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# Addressing bee diversity through active learning methodologies enhances knowledge retention in an environmental education project

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**ABSTRACT**

The Brazilian ecosystems harbor a significant portion of global bee diversity. Despite their magnitude as pollinators, Brazilian native bees are mainly unknown. Considering the importance of scientific literacy in fostering environmental responsibility, we analyzed the BeeDiversity project's impact on the scientific knowledge of eight to nine-year-old students. This study outlines the challenges of implementing the BeeDiversity project as a curricular component, including live bee observation and active learning methodologies. Students' knowledge about bees significantly improved after participating in the project. Although the students mastered the concept of the ecological role of bees as pollinators, they were unaware that this ecosystem service is operated mainly by solitary bees. Learning retention was confirmed after five months. Active learning proved more effective than traditional methods. Handling a live hive and learning about solitary bees' pollination roles generated high enthusiasm and engagement. Therefore, focusing on educational strategies addressing bee diversity beyond the typical honeybee (*Apis mellifera*) might effectively stimulate a broad environmental consciousness.

**Keywords:** biodiversity, conservation, endangered species, science education, native bees

## INTRODUCTION

There are more than 20,000 described species of bees around the world, of which 1,670 are from Brazil, and the vast majority of them have solitary habits (Imperatriz-Fonseca & Nunes-Silva, 2010; Imperatriz-Fonseca et al., 2011; Johnson et al., 2014). Despite this enormous diversity, most people are familiar with the reasonably large fuzzy yellow-and-black striped bees, like honeybees, ignoring the variety in sizes, shapes, and colors of other bee species (Johnson et al., 2014). Even so, despite the bees being among the most ecologically and economically essential invertebrates (Klein et al., 2007), people generally dislike them (Bjerke & Ostdahl, 2004; Snaddon & Turner, 2007).

In Brazil, the introduced *Apis mellifera* species, also known as the Africanized bee, is the leading honey producer (Imperatriz-Fonseca & Nunes-Silva, 2010). Because of their high productivity and sizeable national market, many studies have been conducted about this species (Lopes et al., 2005).

Native bee species are barely known and studied despite their fundamental ecological importance. Their vast diversity differs significantly in size, shape, color, and habit requirements from Africanized bees. Some are green or bright metallic blue. Others may have more bristles, and some are tiny, like ants (Food and Agriculture Organization of the United Nations [FAO], 2004; Johnson et al., 2014). It is highly relevant to know the importance and diversity of these native bees. They are insects whose most species have nectar and flower pollen, their primary source respectively of energy and protein, according to Nogueira-Neto (1997). Visiting flowers to seek resources, they perform pollination, a vital ecosystem service for plant reproduction (FAO, 2004).

Pollination, a widely recognized vital regulatory mechanism within ecosystems, plays an indispensable role in producing essential resources such as food and biofuels. It is particularly crucial for the preservation and sustenance of biodiversity (Imperatriz-Fonseca & Nunes-Silva, 2010). Bees, one of the key pollinators, have been experiencing a decline in populations worldwide for the past 30 years, as highlighted in the study by Wright et al. (2017). The study suggests that parasites and pathogens, exposure to pesticides, and less abundant food (mainly due to environmental changes and habitat loss) are among the main reasons for this occurrence. The potential consequences of this decline are significant and underscore the need for immediate action.

In Brazil, in the last update of the red book of endangered species, five species of bees were registered in some category of threat, one of them as vulnerable (VU) and four of them as endangered (EN): *Arhysosage cactorum* (VU); *Melipona capichaba* (EN), *Melipona rufiventris* (EN); *Melipona scuttelaris* (EN); *Partamona littoralis* (EN). The other two species are nearly threatened (NT) (ICMbio/MMA, 2018). All of them are from the Cerrado (Brazilian Savanna) and Mata Atlântica (Atlantic Rainforest), which correspond to the two more threatened biomes in Brazil. According to Allen-Wardell et al. (1998), the loss of pollinators from a community may not be easily reversible. The timescale for natural colonization and how to recover the loss of native pollinators is unknown. Schönfelder and Bogner (2017) concur that there is a prevailing consensus among scientists and stakeholders regarding the imperative for heightened awareness regarding the importance of conserving pollinators at both local and global scales.

Concerning the above scientific concepts, the knowledge of younger children about bee diversity and the contribution of native bees might be strategic to create awareness and sustainable consciousness. Allen-Wardell et al. (1998) underscore the imperative for educational initiatives aimed at fostering heightened awareness regarding native pollinators and their critical role in the pollination of both wild and cultivated plants. Furthermore, they emphasize the significance of conservation efforts directed towards these essential organisms. For Schönfelder and Bogner (2017), the answer to these current challenges is also environmental education, involving formal and informal learning contexts. In a formal context, educators do not receive training targeting the knowledge gap about bee biology because the scientific literature still elucidates it. Moreover, environmental education projects remain to clarify the role of active learning in promoting knowledge and conservation actions. Knowledge acquisition is foundational to effective environmental education programs (Theobald et al., 2020).

The primary goal of the BeeDiversity project is to foster knowledge that encourages affection and pro-environmental behavior toward bees. This concise environmental education project, designed for elementary school students, utilizes active learning methodologies, including live observation of bees, to engage students. The project aims to create awareness about the diversity of the bee world, countering the misconception perpetuated by social media and formal education that the black and yellow striped honeybee (*Apis mellifera*) is the sole pollinator. This study evaluated the effectiveness of the BeeDiversity project in enhancing and solidifying elementary school students' understanding of stingless native bees, covering their anatomy, physiology, behavior, and ecology.

## MATERIAL AND METHODS

### Cohort

The study was conducted with students enrolled at Diadema Municipal Francisco Daniel Trivinho School, a public elementary school in the State of São Paulo, Brazil. Diadema city has large urban and rural areas, surrounded by the Atlantic Rain Forest and the Billings Reservoir, which supplies part of the city with water. The students (N = 34) were in grades 3 or 4, with an age range from 8 to 9 years old and a gender ratio of 21 girls to 13 boys. Students and their parents agreed and consented to participate in the study, which was reviewed and approved by the Institutional Review Board of UNIFESP (CAAE:16561619.8.0000.5505). The environmental education project was named the BeeDiversity project, and it was temporarily included as a curricular content in the regular school year. All materials used in the project were provided by the study researchers. Living native bees from Brazil, including social and solitary species, were utilized as didactic materials in compliance with and approval from the Institutional Review Board (IRB) (CEP1049071115).

