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A local citizen science project on biodiversity: At the crossroads of science and environmental education

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ABSTRACT

Citizen science (CS) projects are becoming an increasingly popular method for engaging students in science and environmental education. This study examined the effectiveness of participation by primary school students (aged 8-11) in a French local CS project. We investigated changes in naturalist knowledge and awareness raised of biodiversity issues through pre- and post-test questionnaires. This project involved field trips and the participation of an ecology researcher inside and outside the classroom. The results suggest that it enabled students to develop better naturalist knowledge of the project's sentinel species (tits and honeybees). Students also seem more aware of the importance of biodiversity and the issues involved. In discussion, we highlight three levers for implementing a CS project to develop biodiversity education: two through our research (field trip, direct involvement of the researcher) and a third that comes under the institutional context (integration of CS into the curriculum).

Keywords: biodiversity, citizen science, formal school, field trips

INTRODUCTION

Citizen science (CS) is an approach where researchers engage the public (non-professional scientists) in the scientific research process, most often in the collection and submission of data (Bonney et al., 2014; Vohland et al., 2021). CS projects have increased in number over the last twenty years, particularly on the topics of the environmental and ecological sciences, in a context of global change (Burgess et al., 2017; Fraisl et al., 2022; McKinley et al., 2017) and more specifically in the biodiversity conservation domain (Bryn et al., 2023; Peter et al., 2019, 2021). Indeed, biodiversity is one of the most popular categories of CS projects. It contributes to various themes such as conservation biology, ecological restoration and climate change, and concerns different taxonomic groups such as birds, insects and plants. Not only does CS represent an extraordinary potential for expanding scientific knowledge about global biodiversity, with the sharing of data over larger spatial and temporal scales (Callaghan et al., 2020; Pocock et al., 2018), but it also constitutes a considerable advantage for the increased scientific literacy and awareness gained by the participants.

For these last two reasons, over the last ten years, CS projects have begun to be integrated into teaching practices and are increasingly taking place in schools (Berndt & Nitz, 2023; Bopardikar et al., 2023). In the learning and education fields, CS is a relevant approach that contributes both to the integration of science teaching with education, and to environmental education (EE) (Aivelo & Huovelin, 2020; Dillon, 2016; Wals et al. 2014). In these domains, the notion of biodiversity and the problems of its conservation constitute one of the great challenges, due to its complexity and high degree of abstraction. That's why this theme of biodiversity plays a major role in the CS projects in schools (Aivelo, 2023; Aivelo & Huovelin, 2020; Christ et al., 2022; Kelemen-Finan et al., 2018).

While the majority of CS projects are on a large national or regional scale (Hecker et al., 2018), local projects seem to be more relevant to students learning. Thus, contextualizing scientific learning in natural environments close to the school enables students to deeply engage in their scientific learning (Ayotte-Beaudet et al., 2019, 2023, 2024). This study also supports this idea. In order to be effective, biodiversity education must offer student-centered teaching and learning methods that develop experiential learning skills based on concrete and direct experiences and hands-on activities (Jose et al., 2017).

Citizen Science for Biodiversity and Science Education

The numerous systemic reviews reporting on the contribution of CS in the field of biodiversity (Peter et al.,

2019) and beyond in the field of environmental sciences (Aristeidou & Herodotou, 2020; Ballard et al., 2024; Bonney et al., 2016; Finger et al., 2023; Groulx et al., 2017; Vasiliades et al., 2021) converge on the following learning and education science benefits.

Understanding Scientific Content and Knowledge

The most common learning outcome documented in reviews of literature is science content knowledge gains, with, for example, 56 out of 100 articles for Ballard et al. (2024) in the general environmental field, and 11 out of 14 articles for Peter et al. (2019) in the more specific field of biodiversity. Participation and engaging directly in scientific research is an effective way for individuals to gain knowledge related to science and biodiversity.

Studies have shown that students acquire scientific knowledge linked to the specific content of the CS project. For example, Carson et al. (2021, p. 21) report an improved ‘understanding of the coastal environment and human impacts’ and ‘an increased ability to identify marine organisms and their challenges’ in primary and secondary school students; while other projects highlight the improvement in participants’ knowledge of living organisms such as pollinator insects (Baptista et al., 2018; Saunders et al., 2018), mammals (Schuttler et al., 2019) or birds (Hirschenhauser et al., 2019), often leading to gains in naturalist knowledge.

Understanding of Scientific Methods and Processes

CS projects imply that students develop not only scientific knowledge, but also knowledge about science and scientific research, e.g., methods and activities through which science progresses (Cronje et al., 2011; Queiruga-Dios et al., 2020). More often, CS projects aim to introduce students to scientific protocol by collecting data that can be analyzed by researchers. Students are actively involved in data collection, giving them a practical understanding of scientific methods and processes, and have the opportunity to learn through hands-on experience.

These concrete field experiments can also help students develop a skill in scientific observation and leads them to make more unsolicited observations about particular living organisms (Ayotte-Beaudet et al., 2024). We know that cultivating skill in observation is one of the essential steps in inquiry-based learning strategies (Boaventura et al., 2013, 2021; Klofutar et al., 2022). In the field, observation is key, bearing in mind that in order to observe, students must be prepared on a conceptual level. Scientific observation is a selective process that requires, at the very least, a target of attention and a goal (Hodson, 2015).

By engaging in these CS activities, students can develop critical thinking skills and a deeper understanding of scientific concepts (Shah & Martinez, 2016). Indeed, Saunders et al. (2018) consider CS particularly relevant to addressing current societal environmental sustainability challenges, since it engages the students directly with environmental science, giving them an understanding of the scientific process and the skills to observe local manifestations of global challenges.

