted three analytical dimensions: general aspects, textual production, and drawings. In the general aspects, we verified the completeness of the forms and the level of accuracy of the information, classified as fully correct, partially correct, or incorrect. In textual production, we analyzed whether the "curiosities" item addressed the organism's morphology, whether the drawings included labels indicating characteristics, and whether the names assigned by students considered morphological aspects.

In the analysis of the drawings, we observed the presence of biotic and abiotic elements in the setting, the use of colors, anthropomorphic features, and the level of detail of the illustrated organism. The drawings were classified into three levels of detail—high, medium, and low—based on the presence of relevant morphological characteristics and their correspondence with the observed organism. The categories identified in the Technical Sheets were also quantified in order to complement the qualitative analysis and enable the identification of frequency patterns in students' productions.

Figure 4 presents, in a synthesized manner, the process of data collection, organization, and analysis in the study, highlighting the articulation between the instruments used, the investigated objectives, and the adopted analytical procedures.

Figure 4

Synthesis of the process of data collection, organization, and analysis in the study



Source: Prepared by the authors (2026).

Results and Discussion

Learning Related to Scientific Content Knowledge — Concept and Principles of Citizen Science

In the analysis of the pre-test questionnaire, we observed that 7% of the students did not answer this question, while another 6% provided responses unrelated to the concept (for example, S57: "it is very cool" and S35: "I have never heard of it"), and 15% mentioned the words science and/or scientist (for example: S12: "it is a science for adults" and S42: "it is when the scientist works"), without making direct reference to the principles of citizen science. After analyzing the Research Diary and the post-test, we identified that Principle 1 was the most frequently cited by students, followed by Principle 4, with a higher incidence of mentions in the Research Diary (Table 1).

Table 1

Citizen science principles identified in students' responses, including the quantification of absolute frequency of responses in the pre-test (PTQ) and post-test (POQ) questionnaires and in the Research Diary (RD), as well as examples of representative responses for each principle (n = 96)

Citizen Science Principles (adapted from ECSA, 2015; Robinson et al., 2018)	Pre-test	RD	Post-test	Examples of Responses (RD and POQ)
1. Active engagement of citizens in scientific activities	0	72	59	*S15–POQ: "It is children's science"* *S70–POQ: "It's like us. We are not professional scientists, but we are scientists"* *S79–RD: "All people in the world can be part of citizen science"*
4. Participation of citizens in different stages of the scientific process	0	32	19	*S2–RD: "A person has a question, then they go and look for the answer by researching"* *S10–POQ: "Asking questions and researching on the computer"*
7. Public sharing of data and metadata in open access	0	13	2	*S87–RD: "When you share your work"* *S94–POQ: "It is sharing research with the whole world"*

Note 1. RD = Research Diary

Note 2. The wording of the principles was adapted for analytical purposes.

Source: Prepared by the authors (2024).

These results indicate that part of the students did not have the repertoire to define the concept of citizen science in the pre-test, which was expected, and that this knowledge was expanded throughout Stage 4. Although 14% still indicated that they did not know how to define it in the post-test, the majority broadened their understanding by incorporating one or more of the three analyzed principles. In line with Haklay (2021), we recognize that citizen science does not have a single definition; nevertheless, the results demonstrate a meaningful understanding of the active engagement of citizens in scientific activities and the possibility of participation in different stages of the scientific process. These elements converge with the approach developed in the TLSCS, especially in Stage 4, in which students explored different citizen science initiatives, with emphasis on the iNaturalist platform.