### Study Design

This study applied a mixed-method approach to educational research in order to develop and evaluate the effectiveness of an environmental education project in promoting knowledge acquisition about bee biology and biodiversity. The BeeDiversity project was designed to include learning activities from traditional to active learning methodologies. **Figure 1** demonstrates the timeline and sequence of activities developed in the project and the instruments used to evaluate its effectiveness. A pretest concept inventory was applied before the first meeting, and a post-test concept inventory was applied four weeks later to evaluate the learning gains promoted by the BeeDiversity project. In order to evaluate the consolidation of learning by the students, a retention concept inventory was applied five months after the last meeting of the project.

### Development of the BeeDiversity Project

The BeeDiversity project was developed to engage the students in learning about the biology and biodiversity of bees by exploring and understanding the anatomy, physiology, behavior, and ecology. Given that one of the study's objectives was to assess various educational methodologies, certain learning content was delivered through active learning methodologies. The project encompassed five units with 3-hour meetings in each unit and 15 hours spread over four weeks. The scientific concepts, learning objects, and learning activities of each unit are listed below:

#### *Unit #1*

We utilized reading and observing book figures to instruct students on the anatomy and physiology of general invertebrate animals, arthropods, and Africanized honeybees (*Apis mellifera*). Students collaboratively drew a bee as a group activity to reinforce learning consolidation.

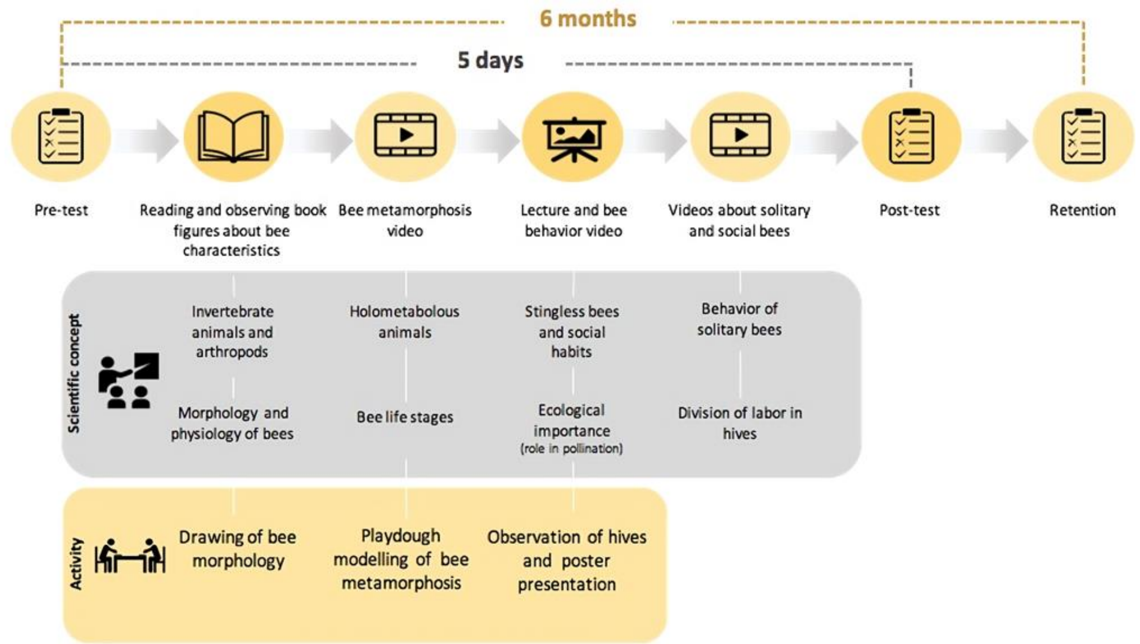


**Figure 1.** Study design of the BeeDiversity project (the timeline demonstrates the scientific concepts, the type of activities, and the instruments of analysis used throughout the project's application) (Source: Authors' own elaboration)


**Figure 2.** Material for bee observation in the classroom: (A) observation hive with acetate cover (facilitates internal observation of the colony by students) (Source: Ricardo Lopes) & (B) top view of *Melipona quadrifasciata* colony with pots containing both stored pollen (lower left circle with long red dashes) and honey (right-hand circle with short green dashes), brood disc containing open cells under construction and capped cells with brood inside (black arrow), wax casing (dashed blue arrow) (Source: Patrícia Miranda Pinto)

### *Unit #2*

Students watched a national geographic Brazil video of bee metamorphosis entitled, *The bee development, from hatching eggs to adult phase*, available at https://www.youtube.com/watch?v=Qjs5dc8TSus. The video and discussion addressed the biology of holometabolous animals and bee life stages. We employed Playdough modeling to facilitate active learning of bee metamorphosis.

### *Unit #3*

The session commenced with a lecture on stingless bees and their social habits, followed by a video presentation highlighting the pivotal role of bees as pollinators and their ecological significance in ecosystem maintenance. Specifically, the video titled, *No bee, no food*, produced by the non-governmental organization "*Bee or Not to Be*" and accessible at https://www.youtube.com/watch?v=BvGwLGmwOzE was utilized to underscore the critical importance of bee pollination for food production. Instructors provided social beehives for observation, prompting group discussions regarding the social interactions of *Melipona quadrifasciata* (**Figure 2**), a common species found in southeastern Brazil, popularly known as "mandaçaia." These bees are social, stingless, and notably docile, as Santos (2002) described.

### *Unit #4*

The instructor facilitated a round-group discussion to recall information from previous classes, after which the students collaborated to create, produce, and present a poster on a chosen topic covered in the course.

### *Unit #5*

The video, *The secret world of gardens: Solitary bees*, available at https://www.youtube.com/watch?v=QQ6mzvVf4EU addressed discussion about the existence of solitary bees and their differences from social bees.

**Table 1.** Affirmations

| QN | Types of affirmations | Scientific knowledge & skills | Category |
|---|---|---|---|
| Q1 | "Insects have skeleton; they are vertebrate animals." "Insects, like bees, are vertebrate animals; that is, they have skeleton." | Identify bees as invertebrate animals. | Anatomy & physiology |
| Q2 | "Bees have six legs." "Bees have 3 pairs of legs; that is, they have 6 legs." | Identify body structure and classification of insects. | Anatomy & physiology |
| Q3 | "Bees are bom like eggs." "Before being larvae, bees were in eggs." | Understanding bee development. | Anatomy & physiology |
| Q4 | "All bees eat only honey." "Bees eat only honey." | Identify the eating patterns of bees. | Behavior |
| Q5 | "There are no bees that lives alone; they only live in hives." "All bees live in hives. Bee do not live alone." | Understand the diversity and social habits of bees. | Behavior |
| Q6 | "Bees are responsible for pollinating most plants." "Most plants are pollinated by bees." | Understand theecological role of bees, and their relationship with pollination. | Ecology |
| Q7 | "The bee's noses are the antennae." "Bees smell using the antennae." | Identify the sensory system of bees. | Anatomy & physiology |
| Q8 | "The worker bees produce the royal jelly." "Bees called worker are the ones that produce the royal jelly." | Understand the behavioral relationship in bee varieties. | Behavior |
| Q9 | "Bees undergo metamorphosis." "Bees undergo transformations called metamorphosis." | Understanding bee development. | Anatomy & physiology |
| Q10 | "All bees have a stinger." "The sting is present in all bees." | Identify misconception about the anatomical diversity of bees. | Anatomy & physiology |
| Q11 | "The drone is bigger than the worker." "The worker bee is smaller than the drone." | Identify sexual dimorphism in bees. | Anatomy & physiology |
| Q12 | "All bees only collect honey as a resource from flowers." "Bees only collect honey from flowers." | Identify misconception about the relationship between honey production and resource collection. | Behavior |
| Q13 | "All bees have four wings." "Beeshave 4 wings." | Identify body structure and classification of insects. | Anatomy & physiology |
| Q14 | "Many plants are not pollinated without bees." "If there were no bees, many plants would not be pollinated." | Understand the ecological role of bees, and their relationship with pollination. | Ecology |
| Q15 | "There are bees that are solitary; they do verything by themselves." "Some bees do everything by themselves; they are called solitary bees." | Understand the diversity and social habits of bees. | Behavior |