Motivation, Attitudes, and Engagement

A review by Peter et al. (2019) shows that applying CS in the field of biodiversity can improve participants’ behavior in 8 out of 14 articles and their attitudes in half of the articles. Perelló et al. (2017) emphasize that 81% of the students reached top levels regarding motivation and participation attitudes.

By working on authentic scientific research problems, students see the tangible impact of their contributions, which enhances their interest in science, and particularly, in environmental science (Aivelo, 2023; Hiller & Kitsantas, 2014; Shah & Martinez, 2016; Vitone et al., 2016). Studies’ results show an increase in students’ interest and positive attitudes toward the species studied, such as rats (Aivelo, 2023), ants (Vitone et al., 2016) or wild bees (Ganzevoort & van den Born, 2021; Kelemen-Finan et al., 2018). The pedagogical approaches used to participate in these authentic scientific projects are ‘more exciting and engaging than traditional classroom experiences, helping to mitigate the loss of interest in science’ (Williams et al., 2021, p. 1038). Students seem to be more involved thanks to the CS projects, which makes science more meaningful and helps to improve their attitude toward science. Indeed, in the same way, field trips enable students to engage in the activity and construct meaning in science learning (Chalmeau & Julien, 2023).

Citizen Science for Environmental Education

While CS has a number of outcomes, ranging from enhancing scientific knowledge, methods and processes of scientific engagement, it is also increasingly used as a tool for EE. CS has proven to be a powerful tool for EE by extending beyond the development of knowledge and skills in science learning and education, fostering engagement with local ecosystems, enhancing environmental literacy, and promoting pro-environmental values, attitudes and behavior (Adamou et al., 2021; Ardoin et al., 2020; Ballard et al., 2024; Branchini et al., 2015; Dunkley, 2017; Merenlender et al., 2016; Wals et al., 2014).

EE through CS projects integrates various educational strategies to help students understand the importance of biodiversity, the threats it faces, and the actions needed to protect it.

To provide an authentic experience in the local natural environment, CS projects involve using the experiential learning and learning in natural environments approaches, which have been proven to be effective for science and EE. These approaches are also considered as a meaningful context for transformational learning, which can empower students and lead to pro-environmental behavior (Goldman & Alkaher, 2023).

Experiential Learning / Providing an Authentic Experience in the Natural Environment

The concept of experiential learning, theorized by Kolb (1984), postulates that effective learning is based on a transformative experience. Experience can be defined as a process of linking thoughts and actions at the level of people’s interactions with their environment (Dewey, 1938). Phillips et al. (2019, p. 668) make the link between the experiential approach and CSs, pointing out that 'the hands-on nature of CS aligns well with experiential learning theory because of the tangible experiences that participants can reflect upon easily'.

In EE, this approach is particularly powerful because it involves hands-on activities and direct interaction with natural environments (Chalmeau & Julien, 2023; Julien & Chalmeau, 2022). This process promotes the emergence of emotions through the sensory exploration of this natural environment. It emphasizes learning through action, reflection, and application, encouraging active engagement with ecological concepts and fostering a deeper understanding of environmental issues. Research shows that immersive, nature-based experiences foster a greater emotional and intellectual connection to the natural environment (Rickinson et al., 2004). In a school context, direct interactions with diverse living and non-living aspects of nature have been shown to foster a positive relationship towards nature (White et al., 2018). Some studies have indicated that engaging students in sensory nature experiences is key to gaining deeper awareness of, knowledge of, and attitudes towards local biodiversity (Beery & Jørgensen, 2018; White et al., 2018).

Recent experimental studies have found increases in both nature connectedness and wellbeing for participants taking part in CS activities (Eichholtzer et al., 2024; Pocock et al., 2023). The experiential dimension thus appears to have repercussions beyond scientific learning and understanding of environmental issues, since it also impacts a holistic dimension such as a sense of wellbeing.

Place-(Nature)-Based Education

Nature-based CS refers to programs that occur in outdoor environments marked by biophysical natural elements and place based firmly rooted in the place of local context. Place-based education is a 'pedagogical approach that emphasizes the connection between a learning process and the physical place in which teachers and students are located' (Yemini et al., 2023, p. 1). CS projects at the local level has an intrinsic importance, since they allow incorporating local, place-based knowledge into the scientific process. Indeed, leveraging the 'power of place' (Newman et al., 2017) could generate substantial positive impacts on environmental attitudes and behavior, even conservation. Indeed, participation in CS projects can connect people more closely to the places they live, create new understandings of what those places mean, and encourage people to participate more fully in being stewards of those places (Haywood, 2014; Haywood et al., 2016; Newman et al., 2017).

Place-based education is frequently regarded as a key element of effective EE because it links learning to tangible, real-world contexts. In nature-based CS projects, educational experiences take place outdoors, in natural settings, such as forests, rivers, or other ecosystems. By immersing students in real-world ecosystems, it fosters a deeper connection to nature, enhances critical thinking and problem-solving skills, and promotes environmental stewardship (Groulx et al., 2017).

Aims and Research Questions

The context of this research is based on the implementation of a pedagogical project for EE, integrating the realization of CS protocols with two main objectives:

1. To expose students to ordinary, local biodiversity by collecting data in the field with a view to acquiring naturalist knowledge.
2. To understand some of the issues involved in studying biodiversity (sentinel species) as indicators of global warming. In this context, students are introduced to researchers, their research objects and questions, as well as their methods and tools.

The research question is as follows: To what extent does involvement in a CS program help develop naturalist knowledge and raise awareness of biodiversity issues as indicators of global warming?