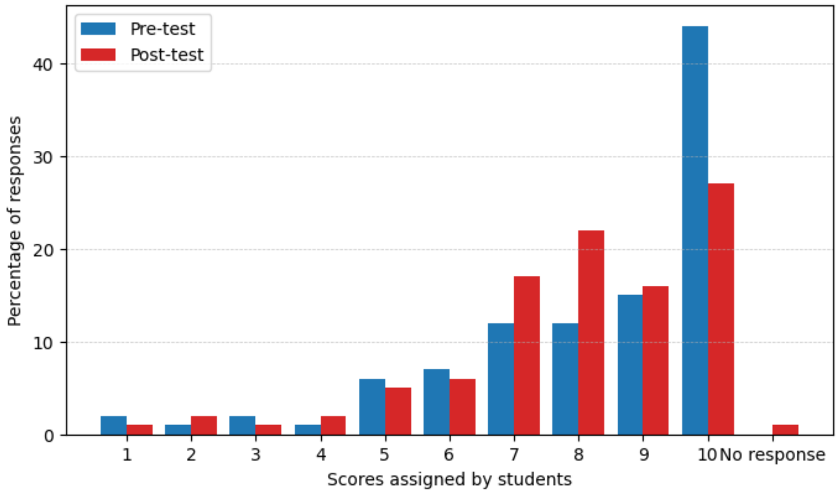
The continuous use of iNaturalist throughout the proposal also strongly engaged the students, particularly when they noticed interactions from identifiers from different countries with the school biodiversity project. Records in the Field Diary show the enthusiasm of the classes in response to these interactions and their sense of accomplishment upon realizing that the cataloged organisms had been recorded by themselves. These findings reinforce the understanding of citizen science as a process of public participation in science and indicate that students began to recognize themselves as part of scientific practice, in line with Principle 1 and with what is expected from initiatives of this nature (Conrad & Hilchey, 2011).

Learning Related to *Self-Efficacy*

In the question "Do you feel prepared to participate in a scientific project at school?" (Figure 5), the mean score obtained by students in the pre-test was 8.18 (standard deviation = 2.24), while in the post-test it was 8.02 (standard deviation = 2.02). The comparison between the two moments did not indicate a statistically significant difference between the mean scores ($p = 0.59$). Even so, the distribution of responses suggests a shift: although the percentage of students who assigned a score of 10 decreased in the post-test, there was an increase in responses concentrated between 7 and 9, without a significant rise in lower scores. This shift may indicate, as an interpretative hypothesis, not a reduction in self-efficacy, but rather a more realistic perception of what it means to participate in a scientific project after the concrete experience of the proposal.

Figure 5

Percentage of student responses (n = 96), on a 10-point Likert scale, to the question "Do you feel prepared to participate in a scientific project at school?"

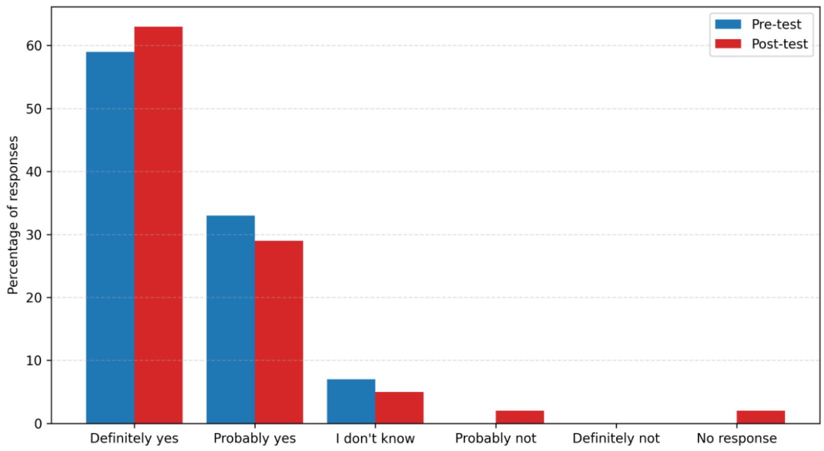


Source: Prepared by the authors (2024).

In the question "Do you believe it is possible to collaborate on a scientific project?" (Figure 6), the mean score obtained by students in the pre-test was 4.50 (standard deviation = 0.66), while in the post-test it was 4.60 (standard deviation = 0.64). The comparison between the two moments did not reveal a statistically significant difference between the mean scores (p = 0.28), indicating stability in responses before and after the implementation of the TLSCS. This result is also reflected in the distribution of responses, as affirmative alternatives maintained the same incidence in both questionnaires (92%), with only slight variations in the responses "I don't know" and "probably not."