Note. QN: Query number

### Learning Analysis

A questionnaire was used to collect knowledge acquisition data before, after, and after five months of intervention. Due to the low age range of the students and to avoid mental fatigue, a simplified questionnaire was created, and students had to judge affirmations as true, false, or I'm not sure. The questionnaire was validated by two bee biology specialists and one education specialist. **Table 1** presents the identification of each affirmation, the type of affirmations included in the different versions of the questionnaire, the scientific knowledge or skill addressed in each affirmation, and the categorization of the content as anatomy and physiology, behavior, or ecology. The questionnaire applied pre- and post-intervention was identical; however, the retention questionnaire was structured with different affirmations to analyze the same scientific knowledge or skill as previous questionnaires.

A total of 29 students were included in the study because they completed all questionnaires. The scores of the students in each questionnaire were considered an index of learning gain. Normalized learning gain was used to verify to which extent the project promoted knowledge acquisition according to different topics (anatomy & physiology, behavior or ecology) and to compare the effect of traditional methodologies (image observation and video) and active learning methodologies (drawing, modeling, hive observation and poster presentation). Normalized learning gain was calculated using the difference in percentage between post-test or retention and pretest scores divided by 100 subtracted from the pretest score (normalized gain = (post-test% or retention%) - (pre-test%) / (100 - pre-test%) (Hake, 1998). Statistical analysis was performed using GraphPad Prism 5 software. Non-parametric data analysis was applied, such as the Kruskal-Wallis test with Dunn's multiple comparison post-test and the Mann-Whitney test. Scores and normalized learning gains are presented as the mean and standard deviation, with $p < 0.05$ as the significance level. The correlational study was performed considering the variables: gender, overall performance in the post-intervention and retention phase, previous knowledge in each category, learning in each category, and retention in each category. Because there were several tied values and a small sample size, Kendall's Tau was used to identify putative correlation. The correlational study was performed using the software PAST 3.

## RESULTS

### Partnership With Local Stingless Beekeepers and University Meliponaries Facilitates the Implementation of Live Bee Observation

When the children were informed that they would learn about the importance of an insect, some were reluctant, mentioning "not liking bees because they sting". Such an obstacle can be overcome following Schönfelder and Bogner's (2017) recommendation, which demonstrates that the perceived danger associated with fear must be reduced to support the willingness to protect bees. Therefore, the authors suggest using live animals for education to direct students' emotions. Moreover, it was suggested to use images or videos of hives available on specialized internet pages as an alternative to improve the concern about bee conservation as pollinators when working with living organisms was not possible.

Fortunately, for this project, it was possible to present hives with alive bees (*Melipona quadrifasciata)* to the students. As shown in **Figure 2**, students were in close contact with the world of bees due to using observation hives. This observation of live bees was possible because didactic observation colonies containing acetate top and side were prepared, allowing colony structures to be observed and where the students could observe the bees working in their colony (part A in **Figure 2**). The observation colonies used in this work were made from good quality, durable wood. One side and the top lid are closed with acetate and covered with a wooden lid when the colony is not used for demonstrations. On demonstration days, the bees are locked inside the colony without being able to go outside. It is permanently closed the night before so that all the bees are inside the colony and reopened in an appropriate place (usually a meliponary) after they have been used to demonstrate to the community. Food is stored in their pots and can normally be consumed by the workers while locked inside the colony for a few hours during the demonstration.

Besides visualizing the internal structures (part B in **Figure 2**) of a stingless bee colony, they could differentiate the workers (who were working on various activities) from the queen and observe her in an oviposition process.

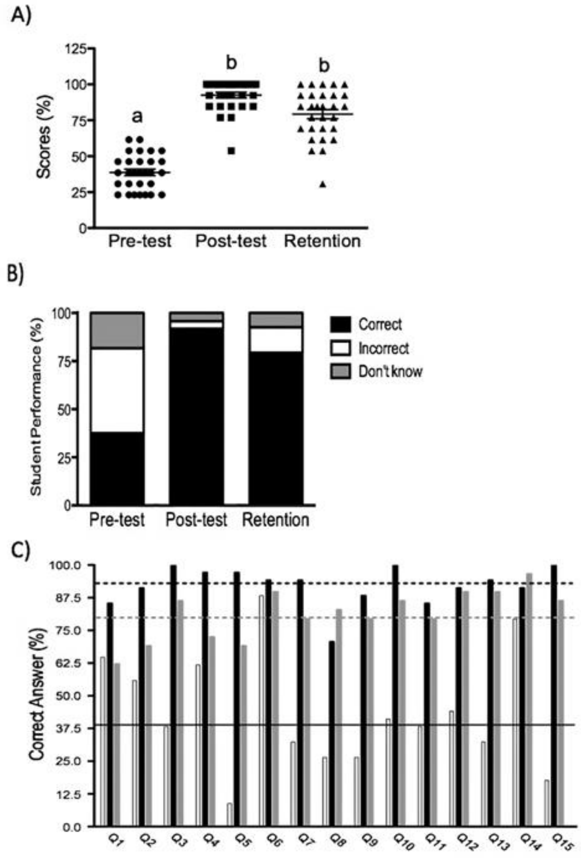


**Figure 3.** Learning gains of the students: (A) scores of the students in pre-, post-, and retention tests, (B) student performances in pre-, post-, and retention tests; & (C) profile of correctness performance of the students according to each conceptual question (continuous line: mean of correct answers in pretesting; black dashed line: mean of correct answers in post-testing; gray dashed line: mean of correct answers in retention test; different letters: $p < 0.05$; & ret: retention) (Source: Authors' own elaboration)