The hypothesis was that participation in the project had a positive influence on students' learning success. Involvement in a CS program

(1) enriches the notion of biodiversity (definition and issues) and

(2) develops naturalist knowledge.

MATERIALS AND METHODS

Curricular Context

In French primary school, the theme of *biodiversity* is studied from kindergarten onward. With students aged 8 to 11, the challenges of biodiversity in relation to climate change can be a learning objective (Ministère de l'Education Nationale [MEN], 2020). In fact, one of the main objectives of school science programs is to 'identify environmental issues'. In this context, students are expected to work on 'biodiversity, a dynamic network' and 'identify the nature of interactions between living beings and their importance in populating environments'. In the life sciences discipline, the term biodiversity appears six times, indicating the importance given to this notion. In terms of activities, this can lead to 'working from the immediate environment: observation and analysis of data gathered during field trips'. Furthermore, while there is no mention of CS in the programs, it works to 'enable pupils to get involved in concrete actions and projects linked to themes related to education for sustainable development'.

Participants

A total of 25 students from 3rd to 5th grade (aged 8-11 of formal education at school in France), belonging to one class within one elementary public school from the Toulouse region (France), participated in this study. The school is located in a small rural village with around 240 inhabitants (2021 census).

ECONECT Project

What's special about this project is that, from the outset, it has included the participation of teacher-researchers in the field of EE, in order to contact the classes and implement protocols in line with the levels and curricula, particularly in natural sciences.

The Econect project brings together six research laboratories and three companies based in the Toulouse City region (southwest of France). Its aim is to develop a communications infrastructure enabling remote monitoring of autonomous, connected and scalable systems for measuring

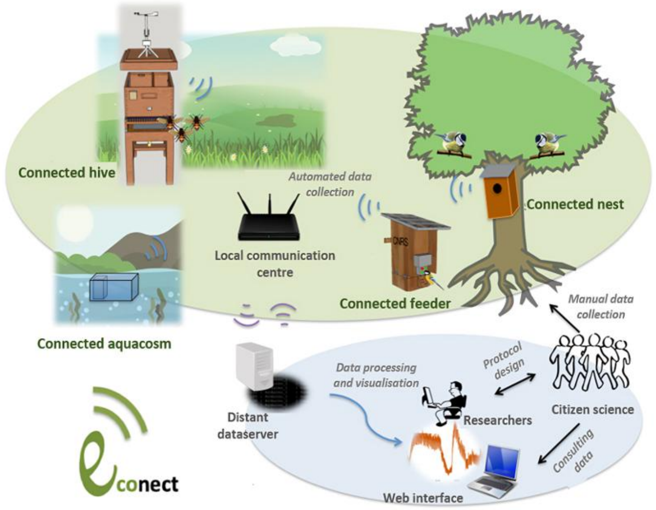

Figure 1. Diagram showing the typical architecture of an Econect measuring station, with proximity communication between the sentinel devices and the local communication center, which will then transfer the data to the server in Toulouse (Source: https://econect.cnrs.fr/; modified and translated by the authors)

the responses of so-called 'sentinel' species to anthropogenic threats and climatic stresses (**Figure 1**).

A network of eight Econect measuring stations have been deployed along three ecological gradients (altitude, urbanization, and type of agriculture) characterized by a spatial analysis of land use and the quality of natural habitats, and by the measurement of pollutant concentrations (heavy metals and pesticides) in various environmental compartments. Three sentinel systems are being considered:

- the connected hive for honeybee species (*apis mellifica*),
- the connected feeder and nest for blue and great tits (*cyanistes caeruleus* and *parus major*), and
- the connected aquacise, for a species of aquatic gastropod (*lymnaea stagnalis*).

Our work, as researchers in environmental and sustainable development education, consisted of:

(1) establishing CS protocols co-constructed with the project's ecology researchers and schoolteachers,

(2) setting up an EE project involving the implementation of one or more of these CS protocols, and

(3) analyzing student participation in these protocols.

Procedure

As a part of the project, students performed a set of activities related to biodiversity and sentinel species (**Table 1**).

Table 1. Sequence of stages in the educational project, with descriptions of in-class and outdoor activities