Figure 6

Percentage of student responses (n = 96), on a Likert scale, to the question "Do you believe it is possible to collaborate on a scientific project?"

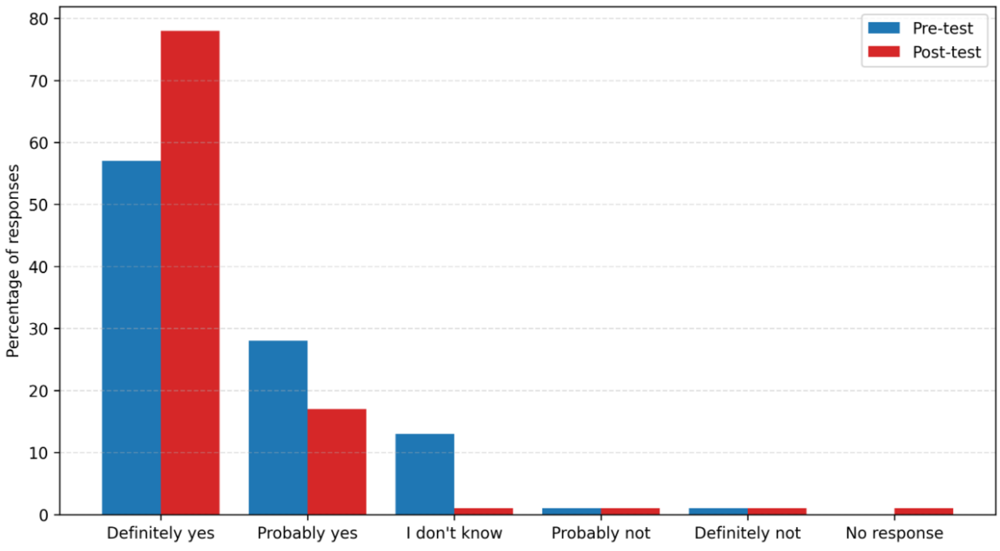


Source: Prepared by the authors (2024).

In the question "Do you think it is possible to do science at school?" (Figure 7), the mean scores obtained by students were 4.40 (standard deviation = 0.89) in the pre-test and 4.68 (standard deviation = 0.66) in the post-test. The comparison between the two moments indicated a statistically significant difference ($p = 0.01$), with an increase in the mean score after the implementation of the TLSCS. This result is consistent with the distribution of responses, as the percentage of students who considered it possible to do science at school increased from 85% in the pre-test to 95% in the post-test, accompanied by a reduction in "I don't know" responses. These findings suggest that, although students initially showed a positive perception of this possibility, the experience of the proposal contributed to strengthening and consolidating the understanding of the school as a legitimate space for investigation, data production, and the dissemination of scientific learning outcomes.

Figure 7

Percentage of student responses (n = 96), on a Likert scale, to the question "Do you think it is possible to do science at school?"

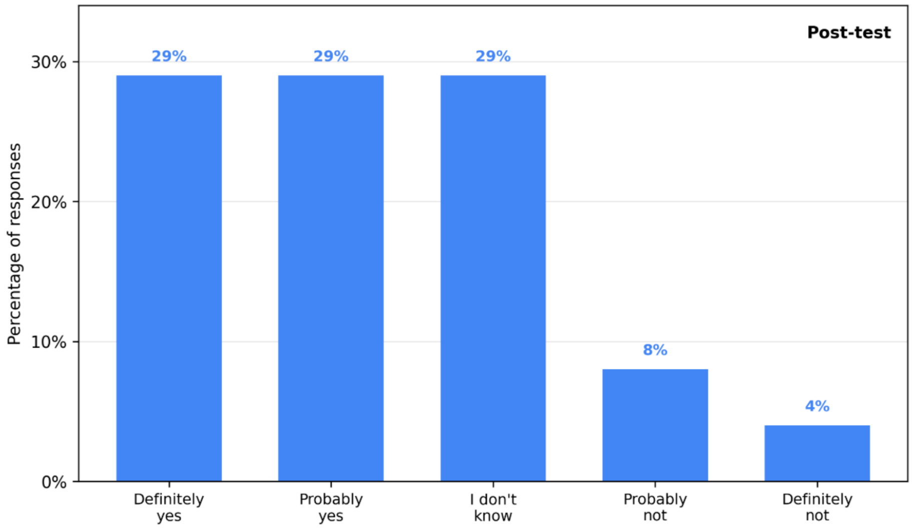


Source: Prepared by the authors (2024).