## The Beediversity Project Improves Conceptual Knowledge

Although conceptual knowledge is not a guarantee of execution of good behavior and attitudes toward bee conservation due to the influence of the knowledge-action gap, it is necessary to comprehend which knowledge prevails in the target population in order to provide data for future environmental education project design. Students participating in the BeeDiversity project presented a basal knowledge of approximately 39% of the concepts covered in the questionnaire (part A in **Figure 3**). The project's effectiveness was demonstrated by a significant increase of 2.38 times in the student's performance in the post-intervention questionnaire (pre = 38.74 ± 12.23 vs post = 92.57 ± 10.59, $p < 0.0001$). Similarly, the retention of knowledge after five months of the intervention was maintained high by approximately twice (retention = 79.29 ± 17.10) the score of students in the pre-intervention questionnaire. There was no significant difference between the student scores in the post-intervention and retention questionnaires. The effect sizes were substantial for students' performance in both post-intervention ($d$ = 4.7, CI = 3.293 - 6.119, N = 29) and retention ($d$ = 2.72, CI = 1.716 - 3.739, N = 29) analysis. The data also demonstrates that the percentage of students who declare not knowing a concept was reduced in post-intervention (4.3%) and retention (7.4%) when compared to the pre-intervention (18.3%) performance (part B in **Figure 3**).

Part C in **Figure 3** presents the percentage of correct answers according to each question covered in the questionnaire, and horizontal lines illustrate the mean performances of students for pre-intervention, post-intervention, and retention.

Students augmented their knowledge in all concepts concerning bee biology, diversity, and ecology; however, specific knowledge requires attention for clarification, such as the low prior knowledge and the knowledge resistant to consolidation of learning. Even before the intervention, the students mastered the knowledge covered in Q6 and Q14. That knowledge was related to the role of bees as pollinators. The knowledge covered in Q5 and Q15 dealt with the existence of solitary bees and their participation in the global pollination process. As depicted in part C in **Figure 3**, the students' performance for Q5 and Q15 was below 15% in the pretest.

Nevertheless, after the intervention, students' performance in correct answers increased to 97.06% and 100% for Q5 and Q15, respectively. The retention rate for these two questions was maintained high at 77.55%. The students' performance in Q1, Q2, and Q4 revealed that they struggled to consolidate the concepts. Concepts in Q1 and Q2 addressed anatomy used for the classification of invertebrates, and Q4 dealt with the misconception that "bees eat honey," which is imbricated in the ideas of the lay public.

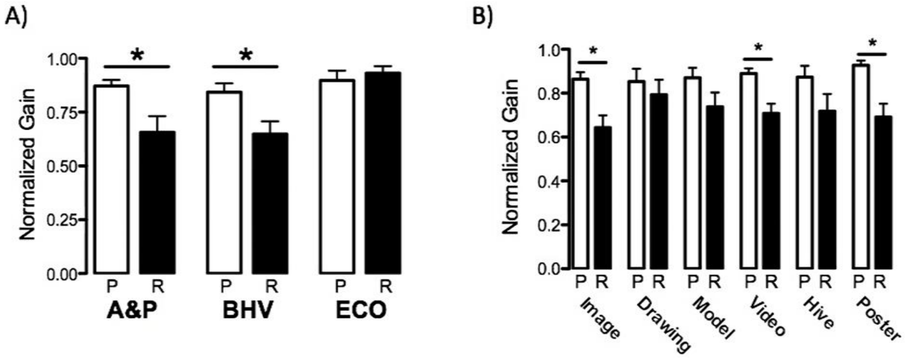


**Figure 4.** Learning gains according to topic and method of instruction: (A) normalized learning gain related to anatomy and physiology (A&), behavior (BHV), and ecology (ECO) questions & (B) normalized learning gain generated by the method of instruction (P: post-test; R: retention test; & *: $p < 0.05$ vs. post-test) (Source: Authors' own elaboration)

Finally, one atypical phenomenon was observed in students' performance for Q8, where students increased their knowledge measured by the retention test rather than diminished it as occurred to all other questions. This phenomenon can be attributed to the student's motivation about the topic since it was addressed by a specialist teacher in the group, who differs from the teacher responsible for addressing the themes of the BeeDiversity project. Considering that a concept like the one dealt with in Question 8 is of limited knowledge within the population and tends to generate conflicts of interpretation, a more detailed approach was needed, involving explanations accompanied by visual material, so that the students could understand and confront the consensus established by the population regarding the topic.

## Active Learning Methodologies Prevent Forgetting Conceptual Knowledge

Part A in Figure 4 depicts the normalized learning gain after the intervention (P) and knowledge retention after six months (R). The acquired knowledge was high for all topics: anatomy and physiology (A&P), behavior (BHV), and ecology (ECO). Although the learning gain for all topics was significant, the retention for A&P and BHV learning was significantly reduced when compared to post-intervention (A&P: P = 0.87 ± 0.16 vs R = 0.66 ± 0.40, p = 0.002; BHV: P = 0.84 ± 0.24 vs R = 0.65 ± 0.32, p = 0.001). Nevertheless, the normalized learning gains for ecology concepts generated after the intervention were high and consolidated well in the retention test. The ecology concepts dealt with the role of bees as pollinators.

As presented in part B in Figure 4, the retention rate is relatively high for methodologies of instruction based on active learning compared to passive learning methodology. All activities proposed in the intervention effectively promoted retention because the rate of learning gains was superior to 0.6 after 26 weeks of exposure to the learning experience. Studies by Khajah et al. (2014) showed a forgetting rate of approximately 40% of the learned content of students exposed to the worst condition for retention after 26 weeks of learning and reviewing scientific concepts. Our results showed a 26% and 13% forgetting rate for passive and active learning methodologies, respectively. The retention rate for knowledge acquired when students passively learned by seeing images or watching films was significantly reduced (image: P = 0.86 ± 0.18 vs R = 0.64 ± 0.30, p = 0.002; video: P = 0.87 ± 0.30 vs R = 0.71 ± 0.24, p = 0.0003) when compared to activities that actively engaged the students in learning, such as drawing structures of the bees, modeling the metamorphosis of the bees and observing the complexity of living bees in a hive. Surprisingly, the knowledge retention acquired within the poster presentation activity was significantly reduced compared to post-intervention (P = 0.93 ± 0.13 vs R = 0.68 ± 0.32, p = 0.0004). This effect might result from the impressive post-intervention learning gain promoted by the poster preparation and presentation.