Stage	Activities and contents
Stage 1: November 2021 to February 2022	**In class:** Questionnaire (pre-test) completed by students. Work on documentary texts (migratory birds, goshawks, great tit) to acculturate students to the world of birds. Feeder construction and installation in the playground. Observation and identification of common birds at feeders.
Stage 2: April 8, 2022	**Outdoors (Econect station) in three locations chosen in relation to the activity:** This outing was broken down into three rotating workshops linked to the Econect project protocols to be carried out the following time. - *Tree species identification workshop.* Based on observations, we define a leaf and how to recognize a simple leaf from a compound leaf. The associated vocabulary is defined by the students: petiole, limb, vein, bud, leaf, and leaflet. Students work in pairs to identify two leaves, using "tree identity" cards and a simplified identification key. - *Phenology workshop.* **1.** Presentation of a tree's life cycle (beech): 'Over the course of a year, how does a tree develop? What are its stages?' **2.** Observation of an oak and an ash: use the phenology sheets to try to determine the stage of the tree based on what you can actually see. **3.** Make them understand the impact of global warming (oak example) on phenology and possible shifts in the trophic chain. Observe the consequences on the phenology of caterpillars and tits. **4.** Explain the objectives of Econect's researchers: to accurately record (with the help of students) dates for tree's stages of development. - *Food chains workshop.* **1.** Explore food chains based on oak and ivy, using two sets of photos and arrows, with each arrow indicating the direction in which organic matter circulates (is eaten by). **2.** Students build several food chains to deduce that plants are always the first link. **3.** Students are asked to explain why the Econect's researchers need to know whether there is an oak tree or ivy near the nesting boxes.
Stage 3: April 22, 2022	**Outdoors at the 6 connected nests to the Econect station (three rotating workshops):** With the help of a supervisor, the students completed the protocols for each nesting box: **1.** Habitat around the tree carrying the nest (identification of the tree, estimation of the vegetation cover around the tree, height and circumference of the tree, presence of oaks and ivy around the tree, etc.). **2.** Phenology of the tree carrying the nest
Stage 4: May 31, 2022	**In class:** The ecology researcher (head of Econect project) explained to the students the stakes and the implementation of the Econect project on sentinel species through a slide show. He also showed some of the instruments used in the project, such as sensors. **Outdoor on the Econect station (three rotating workshops):** - *Tit sentinel.* With a telescopic rod from a GoPro, the students were able to observe the presence of tit nests, eggs or chicks in the nesting box, which enabled them to revisit the different stages in the life cycle of these species. They were also able to see the connected feeder and the images it could broadcast. - *Bee sentinel.* At the connected hive, a camera with a macro lens was positioned to film the bees' flight path. Students see live footage on a tablet, demonstrating different types of bees in a hive (queen, worker and drone) and their respective roles. - *Limnea sentinel.* Discovery of the pond's aquatic environment and the various species present: insects, plants and molluscs (limnea). Using a tablet, they were able to view various aquacosm data (physico-chemical parameters) collected via sensors.
Stage 5: July 4, 2022	**In class:** The teacher gave the students the end-of-project questionnaire (post-test).

Table 2. Pre- and post-test questions (*the last question was asked only in the post-test phase)

		Questions
Biodiversity	Q1	What does biodiversity mean to you?
	Q2	Is biodiversity in danger?
	Q3	If so, what are these dangers?
Bee sentinel	Q4	What are the different types of bees that can be found in a hive?
	Q5	Are bees in danger?
	Q6	If so, what are these dangers?
	Q7	What role do bees play in nature?
Tit sentinel	Q8	Which of these three birds is a great tit?
	Q9	Do you know of any other bird species that can be seen around your home?
General feelings	Q10*	What did you like about the Econect project?

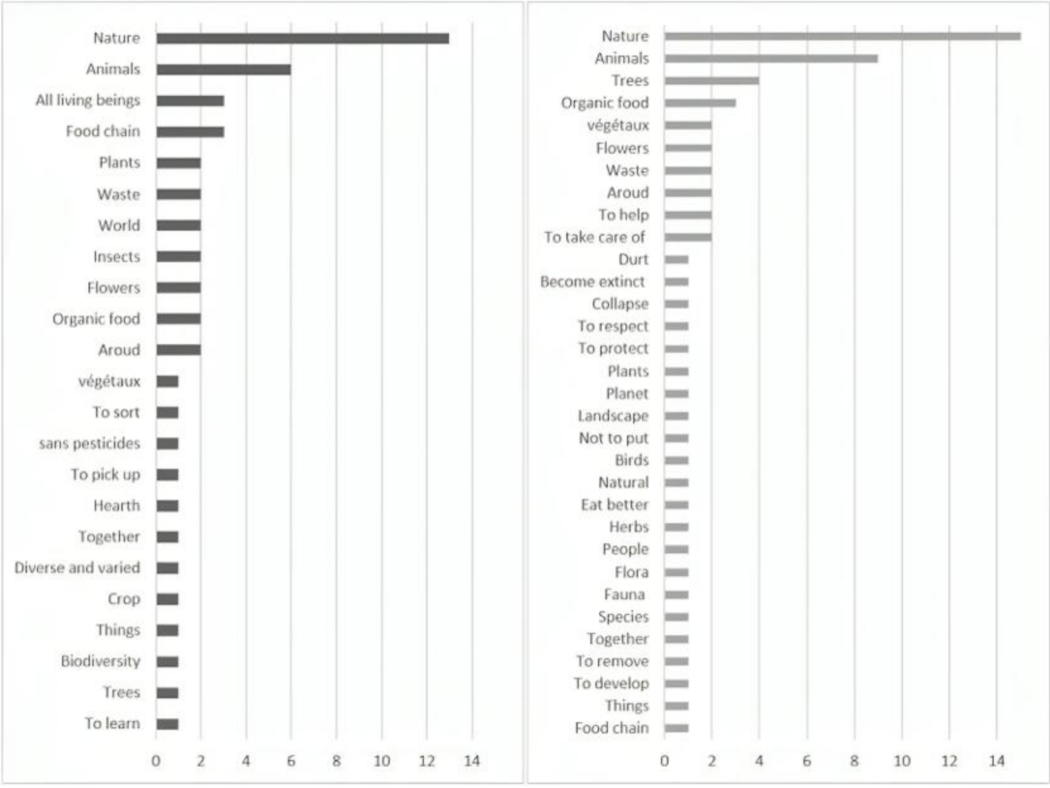

Figure 2. Occurrence of words used by students to define biodiversity in pre-test (dark grey on left) and post-test (light grey on right) situations (Source: Authors' own elaboration)

Data Collection

In order to assess the students' previous knowledge, a pre-test was applied to students before the beginning of the CS project. The same test was applied after the project (post-test). These tests included seven questions to assess the students' knowledge of biodiversity and sentinel species (**Table 2**).

Data Analysis

The answers to the open questions were content-analyzed and sorted into broad categories according to the type of responses given. Coding was discussed between the two researchers and a primary-school teacher. Reliability of the categories used to analyze the contents is derived from the common thread of the researchers and the teacher. Students' answers to Q3 are sorted into five categories: pollution, habitat destruction, global warming, overexploitation and others. Students' answers to Q7 are sorted into two categories: pollination and/or flower reproduction and others. Students' answers to Q4 are sorted into four categories: 3/3 correct answers, 2/3 correct answers, 1/3 correct answers and bad answers.