In the analysis of the question "Do you feel confident to create your own scientific project?" (Figure 8), 58% of the students provided affirmative responses, while 12% indicated negative responses and 29% selected "I don't know." This indicates a high perception of self-efficacy for creating a scientific project among the group of students analyzed.

Figure 8

Percentage of student responses (n = 96), on a Likert scale, to the question "Do you feel confident to create your own scientific project?"

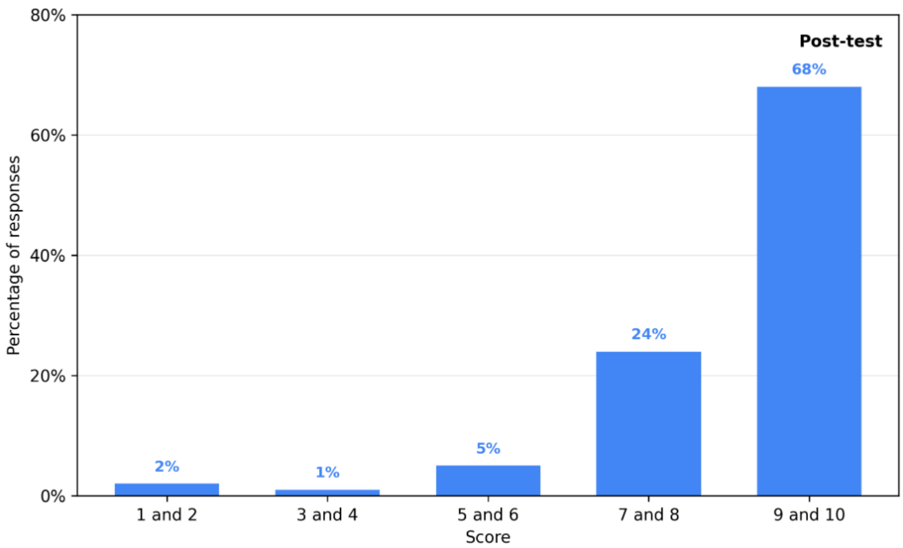


Source: Prepared by the authors (2024).

Regarding the question "How do you evaluate your participation in the school biodiversity project?" (Figure 9), 92% of the responses received scores above 7, indicating that students have a high perception of self-efficacy regarding their participation in the biodiversity project developed at school.

Figure 9

Percentage of student responses (n = 96), on a 10-point Likert scale, to the question "How do you evaluate your participation in the school biodiversity project?"



Source: Prepared by the authors (2024).

Overall, students already demonstrated a high perception of self-efficacy at the beginning of the proposal, which remained high and, in some aspects, increased after the intervention, in line with the findings of Barbieri et al. (2023) and Lüsse et al. (2022). In the present study, however, the data also suggest an important aspect: rather than a linear increase in self-efficacy, the experience of school-based citizen science appears to have fostered a more realistic perception of what it means to participate in a scientific investigation. This can be observed, for example, in the redistribution of responses to the question regarding feeling prepared to participate in a scientific project at school, in which the decrease in the score of 10 occurred alongside an increase in scores of 7, 8, and 9, without a significant rise in lower scores. This pattern may indicate that the concrete experience of the proposal led students to develop less idealized and more accurate self-assessments regarding the demands involved in scientific practice.