Figure 5 illustrates the educational products elaborated by students in response to the active learning methodologies as educational strategies of the BeeDiversity project. Using drawings is a common strategy applied in environmental education programs. Students used drawing to optimize anatomical and physiological knowledge (part A in Figure 5). In part B in Figure 5, an activity is depicted where children employed modeling clay to consolidate the information presented in unit #2. This method adheres to the same principle as using drawings, as it allows for playfulness and does not pressure the participants. This aspect was essential since the subject matter (bee metamorphosis) was challenging to comprehend, and the play dough aided the participants in consolidating scientific concepts.

Regarding the activity depicted in part C in Figure 5, participants were given an opportunity to interact with an observation hive, which involved observing living bees executing their social and functional activities. This hands-on experience allowed the students to understand better bee behavior, diet, care for the colony's organisms, and social interaction. The consolidation activity depicted in part D in Figure 5 showcases a presentation moment where participants, working in groups, had the opportunity to create posters on various topics covered within the BeeDiversity project. The instructor facilitated the activity, encouraging participants to collaborate in creating the presentation materials. This process required the students to focus and recall the concepts learned accurately to represent them correctly on the posters later presented to the class. This exercise reinforced their understanding of the subject and fostered teamwork and presentation skills.


**Figure 5.** Representative images of the students' outcomes–Active learning methodologies: (A) image of student's drawings of bee anatomy; (B) image of a student's modeling project using play dough to explain metamorphosis; (C) image of students observing a hive; & (D) image of students presenting a poster (Source: Authors' own elaboration)

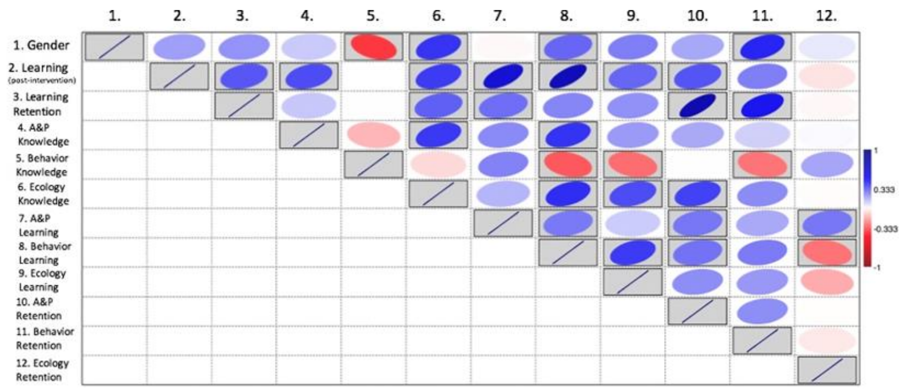


**Figure 6.** Correlational matrix (correlation analysis of the student's outcomes in the survey according to gender, general performance post-intervention and retention, and performance as specific contents of knowledge, learning, and retention; gray-boxed cells express significant differences; & blue and red ellipses express positive and negative correlations, respectively) (Source: Authors' own elaboration)

### Correlational Analysis

Correlational analysis revealed that gender is associated with different performances in particular contents (**Figure 6**). Girls of this study cohort presented lower basal knowledge about behavior ($\tau$ = -0.382, p = 0.003); however, the performance of girls was positively correlated with high scores in both post-intervention ($\tau$ = 0.301, p = 0.021) and retention ($\tau$ = 0.446, p < 0.001) of knowledge about behavior. Previous knowledge about anatomy and physiology contributed positively to acquiring higher scores in the post-intervention questionnaire ($\tau$ = 0.355, p = 0.006). But higher scores in A&P in the pre-intervention questionnaire were positively correlated to higher learning gain in contents of behavior in the post-intervention questionnaire ($\tau$ = 0.412, p = 0.001). The effectiveness of the intervention can also be observed in the negative correlation between the scores of the student in the pre-intervention questionnaire and the magnitude of the learning gain in knowledge of behavior ($\tau$ = - 0.317, p = 0.015) and ecology ($\tau$ = - 0.281, p = 0.031) in the post-intervention questionnaire.

## DISCUSSION

Educating younger citizens through a project focusing on bee biology might be a successful strategy to guarantee pollinators' awareness and conservation. However, environmental education programs naively concentrate their approaches on uniquely exploring the most well-known, yellow-striped honeybee. Understanding the intricate dynamics within native bee communities, particularly those of solitary species, holds immense significance for maintaining ecosystem health and resilience. As the global decline of pollinator populations raises concerns, it becomes increasingly evident that a multifaceted approach to preservation, supported by active learning initiatives, is imperative to ensure the continued preparation of the younger generations in this combat.

Through the results presented in this article, we emphasize the necessity of delving into bee diversity, focusing on native and solitary bees, recognizing the importance of active learning methodologies, and advocating for particular learning paradigms to foster effective conservation outcomes.

Considering this study as a description of a project to improve awareness of bee conservation among elementary students, promoting the contact of the students with living bees was the challenge to overcome in this project. The observation of a hive with living bees can be considered an active learning methodology because the nature of the observation elicited myriad inquiries in addition to the reflection elaborated by the instructors. The fear of sting contributes to bee aversion in the population; however, fewer learners are aware of stingless bees. Research has found that increasing a person's connection to nature positively influences their ecological intentions and associated behaviors (Otto & Pensini, 2017; Pensini et al., 2016) since the support for population declines is more likely among individuals who fear a particular species (Bencin et al., 2016) and negative attitudes, such as fear, anxiety, and disgust, are often directed towards bees and other invertebrates. However, due to their ecological importance, it is crucial to address these attitudes and promote sustainable behavior changes for biodiversity and wildlife conservation (Bixler et al., 1994; Silva & Minor, 2017).

Observation of living animals contributes to content retention as they create emotional and affective memories. Through practical experiences like these, participants can enhance their knowledge about wildlife and develop more positive attitudes (Silva & Minor, 2017). Consequently, the school environment becomes ideal for fostering this kind of awareness (Sieg et al., 2018). In this study, using stingless bees, specifically the species *Melipona quadrifasciata*, was a safe approach. Unlike Africanized bees, which possess stingers, stingless bees offer a safer experience. This safety factor facilitates learning, sparks curiosity, and allows students to engage more closely with the subject matter, as observed by Shapiro (2020). Studies have shown that using the grounds and backyards of the school can be a very successful strategy to engage students in learning and creating environmental awareness (Harvey et al., 2020). However, the chances of guaranteeing a bee encounter in the garden of a school are significantly reduced.

Additionally, the risk of sting accidents is increased in expontaneous encounters. Using the beehives is the most suitable strategy to promote close contact of students with living bees. The students can safely observe and analyze the behavior of the bees, understand the geometrical structure of a hive, and comprehend the social interaction of bees. The bee box and the use of stingless bees are double measures that the school boards of education will authorize. Furthermore, because it is an activity of observation and manipulation of invertebrates, most countries will provide permission without ethical restriction, as opposed to strict laws for vertebrate use in education. By using bee boxes produced by university meliponaries and local farms, the activity also created a sustainable sense of responsibility for children's education. When instructors describe the source of the bee hives, children will elaborate on their comprehension that bees can be systematically bred to serve for economic generation and research development, on top of their knowledge of the pollination ecosystem services of bees.