The statistical analyses were carried out using XLSTATS 2024 software[1]. Comparisons between pre- and post-test were carried out with either a Wilcoxon test (for Q4 and Q9). The threshold for statistical significance was set at $p = 0.05$.

RESULTS

Biodiversity Definition

In both pre- and post-test, 'nature' terms prevail, followed by 'animals' and 'plants' (**Figure 2**).

[1] Lumivero. (2024). XLSTAT statistical and data analysis solution. https://www.xlstat.com/fr

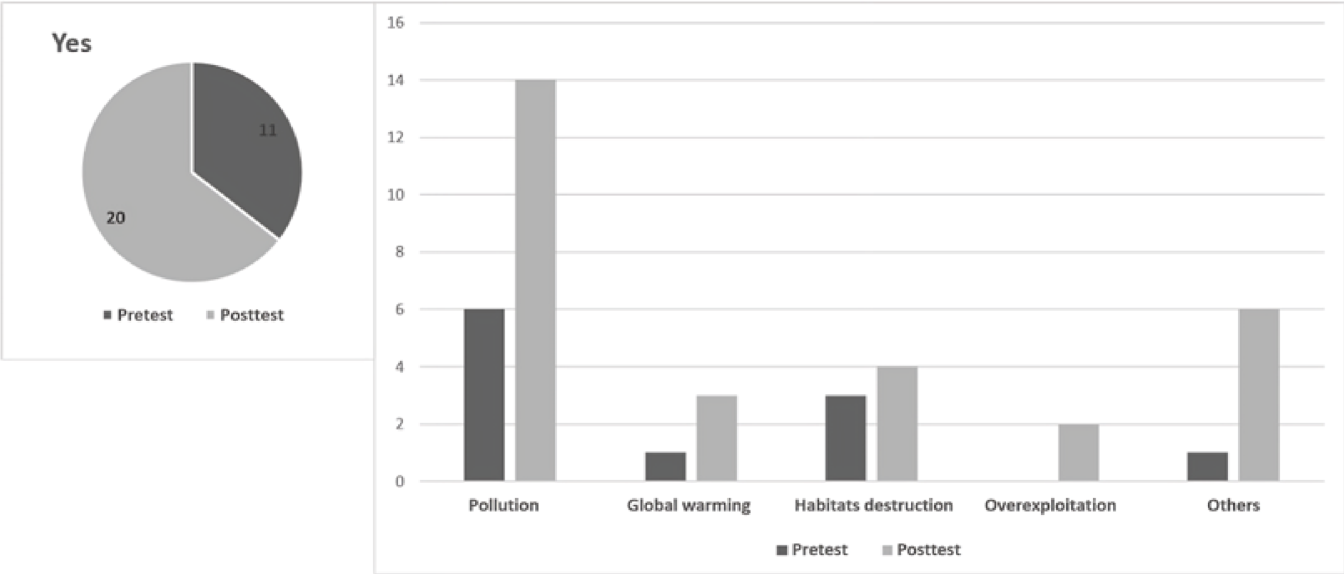

Figure 3. Left: Answers to the question 'is biodiversity in danger?' (in pre-test: 22 students out of 23 replied & in post-test: 25 students out of 25 replied) & Right: Answers to the question 'if so, what are these dangers?' (in pre-test: 10 students out of 23 replied & in post-test: 18 students out of 25 replied) (Source: Authors' own elaboration)

'Nature' is the word most often used to define biodiversity, with 15 occurrences in the pre-test (n = 20) and 13 in the post-test (n = 22). The generic term 'animals' or fauna is used ten times in pre-test and five times in post-test. Students sometimes mention more specific groups, such as insects and birds. The terms 'plants' or 'flora' are cited much less often, although other words designating vegetation (trees and grasses) are used (seven times in pre-test and four times in post-test). Finally, a new term appears in the post-test for three answers: 'living beings', or 'living things' to define biodiversity.

Some definitions evoke the notion of interdependence. In the pre-test, we found just one answer along these lines: 'For me, biodiversity is a bit like the food chain, meaning that if one species in nature becomes extinct, biodiversity collapses'. In the post-test, three students mention 'food chains'.

We also note that some students don't define biodiversity as an 'object' but more as an action, an attitude or a commitment. In the pre-test, we find 'remove waste', 'don't litter', 'take care of', 'look after', 'protect', 'respect' (n = 6 answers out of 20 centered on an action or attitude). In the post-test, only one response remains with 'collect garbage' and 'sort rubbish'. On the other hand, these eco-citizen concerns are well represented in the post-test in the dangers for biodiversity, associated with the generic term 'pollution'.

It's worth noting that three students' answers reveal a cognitive misunderstanding. They seem to be confusing with two terms that begin with the same syllable: biodiversity and organic food. Indeed, in French, organic food is commonly referred to as 'alimentation bio' short for 'biological'.

Dangers for Biodiversity

Twice as many students think biodiversity is in danger after the educational project (11 in pre-test vs. 20 in post-test). Conversely, 12 of them think it's no danger in the pre-test, and only 5 in the post-test (left part in **Figure 3**).