At the same time, the increase in affirmative responses to the question "Do you think it is possible to do science at school?" reinforces the interpretation that the intervention contributed to consolidating the school as a legitimate space for investigation, data production, and knowledge dissemination. Although the investigated context is not directly linked to academic performance, these findings align with studies that associate higher levels of self-efficacy with better conditions for engagement and learning in science (Lüsse et al., 2022; Macakova & Wood, 2022). This pattern also aligns with Gonzalez et al. (2024), indicating that school-based citizen science experiences may foster positive perceptions of self-efficacy in Basic Education, even if these perceptions are not expressed in a linear or homogeneous way across the different items analyzed. Taken together, these findings suggest that the experience of school-based citizen science can strengthen students' belief in the possibility of doing science at school, while also promoting more realistic perceptions of the demands involved in participating in scientific practices.

Learning Related to Scientific Inquiry Skills — Observation

A total of 119 Technical Sheets completed by students were collected. However, five were excluded due to the absence of drawings, as this element was considered crucial for the analysis of the documents. This resulted in 73 sheets on animals, 34 on terrestrial plants, and 7 on fungi/lichens (2 on mushrooms and 5 on lichens, treated as the same type of sheet). The results of the analysis of the Technical Sheets were organized in a table to facilitate understanding (Table 2).

Table 2

Results of the analysis of the Technical Sheets completed by students, referring to general aspects, written production, and drawings

Aspects	Indicators		A (N=73)	TP (N=34)	FL (N=7)	T (N=114)
General	Completion of all items	Yes	65	27	4	96
	Level of accuracy of information	Fully correct	48	26	6	80
		Partially correct	25	8	1	34
		Fully Incorrect	0	0	0	0
Related to written production	Themes described in "curiosities"	Morphology	39	17	2	58
		Others	26	11	3	40
	Indication of characteristics in organisms through labels	No	72	33	7	112
	Use of morphological aspects to name the observed organism	Yes	30	20	7	57
Related to drawings	Presence in the setting	Biotic factors	10	4	4	18
		Abiotic factors	12	1	0	13
		Both	38	20	3	61
		None	13	9	0	22
	Presence of colors	Yes	70	32	7	109
	Anthropomorphic elements	Yes	14	1	0	15
	Level of detail of the organism	High	6	7	1	14
		Medium	36	15	6	57
		Low	31	12	0	43

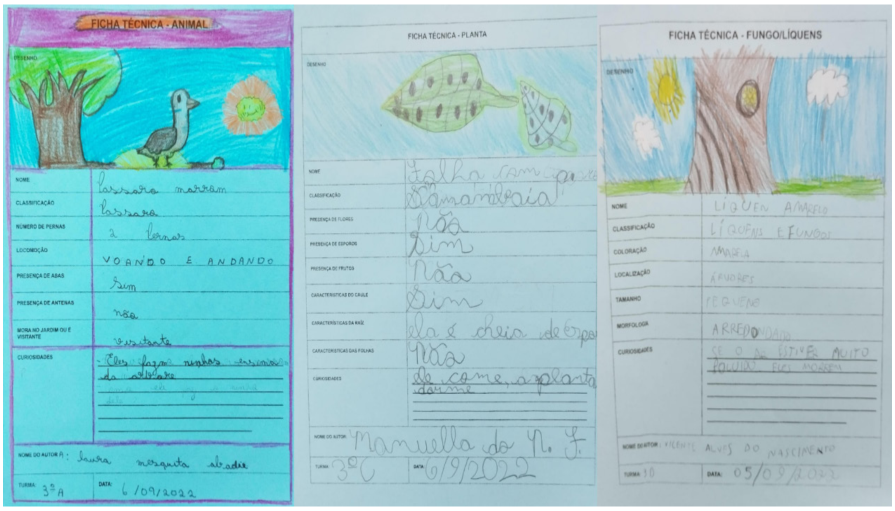
Note. A = animal Technical Sheets; TP = terrestrial plant Technical Sheets; FL = fungi/lichen Technical Sheets; T = total number of Technical Sheets.

Source: Prepared by the authors (2024).

We observed that most of the Technical Sheets were completed in full and with accurate information (Figure 10), with none containing entirely incorrect information. Regarding the written component, 58 (51%) included the "curiosities" item with information about the morphology of the observed organism, such as: "it is a brown insect that flies," "they can have different colors and stay on trees," and "the wings and legs are larger than the body."