An important point worth mentioning is that the solitary behavior of bees is not part of children's imagination, as it is not addressed in formal education. What is commonly portrayed in children's drawings is the bees' social behavior (as discussed above). Thus, aiming to contribute to the bee biodiversity content, the approach about the existence of bees with solitary behavior (85% of all bees in the world) (Batra, 1984; Michener, 2007), we visualized that the approaches were efficient when we observed the pre-intervention, post-intervention, and retention data.

Identifying the scientific concepts that are quickly learned and distinguishing them from those that present resistance to earning can enlighten creators of environmental education projects to where efforts should be driven. Our results demonstrated that the studied cohort presented a basal knowledge of approximately 39%. The effectiveness of the BeeDiversity project, as a successful project to promote knowledge acquisition, is depicted by the impressive performance of students on the post-test (approximately 93%) and the consolidation of learning measured in the retention test (approximately 79%). Regarding students' knowledge classified as very low, the Q5 and Q15 deserve attention due to their expressive variation between pre-intervention and post-intervention. Both questions addressed the knowledge/competency "understanding the diversity and social habits of bees," where the awareness about the existence of solitary bees. Nevertheless, Q5 revealed a difficulty for students in consolidating their learning. One reason for the below-average retention for question Q5 is the sentence structure elaborated for the retention questionnaire. A plausible explanation for this finding is that working with negative sentences can confuse (Agmon et al., 2022), and negative statements about ecosystem services are more challenging to understand than positive ones (Solveig et al., 2023). Although the retention rate in Q5 was reduced, an approximately 70% rate is still high and might guarantee foundational knowledge for future awareness about the existence of solitary bees. According to Santos (2002), the diversity of bees in Brazil is great, but we know little about the life of most of these species. As bees are of great interest because they are animals of great ecological importance, performing an indispensable service to the environment (ecosystem service of pollination), it is of most importance that projects such as ours be executed to bring broader knowledge to the general population about the biodiversity of bees, as they need to know to preserve.

Regarding questions Q1 and Q2, for whose student's learning retention was defective, the knowledge covered in Q1 might be misaligned with the curricular momentum of the cohort, and in Q2, mathematical reasoning might have played a role. Q1 encompasses the concepts of exoskeleton and invertebrates, which are very complex terminologies that might provoke misunderstandings. When the project was developed, the students had not yet had contact with this curricular content because the educational system was transitioning from parâmetros curriculares nacionais [national curriculum parameters] (Brasil, 1998) to Brazilian national common core (BNCC) (Brasil, 2017). Although the BNCC expects students to learn to compare the characteristics of animals at the end of grade 3, the NCP suggests this curricular content for the students in grade 6. The fact that students failed to retain the knowledge analyzed by Q1, Q2, and Q4 revealed the importance of environmental educational studies applying retention or follow-up tests instead of solely a test immediately after the intervention. The majority of environmental educational studies evaluate the success of a program in a period immediately or short to the end of the activities and fail to provide evidence of long-term impact due to a lack of follow-up study design. Fujitani et al. (2016) ensures that more robust controlled trials with retention tests are necessary to confirm that ecological knowledge and cognitions acquired from lectures will not be forgotten.

Regarding the knowledge analyzed in Q4, which deals with the feeding of bees, the population generally gathers in its popular imagination that feeding bees is done only through the consumption of honey. A great reinforcer of this concept can be related to the fact that in cartoons, bees stock only honey and rarely reference the stocking and consumption of pollen as a vital essential food resource for these individuals. This issue is critical to work on since pollen consumption by larvae and adults is considered a synapomorphy of the bee group (Michener, 2000). Another critical point about pollen is that it is the primary source of proteins and lipids and is necessary for brood rearing and the satisfactory development of adult bees (Crailsheim, 1990; Hoover et al., 2006; Roulston & Cane, 2000). This knowledge is reluctant to be consolidated because bee nutrition was not directly addressed in the BeeDiversity project, nor were specific active learning activities designed to demystify this misconception of honey consumption by bees. Future project design could include scientific content and activities addressing pollen structure, function, and pollen transport since the protein provided by this food makes all the difference to the colony's development (Di Pasquale et al., 2013). As expected, there was no statistically significant difference between post-intervention and retention for the learning gain about ecology because pollination by bees is a widespread knowledge continuously reinforced outside formal education, such as cartoons and movies (McNeil, 2008).

The educational resources applied in the BeeDiverstiy project confirmed that active learning methodologies significantly enhance elementary education students' learning process, at least knowledge acquisition. Active learning methodologies have positively impacted university students by promoting a solid sustainability consciousness that empowers them to establish a different relationship with the environment (Quintero-Angel et al., 2023). Likewise, transformative learning occurs when active learning pedagogies engage students toward an effective education for sustainable development (Howell, 2021). Moreover, active learning interventions promote results not exclusively in terms of cognitive gains of conceptual knowledge but also in terms of sustainability competencies (Kioupi et al., 2022). Among all active learning methodologies applied in our project, observation of a hive with living bees exponentially enhanced the students' interest. Bueddefeld et al. (2022) have demonstrated that engaging participants in an interpretative program to build a bee box improves knowledge acquisition to understand the issues native bees face and actions related to native bee conservation. Bringing an observation hive with live bees to a classroom is a planned event to promote a close-up encounter with a living species, which offers a lived experience as a curricular component (Ruck, 2022). Although broadly utilized in environmental education projects for children, drawing activities are an effective strategy capable of exploring children's perceptions of an object (Mays et al., 2011). Therefore, drawing has been recognized to facilitate expression and generate more comprehensive and insightful data than writing (Rollins, 2005), as planned to reinforce the concepts addressed in unit #1 in this project.

Additionally, the results obtained for the improvement of the students after drawing, poster creation and presentation might corroborate the findings that these methodologies often lead to a better understanding of the social-ecological systems concept and elicit actions concerning the environmental crisis (Gal et al., 2023). Finally, the BeeDiversity project encompasses active learning methodologies, including playdough modeling, the theoretical foundation of which was project-based learning. Each activity was a mini project, aiming to actively nurture students' cognitive outcomes (knowledge) and behavioral outcomes (awareness) (Yolcu, 2023) employing promoting imaging, abstracting, pattern recognition, dimensional thinking, empathizing, modeling and synthesizing ideas about ecology, animal behavior, and anatomy and physiology for the environmental cause (Root-Bernstein et al., 2014).