The dangers cited by students concern pollution, habitat destruction, global warming and over exploitation (right part in **Figure 3**). In the pre-test, 11 dangers were cited by 10 students, whereas in the post-test 29 dangers were cited by 18 students, giving an average of 1.1 dangers cited per student in the pre-test and 1.6 in the post-test. In terms of the dangers cited, pollution was the most common (rising from 6 to 14). In addition, global warming was cited more often and overexploitation appeared. The students seem to have reinforced their knowledge on this subject, because at the end of the sequence, eight more of them suggested a response to the nature of the dangers to biodiversity. The number of causes rose from 11 to 29. In post-test, 'others' category represents endangered species and therefore does not answer the question posed. However, they translate the term 'danger to biodiversity' by 'extinction of species' without giving a cause. For them, this extinction is a sign of endangered biodiversity.

Bee Sentinel

In the pre-test, none of the students gave the three correct answers for the three types of bees in a hive (the worker, the drone, and the queen). The majority of them give only one or two correct answers and four students give a bad answer (bumblebees or hornets for example). On the other hand, in the post-test, all of them gave two or three correct answers in the post-test (**Figure 4**). The increase in scientific knowledge following the CS project is significant (p = 0.001). Concerning 'are bees in danger?', more students in the post-test considered bees to be in danger (17/21 vs. 10/24). Of the 15 responses naming these dangers, most mention pesticides (7 vs. only 3 in the pre-test). What's more, in the pre-test (as opposed to the post-test), half the answers are not related to the question asked ('*some people kill bees*'; '*bees sting us so they die*'). Finally, to the question 'what role do bees play in nature?', the majority of answers concern the role of bees in pollination and/or flower reproduction. In post-test, almost twice as many people mentioned this role (11/10 vs 20/25).

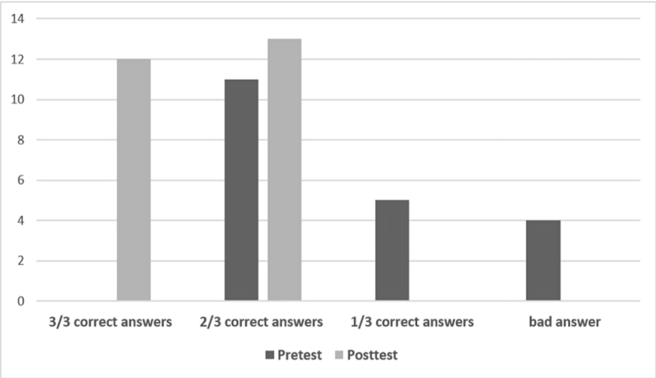

Figure 4. Answers to the question 'what are the different types of bees that can be found in a hive'? (in pre-test: 20 students out of 23 replied & in post-test: 25 students out of 25 replied) (Source: Authors' own elaboration)

Tit Sentinel

On the whole, the students were able to recognize the great tit in one of the 3 bird photos: 17/23 in the pre-test and 24/25 in the post-test. On average, students cite more bird species in the post-test: 4.3 vs. 3.3 (**Figure 5**).

This difference is significant (Wilcoxon test, p = 0.045). Whereas in the pre-test, students named 20 different species, in the post-test they named ten more. The three most cited in pre- and post-test are, in order, the robin, the magpie and the pigeon. In the post-test, the red kite tied for third place. The hummingbird was the only bird that does not live in this environment that was cited.

Favorite Part of the Project

The vast majority of responses concerned the last day and the experience of the last outing, during which the students worked on the three sentinels (tit, bee, and limnae). On this occasion, they were able to explore the pond where the aquacosm with the limnae was located, fishing for and observing small aquatic animals. The students were very involved and active during this workshop, which their responses revealed to be a very good memory. In the three workshops (**Table 1**), they also showed a keen interest in the technological dimensions of the project which involved a camera to film the different types of bees in a hive, a GoPro camera equipped with a parchment to observe the inside of the nesting box, and sensors integrated into the aquacosm. They also said they enjoyed learning about the science of biodiversity.