Figure 10

Examples of Technical Sheets from each proposed model (Animal, Terrestrial Plant, and Fungi/Lichens) completed by the students



Source: Research data (2024).

The indication of characteristics through labels in the drawn organisms was rare, occurring in only two sheets. The use of morphological characteristics to name the organism was identified in 57 sheets (50%), being more frequent among fungi and lichens (100%) compared to animals (46%) and terrestrial plants (59%). Examples include: "small spider," "green fly," "small white mushroom," "red and yellow flower," and "plant with large fuzzy leaves." The fact that students were unable to name plants, fungi, and lichens may be related to what we refer to as plant blindness (Ursi & Salatino, 2022) and fungal blindness (a term proposed by mycologist Prof. Dr. Nelson Menolli Jr., personal communication).

In the analysis of the drawings (examples in Figure 10), only 22 (19%) did not include a setting associated with the observed organism, while the majority of students (53%) represented both biotic and abiotic factors together. In a similar study conducted by Venturini (2017) on biodiversity in a school in Maringá, PR, the presence of these factors was also observed in most participants' drawings. Furthermore, the use of colors was predominant in 95% of the drawings, corroborating the findings of Venturini (2017). Anthropomorphic elements were identified in only 15 (13%) representations, and half of the drawings presented a medium level of detail of the organism, followed by 37% with a low level of detail. It is worth noting that anthropomorphic elements and descriptive labels were also found in the study by Schwarz (2007), although they were not the main focus of the research.

Figure 11

Examples of some aspects of the individual analyses of selected indicators for the Technical Sheets completed by students (level of accuracy of information, themes described in the curiosities, use of morphological aspects for naming organisms, presence of a setting, anthropomorphic elements, and level of detail of the organism)

Indicators present in the Technical Sheets			
Level of accuracy of information	Fully correct	Partially correct	Fully correct
Themes described in the curiosities	No occurrence of reference to morphology	No occurrence of reference to morphology	No occurrence of reference to morphology
Use of morphological aspects to name the observed organism	Yes	Yes	Yes
Presence in the setting	Yes	No	Yes
Anthropomorphic elements	Yes	No	No
Level of detail of the organism	High	High	Medium

Source: Prepared by the authors (2024).

The observational drawing exercise “integrates the practice of learning a language, aiming at the development of the fundamental skill of observation” (Mazzamati, 2012, p. 85). In addition, there is a historical importance of drawing as a tool for scientific investigation. The students demonstrated a notable development of this skill, evidenced by high incidences in the indicators analyzed in the Technical Sheets. These indicators, dependent on accuracy in observation, proved to be predominantly correct, whether fully or partially. Furthermore, it is noteworthy that many students meaningfully employed morphological aspects when naming the observed organisms, as well as in the descriptions provided in the “curiosities” item.

Fourez’s (1995) approach, which considers observation as a faithful representation of reality, is relevant in this context, as it constitutes a crucial aspect in the study of biodiversity. The advancement in the scientific inquiry skill—observation—under the guidance of the teacher-researcher is in line with the perspective of Hiller and Kitsantas (2022), who suggest that the improvement of scientific observation skills, when guided by experts, is associated with a higher perception of self-efficacy. In this study, although there was no presence of specialists in taxonomic groups to assist the students, the role played by a figure more experienced than the observers (in this case, the teacher-researcher) proved to be crucial, corroborating the findings of the aforementioned study.

Conclusions and Implications

The results of this study provided evidence of student learning related to knowledge about citizen science, perceptions of self-efficacy, and scientific inquiry skills focused on biodiversity observation. Regarding knowledge, the pre-test revealed an important gap, with 72% of students indicating a lack of familiarity with the concept of citizen science. By the end of the TLSCS, changes were identified in students' responses, with a greater presence of elements particularly related to Principles 1 and 4 of citizen science (ECSA, 2015; Robinson et al., 2018), as well as more frequent mentions of participation in different stages of the scientific process.