Although correlational studies explain the causation of effects in knowledge acquisition, they can contribute to direct future studies. Our results imply that girls presented lower levels of knowledge, but their performance in acquiring new knowledge after the intervention and in the retention test was superior to that of boys. Some studies support that males and females have unequal knowledge of different nature conservations (Solveig et al., 2023), and males know more about recognizing certain species than their female counterparts (Mmassy & Røskaft, 2013). Gender concerns should be on the radar when developing environmental education projects about bees because irrational fear of stings might generate aversive feelings in girls. Besides, educating students to understand different characteristics (anatomy and physiology, ecology and behavior) potentially leads to a more evolved environmental consciousness once the correct identification of arthropods relates to more positive attitudes and stated behaviors (Cornelisse & Sagasta, 2018).

Because conservation efforts require substantial public support, any projects to stop or mitigate bee population declines will need awareness and education measures (Wilson et al., 2017). The active learning methodologies applied in the project proved to be suitable and adequate for elementary students, enabling them to establish connections between the content of the units and the reinforcement activities. This process allowed the students to reflect and deepen their understanding, leading to significant learning gains regarding knowledge about bees. Observing a hive with living bees and identifying native bees were the novelty of this project, which encouraged the authors to share the acquired expertise to facilitate replication in other school systems worldwide.

**Author contributions: MMM, JSO, IF, & CL-S:** drafted the manuscript; **MMM, JSO, & CL-S:** collected and analyzed the data; & **MMM & CL-S:** conceived the study. All authors have agreed with the results and conclusions.

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**Data sharing statement:** Data supporting the findings and conclusions are available upon request from the corresponding author.

## REFERENCES

Agmon, G., Yonatan, L., & Grodzinsky, Y. (2022). Negative sentences exhibit a sustained effect in delayed verification tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 48*(1), 122-141. https://doi.org/10.1037/xlm0001059

Allen-Wardel, G., Bernhardt, P., Bitner, R., Burquez, A., Buchmann, S., & Cane, J. (1998). The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation Biology, 12*(1), 8-17. https://doi.org/10.1111/j.1523-1739.1998.97154.x

Batra, S. W. T. (1984). Solitary bees. *Scientific American, 250*(2), 120-127. https://doi.org/10.1038/scientificamerican0284-120

Bencin, H., Kioko, J., & Kiffner, C. (2016). Local people's perceptions of wildlife species in two distinct landscapes of northern Tanzania. *Journal for Nature Conservation, 34*, 82-92. https://doi.org/10.1016/j.jnc.2016.09.004

Bixler, R. D., Cynthia, L. C., William, E. H., & Myron, F. F. (1994). Observed fears and discomforts among urban students on school field trips to wildland areas. *The Journal of Environmental Education, 26*(1), 24-33. https://doi.org/10.1080/00958964.1994.9941430

Bjerke, T., & Ostdahl, T. (2004). Animal-related attitudes and activities in an urban population. *Anthrozoös, 17*, 109-129. https://doi.org/10.2752/089279304786991783

Brasil. (1998). *Parâmetros curriculares nacionais* [*National curriculum parameters*]. Ministério da Educação.

Brasil. (2017). *Base nacional comum curricular: Educação é a base* [*Common national curricular base: Education is the basis*]. Ministério da Educação.

Bueddefeld, J., Ostrem, J., Murphy, M., Halpenny, E., & Brian, O. (2022). Petting bees or building bee boxes? Strategies for transformative learning. *Environmental Education Research, 28*(4), 560-580. https://doi.org/10.1080/13504622.2022.2045905

Cornelisse, T., & Sagasta, J. (2018). The effect of conservation knowledge on attitudes and stated behaviors toward arthropods of urban and suburban elementary school students. *Anthrozoös, 31*, 283-296. https://doi.org/10.1080/08927936.2018.1455450

Crailsheim, K. (1990). The protein balance of the honeybee worker. *Apidologie, 21,* 417-429. https://doi.org/10.1051/apido:19900504

Di Pasquale, G., Salignon, M., Conte, Y. L., Belzunces, L. P., Decourtye, A., Kretzschmar, A., Suchail, S., Brunet, J. L., & Alaux, C. (2013). Influence of pollen nutrition on honey bee health: Do pollen quality and diversity matter? *PLoS ONE, 8*(8), Article e72016. https://doi.org/10.1371/journal.pone.0072016

FAO. (2004). *Conservation and management of pollinators*. Food and Agriculture Organization of the United Nations.

Fujitani, M. L., McFall, A., Randler, C., & Arlinghaus, R. (2016). Efficacy of lecture-based environmental education for biodiversity conservation: A robust controlled field experiment with recreational anglers engaged in self-organized fish stocking. *Journal Applied Ecology, 53,* 25-33. https://doi.org/10.1111/1365-2664.12560

Gal, A., Schur, Y., Nevo, E., & Gan, D. (2023). Using drawings and explanations based on attentive teaching as a means for understanding the social-ecological systems concept. *Environmental Education Research, 29*(2), 287-307. https://doi.org/10.1080/13504622.2022.2141693

Hake, R. (1998). Interactive-engagement versus traditional methods: A sixthousand-student survey of mechanics test data for introductory physicscourses. *American Jornal Physics, 66*, 64-74. https://doi.org/10.1119/1.18809

Harvey, D., Gange, A., & Harvey, H. (2020). The unrealised potential of school grounds in Britain to monitor and improve biodiversity. *The Journal of Environmental Education, 51*, 306-316. https://doi.org/10.1080/00958964.2019.1693330

Hoover, S. E. R., Higo, H. A., & Winston, M. L. (2006). Worker honeybee ovary development: Seasonal variation and the influence of larval and adult nutrition. *Journal of Comparative Physiology B, 176,* 55-63. https://doi.org/10.1007/s00360-005-0032-0

Howell, R. A. (2021). Engaging students in education for sustainable development: The benefits of active learning, reflective practices and flipped classroom pedagogies. *Journal of Cleaner Production, 325,* Article 129318. https://doi.org/10.1016/j.jclepro.2021.129318

ICMbio/MMA. (2018). *Livro vermelho da fauna Brasileira ameaçada de extinção: Volume VII–Invertebrados* [Red book of Brazilian fauna threatened with extinction: Volume VII–Invertebrates]. Brasília, DF.