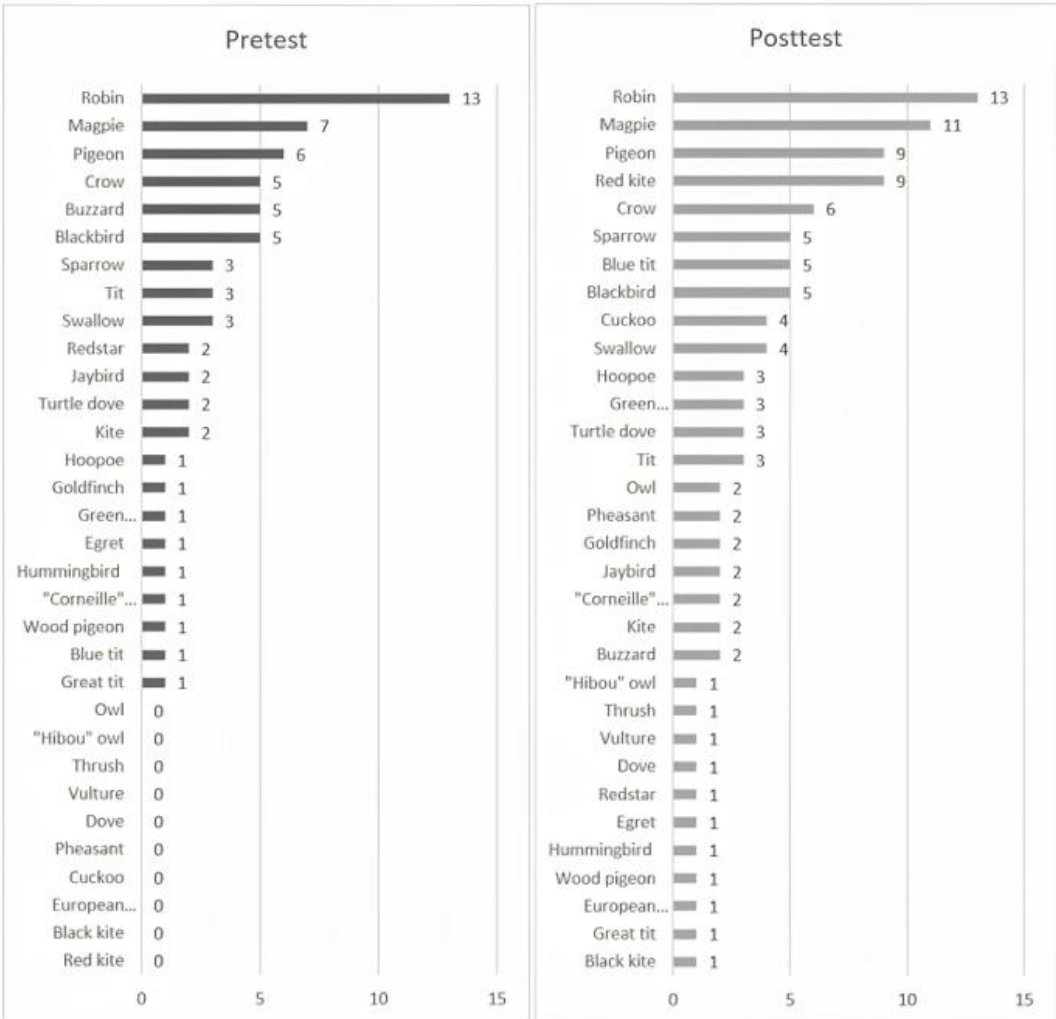

Figure 5. Answers to the question 'do you know of any other bird species that can be seen around your home?' (in pre-test 20 students out of 23 replied & in post-test 25 students out of 25 replied) (Source: Authors' own elaboration)

DISCUSSION

Knowledge About Biodiversity: Conceptual and Naturalistic Dimensions

In both the pre- and post-test, 'nature' is the first word used to define biodiversity. This result for the nature term used as a synonym for biodiversity isn't all that surprising either. Buijs et al. (2008) highlight the way in which biodiversity is associated with concepts of nature in their study of representations of biodiversity. We believe that this result is well explained by Díaz and Malhi (2022, p. 34): 'In public discourse, and in academic circles too, the word biodiversity is now sometimes used interchangeably with two other concepts: nature and the fabric of life, both of which, although lacking technical precision, appear to resonate better than biodiversity with nonspecialists. Nature has the advantage of being simpler and intuitively meaningful to most people without further explanation'.

The other most frequently cited words can be grouped under the broad terms of animals (birds and insects) and plants (trees, grasses, plants, and flowers) and therefore concern the specific level of biodiversity. Indeed, this level is one of the three different organizational levels (genetic diversity, species diversity, and ecosystem diversity) defined by the convention on biological diversity[2]. To our knowledge, we have not found any research studying the definition of biodiversity with students of that age (8-10 years). However, a few studies on the representations of older students show similar results. A sample of Chilean and German students (Menzel & Bögeholz, 2009), Argentinean students (Bermudez & Lindemann-Matthies, 2020) and Moroccan students (Id-Babou et al., 2023) defined the concept of biodiversity at the species level and mainly as 'variety of plants and animals'. For most of the adult populations studied, this concept is known but is also defined in broad terms as 'diversity of animals and/or plants' (Buijs et al., 2008; Kilinc et al., 2013; Lindemann-Matthies & Bose, 2008). The definitions given by the students in our study are mainly centered on the term 'nature', which may imply the ecosystemic dimension of biodiversity. We note that during the proposed sequence, the students did not explicitly work on the definition of biodiversity on these three levels. Furthermore, the curriculum does not define the notion of biodiversity, which means that it is not encouraging teachers to work on it at these three levels in class.

Concerning dangers for biodiversity, the students seem to have reinforced their knowledge on this subject citing more causes (from 12 to 29). In line with what was discussed during the Econect project, the students mention global warming more often, and overexploitation appeared. In the pre-test, three of the five main causes threatening biodiversity were cited, and four out of five in the post-test. In the end, only invasive species were not cited as a cause.

In terms of naturalist knowledge, there was an improvement at the end of the project. For the bee sentinel, more of them were able to name the three types of bee in a hive, became aware of the dangers facing bees, and mentioned their role in nature (pollination and plant reproduction). For the tit sentinel, more of them recognized the great tit among three species and named more bird species visible in their immediate environment. It's also worth noting that some birds are named more precisely (genus and species name for the kites observed on the field trip, and for the tits at the heart of the project), while for other birds (owls) the species name is still not specified. Our students, like those in an Austrian study of the same age (Hirschenhause et al., 2019), name more species at the end of the pedagogical project. Christ et al. (2022) with older pupils (aged 11-15) also show that knowledge of bees and biodiversity increases when participating in a CS project.

Levers for Biodiversity Education

The students particularly enjoyed the last field trip, during which they met and talked with a scientist and handled research instruments and living species. It's not surprising that the students are so keen to learn outside the classroom and to understand the work of an ecology researcher. King et al. (2015), for example, show that science activities that generate positive emotions can boost students' interest and participation in science as well as their longer term memorability. It is recognized that students' emotional state has a strong influence on the effectiveness and quality of their learning. Chalmeau and Julien (2023) highlight students' enthusiasm for fieldwork. Most of the 293 students interviewed, from primary- to secondary-school, expressed a definite interest in fieldwork organized by their teachers. This interest was based partly on an affinity for nature (see the biophilia hypothesis from Kellert and Wilson (1993) and partly on the context.