Regarding self-efficacy, students already showed positive perceptions at the beginning of the proposal, which remained high after the intervention. Although some questions did not show statistically significant differences between the pre- and post-test, there was a significant increase in the perception that it is possible to do science at school. Evaluations of participation in the project were also predominantly positive, suggesting a favorable perception among students regarding their participation in scientific practices.

Regarding the scientific inquiry skill—observation—the analysis of the Technical Sheets completed by the students revealed that most presented accurate and complete information, indicating satisfactory development of this indicator. The analyzed drawings were also rich in detail, including numerous elements related to both biotic and abiotic aspects in their settings. Considering that observation is a descriptive account of natural phenomena that are directly accessible to the senses, such as the description of the morphology of living organisms (Campos & Nigro, 2010), these results were significant.

Our findings corroborate other studies addressing citizen science and biodiversity in the school context, such as Echeverria et al. (2021), Forti (2023), and Stevenson et al. (2021), which provide evidence that the use of the iNaturalist platform as a tool for recording biodiversity data collected in citizen science projects within formal education can contribute to student learning. Among these learning outcomes, the development of skills that contribute to participants' scientific literacy stands out, expanding their understanding of scientific knowledge, how it is produced, and the environment around them, thereby fostering conditions for the development of pro-environmental behaviors.

In line with the principles of citizen science (ECSA, 2015; Robinson et al., 2018), students were able to produce and share useful data about the biodiversity of a school garden, participating in several stages of the scientific investigation. These elements reinforce the understanding that the developed proposal approached a co-created perspective of citizen science in the school context. Such findings are relevant, as an important part of current scientific understanding of biodiversity derives from data collected, transcribed, or processed by volunteers (Bonney et al., 2009; Chandler et al., 2017).

In summary, the results of this study suggest that the co-created citizen science approach in the school context fostered evidence of learning related to knowledge about citizen science, perception of self-efficacy, and biodiversity observation skills in the investigated context. These findings reinforce the relevance of pedagogical strategies that actively engage students in experiences of this nature, while also highlighting the need for longitudinal studies to examine the persistence of these learning outcomes.

This study presents limitations and challenges that must be considered when interpreting the results. The short time interval between the intervention and the post-test allows for the identification of changes in the immediate context of the proposal but does not make it possible to examine the persistence of these learning outcomes over time. Furthermore, although the research design was appropriate for the study's objectives, it proved limited in capturing in greater depth the meanings students attributed to the observed changes. In addition, the study was conducted in a specific school context, and there are inherent challenges in evaluating dimensions such as knowledge, self-efficacy, and inquiry skills through a limited set of instruments. These aspects highlight the need for future research with longitudinal follow-up and more in-depth strategies for listening to participants.

Expanding knowledge about biodiversity is essential to foster pro-environmental behaviors and stimulate young people's interest in nature conservation (Palmberg et al., 2015; Franzolin et al., 2020; Wyles & Ghilardi-Lopes, 2023). In this sense, the proposal investigated in this study contributed to the development of young citizens capable of producing scientific knowledge, aware of their potential to collaborate with science, and able to observe relevant aspects of biodiversity in their surroundings. These competencies are important for fostering more critical and reflective attitudes toward sustainability issues, especially in a context marked by the risk society (Beck, 1996).

Authors' Contribution

Conceptualization: Gonzalez, J. D., Ghilardi-Lopes, N. P.; **Data curation:** Gonzalez, J. D.; **Formal analysis:** Gonzalez, J. D., Ghilardi-Lopes, N. P.; **Funding acquisition:** Ghilardi-Lopes, N. P.; **Investigation:** Gonzalez, J. D.; **Methodology:** Gonzalez, J. D.; **Project administration:** Gonzalez, J. D., Ghilardi-Lopes, N. P.; **Resources:** Ghilardi-Lopes, N. P.; **Supervision:** Ghilardi-Lopes, N. P.; **Validation:** Ghilardi-Lopes, N. P.; **Writing – original draft:** Gonzalez, J. D.; **Writing – review & editing:** Gonzalez, J. D., Ghilardi-Lopes, N. P.

Data Availability Statement

The data will be provided upon request.

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