Imperatriz-Fonseca, V. L., & Nunes-Silva, P. (2010). As abelhas, os serviços ecossistêmicos e o código florestal Brasileiro [Bees, ecosystem services and the Brazilian forest code]. *Biota Neotropica, 10*(4), 59-62. https://doi.org/10.1590/S1676-06032010000400008

Imperatriz-Fonseca, V. L., Alves-dos-Santos, I., Santos-Filho, P. S., Wolf, E., Ramalho, M., Wilms, W., Aguilar, J. B. V., Pinheiro-Machado, C. A., Alves, D. A., & Kleinert. A. M. P. (2011). Checklist das abelhas e plantas melitófilas no Estado de São Paulo, Brasil [Checklist of bees and melitophilous plants in the State of São Paulo, Brazil]. *Biota Neotropica, 11,* 631-955. https://doi.org/10.1590/S1676-06032011000500029

Johnson, B., Jenny, K., Evans, E., & Koomen, M. H. (2014). Bee-wild about pollinators! An interdisciplinary study introduces primary students to the importance of bees. *Science and Children, 52*(4), 44-48. https://doi.org/10.2505/4/sc14_052_04_44

Khajah, M. M., Lindsey, R. V., & Mozer, M. C. (2014). Maximizing students' retention via spaced review: Practical guidance from computational models of memory. *Topics in Cognitive Sciences, 6*(1), 157-169. https://doi.org/10.1111/tops.12077

Kioupi, V., Vakhitova, T. V., & Whalen, K. A. (2022). Active learning as enabler of sustainability learning outcomes: Capturing the perceptions of learners during a materials education workshop. *MRS Energy & Sustainability, 9,* 64-78. https://doi.org/10.1557/s43581-021-00019-3

Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Kremen, S. A. C. C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society of London B, 274,* 303-313. https://doi.org/10.1098/rspb.2006.3721

Lopes, M., Ferreira, J. B., & Santos, G. (2005). Abelhas sem-ferrão: A biodiversidade invisível [Stingless bees: The invisible biodiversity]. *Agriculturas, 4*(2), 7-9.

Mays, R. M., Lynne, A. S., Julie, C. R., Dena, S. C., Anthony, D. C., & Gregory, D. Z. (2011). Use of drawings to explore US women's perspectives on why people might decline HIV testing. *Health Care for Women International, 32*(4), 328-343. https://doi.org/10.1080/07399332.2010.510585

McNeil, M. E. A. (2008). The bee movie: A beekeeper's review. *American Bee Journal, 148*(1), Article 33.

Michener, C. D. (2000). *The bees of the world*. The Johns Hopkins University Press.

Michener, C. D. (2007). *The bees of the world*. The Johns Hopkins University Press. https://doi.org/10.56021/9780801885730

Mmassy, E. C., & Røskaft, E. (2013). Knowledge on birds of conservation interest among the people living close to protected areas in Serengeti, northern Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management, 9*(2), 114-122. https://doi.org/10.1080/21513732.2013.788566

Nogueira-Neto, P. (1997). *Vida e criação de abelhas indígenas sem ferrão* [*Life and breeding of indigenous stingless bees*]. Nogueirapis.

Otto, S., & Pensini, P. (2017). Nature-based environmental education of children: Environmental knowledge and connectedness to nature, together, are related to ecological behaviour. *Global Environmental Change Part Change, 47,* 88-94. https://doi.org/10.1016/j.gloenvcha.2017.09.009

Pensini, P., Horn, E., & Caltabiano, N. J. (2016). An exploration of the relationships between adults' childhood and current nature exposure and their mental well-being. *Children, Youth and the Environments, 26*(1), 125-147. https://doi.org/10.1353/cye.2016.0027

Quintero-Angel, M., Duque-Nivia, A. A., & Molina-Gómez, C. A. (2023). A teaching strategy based on active learning which promotes strong sustainability that empowers students to have a different type of relationship with the environment. *Environmental Education Research, 30*(4), 560-579. https://doi.org/10.1080/13504622.2023.2211757

Rollins, J. A. (2005). Tell me about it: Drawing as a communication tool for children with cancer. *Journal of Pediatric Oncology Nursing, 22*(4), 203-221. https://doi.org/10.1177/1043454205277103

Root-Bernstein, M., Root-Bernstein, M., & Root-Bernstein, R. (2014). Tools for thinking applied to nature: An inclusive pedagogical framework for environmental education. *Oryx, 48*(4), 584-592. https://doi.org/10.1017/S0030605313000100

Roulston, T. H., & Cane, J. (2000). Pollen nutritional content and digestibility for animals. *Plant Systematics and Evolution, 222,* 187-209. https://doi.org/10.1007/978-3-7091-6306-1_10

Ruck, A. (2022). Experts, insects and informality: Three key features within a school-linked conservation initiative. *Environmental Education Research, 28*(1), 146-159. https://doi.org/10.1080/13504622.2021.1978940

Santos, I. A. (2002). A vida de uma abelha solitária [The life of a solitary bee]. *Revista Ciência Hoje, 179*, 60-62.

Schönfelder, M. L., & Bogner, F. X. (2017). How to sustainably increase students willingness to protect pollinators. *Environmental Education Research, 24*(3), 461-473. https://doi.org/10.1080/13504622.2017.1283486

Shapiro, D. (2020). Teaching the science of honeybees. *National Science Teaching Association*. https://static.nsta.org/pdfs/nstareports/nstareports202004.pdf

Sieg, A. K., Teibtner, R., & Dreesmann, D. (2018). Don't know much about bumblebees? A study about secondary school students' knowledge and attitude shows educational demand. *Insects, 9*(2), Article 40. https://doi.org/10.3390/insects9020040

Silva, A., & Minor, E. S. (2017). Adolescents' experience and knowledge of, and attitudes towards bees: Implications and recommendations for conservation. *Anthrozoös, 30*(1), 19-32. https://doi.org/10.1080/08927936.2017.1270587

Snaddon, J. L., & Turner, E. C. (2007). A child's eye view of the insect world: Perceptions of insect diversity. *Environmental Conservation, 34*(1), 33-35. https://doi.org/10.1017/S0376892907003669

Solveig, T., Børresen, R. U., Nyahongo, J., Ranke, P. S., Skjaervø, G. R., & Røskaft, E. (2023). The role of education in biodiversity conservatin: Can knowledge and understanding alter locals' views and attitudes towards ecosystem services? *Environmental Education Research, 29*(1), 148-163. https://doi.org/10.1080/13504622.2022.2117796

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintron, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones II, L., Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., ... Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *PNAS, 117*(12), 6476-6483. https://doi.org/10.1073/pnas.1916903117

Wilson, J. S., Forister, M., Matthew, L., & Carril, O. M. (2017). Interest exceeds understanding in public support of bee conservation. *Frontiers in Ecology and the Environment, 15*(8), 460-466. https://doi.org/10.1002/fee.1531

Wright, G. A., Nicolson, S. W., & Shafir, S. (2017). Nutritional physiology and ecology of honeybees. *Annual Review of Entomology, 63,* 327-344. https://doi.org/10.1146/annurev-ento-020117-043423

Yolcu, H. H. (2023). Using project-based learning in an environmental education course and revealing students' experiences: A case study. *Science Activities, 60*(3), 119-125. https://doi.org/10.1080/00368121.2023.2205825