Our results support the idea that field trips are at the heart of both CS and environmental and biodiversity education. Of the 100 empirical studies of the systematic review in which community and CS projects lead to EE outcomes (Ballard et al., 2024), 95 report on projects that included field-based activities (81 included exclusively field-based activities and 14 also included online activities). In Julien and Chalmeau's study (2022), which examines the responses of 511 French teachers about their practices and motivations, a vast majority of them (90%) reported going on natural field trips and state that improving scientific knowledge and exposure to the scientific approach were the predominant learning reasons why they go out. In the same study, one-third of kindergarten and primary-school teachers and one-sixth of natural science teachers in secondary schools viewed field trips as a lever for implementing EE or education for sustainable development. This essential tool for teaching science, and in particular in the natural science domain, makes learning more concrete and meaningful. It offers a hands-on learning experience that allows students to observe ecosystems and species and interact directly with their natural environment. These experiential learning sessions promote a better apprehension of environment-related contexts. In a local project context of CS on biodiversity, immediate and repeated exposure to the natural environment is important in the acquisition of different types of knowledge. Indeed, the fact that student participation takes place in an everyday life environment, in

[2] https://www.cbd.int/doc/legal/cbd-en.pdf

which they have habits and are used to act, may reinforce the feeling of an ordinary observation and action and leaves room for the construction of knowledge.

In such CS projects, students are invited to collect data in their surrounding environment using protocols proposed by scientists (Bosdeveix et al., 2018). Interaction with these scientists varies according to the aims of the proposed projects but is usually indirect (inputting data into online applications for researchers) or even absent. One of the strengths of our project is that it involves direct interaction with the scientific project leader, who spent a whole day talking to the students inside and outside the classroom, directly at one Econect measuring station. Thus, school can be a privileged space for interactions between science and society. One commonly used model to meet outreach and engagement requirements for science is the 'scientists in the classroom', which involves scientists communicating their discoveries directly to students in a classroom (Fitzakerley et al., 2013). Research has shown that strengthening the links between researchers, teachers and students helps to give science a better image and to foster a love of science and science learning (Clark et al., 2016; Laursen et al., 2007).

Integrating Citizen Science into the Curriculum

When CS is integrated into the curriculum, it provides leverage for its implementation in the classroom, enabling students to build up scientific knowledge (Bopardikar et al., 2023; Christ et al., 2022; Roche et al., 2020; Shah & Martinez, 2016). CS holds the potential to benefit both educators and students alike: it provides authentic exposure to science in action, encompassing scientists, research inquiries, methodologies, data collection, and analysis. This immersive experience fosters active engagement with scientific processes and enriches learning opportunities. This collaboration not only supports scientific endeavors but also enhances public awareness of research themes and discoveries. Indeed, White et al. (2018, p. 3) point out that 'incorporating environmental education opportunities within school curricula is one tool that can potentially assist with reversal of the extinction of experience'.

CS has been part of the French educational landscape for some ten years. The program, nominated 'Vigie-Nature École' [3], is a curriculum proposed by the Natural History Museum of Paris and aimed at schools. It offers ten protocols for discovering and monitoring local biodiversity (such as snails and slugs, birds, bumblebees, bats, plants in urban environments) using a scientific approach. Furthermore, a platform dedicated to these CS operations for the school public provided numerous tools (guides, photos, inventory sheets, etc.) for teachers (Bosdeveix et al., 2018). The aim is also to share the data collected with Museum researchers. For teachers, it's an opportunity to take part in a research program, as part of a comprehensive scientific approach. As they take part in the protocols, students learn more about the biodiversity that surrounds them and hone their observation skills.

At the time of our study (2021-2022), there was no mention of CS in the primary school curriculum. Teachers could implement such projects, but there was no incentive to do so. A few years later, in the current 2023 curriculum (MEN, 2023), not only are the issues of biodiversity and global warming reinforced, but CS is also mentioned as a possible way of giving meaning to scientific learning: 'Biodiversity studies can benefit from participation in citizen or CS projects (such as 'Vigie-Nature École'), which help students get to know school partners while contributing to scientific research'. These curricula have met with some success. For example, in 2022-2023, 448 classes took part in one of the ten observatories offered by the platform. With this recent incentive to get involved in a CS program, it's reasonable to think that more and more teachers will be working on biodiversity issues, enabling their students to understand their contribution to the production of scientific knowledge.

CONCLUSION

In this exploratory study, our first hypothesis seems to have been partially validated, insofar as students continue to define biodiversity as synonymous with nature. On the other hand, the threats to biodiversity are growing in number and content. The second hypothesis, concerning the development of naturalist knowledge, appears to be validated by the increased knowledge of sentinel species involved in the CS project.

We have highlighted three levers for implementing a CS project to develop biodiversity education, two in our research (field trip and direct involvement of the researcher) and a third that comes under the institutional context (integration of CS into the curriculum). Indeed, based on a number of research studies, we can reasonably assume that integrating CS into school curricula in France will encourage teachers to work on biodiversity issues.

Learning through CS enables students to understand environmental challenges in a tangible way, and to develop essential skills for becoming eco-responsible citizens. This educational approach thus contributes to shaping a generation that is more aware and better equipped to meet current and future environmental challenges. From this perspective, environmental or ecological literacy seems to be an essential training course for schools of the 21st century.

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Ethical statement: The authors stated that the study does not require any ethical approval. The study adhered to the highest ethical practices applicable in scientific research. The authors further stated that participating students, their legal guardians and teachers were fully informed about the aims and procedures

[3] https://www.vigienature-ecole.fr/

of the project. They were able to refuse data collection and intervention without giving reasons.

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