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Engaging and assessing students via a museum educational program

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Abstract

Many museums offer educational programs encouraging visitors to "interact" with the subjects in a meaningful way. Students' visit to a museum can be an effective means of introducing them to important science concepts through contact with actual specimens. As part of a properly designed educational program, students' contact with realia can be an invaluable aid to engaging their interest and achieving corresponding learning goals. The present paper details a research project relating to the concept of evolutionary adaption. A worksheet was developed requiring students to work collaboratively during a museum visit to complete activities progressively leading them to the target goals of correlating: (i) the structure of certain physical features of birds with their function and (ii) the structure and function of those features with their respective habitats. The final worksheet activity was an open-ended assessment task aiming to identify the level of learning students had achieved from participating in the program. The results were statistically analyzed and indicated that students had grasped the concept of structure and function of specific traits and their importance to basic survival, but they had not been able to correlate the adaptation with other challenges presented by the habitat.

Keywords: educational activities, museum educational programs, evolution, adaption, assessment

INTRODUCTION

Natural history museums are institutions open to the public and devoted to the collection, exhibition, and research of objects representing nature, living beings, and their biotopes (Pavoni, 2001). Visitors are given the opportunity to interact with these objects, explore real world phenomena, and participate in a learning experience (Hein, 1999). Thus, museums tend to be used as informal environments capable of providing various learning experiences (National Research Council, 2010). More specifically, museums host collections of organisms, dioramas representing biotopes, many different types of species, and other exhibitions relating to the natural world that a visitor rarely sees in real life. Over the last decades, museums have been using their unique resources to foster knowledge, attitudes, and behavior about science (Silverman, 2010). For this reason, many educational activities focused on specific scientific themes have been developed, offering a unique experience to visitors. Apart from activities for individual visitors, groups, or families, there is a variety of programs that can be adapted to reinforce in-school activities (Falk & Dierking, 2000). Thus, students are provided with the opportunity to deepen their understanding of curriculum subjects (Krombaβ & Ute, 2008), since it is believed that museum activities can promote students' knowledge and motivation in science (Martin et al., 2016).

Science museums–and especially natural history museums–often host specific exhibitions themed around evolution, biodiversity, ecosystems, endangered species and similar topics, which are also sometimes taught in school. Among various categories of museum visitors, students represent a frequent one, which can be explained by the fact that such visits are considered to provide an informal overview of the topics previously taught in school. One of the most challenging scientific

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Contribution to the literature

- This research could be useful to science educators since it indicates a way in which a museum-based science educational program can be developed.
- In most museums we do not often find an evaluation process of the programs offered, consequently the present research contributes not only to enlighten this field, but also proposes an assessment tool that could be used by science educators either in the case of programs related to evolutionary adaptations or in a modified version according to the needs of similar cases.
- Furthermore, it could also serve as a suggested means of complementing school science lessons about adaptation, and of providing students with the opportunity of 'discovering' key concepts in the process of evolution for themselves through interaction with realia.

topics in science teaching is evolution (Mujtaba et al., 2018). Although it is a central, unifying concept in biology as it can explain both the unity and the diversity of life, teaching evolution can be a considerably difficult task (Kampourakis & Zogza, 2009). Museums could contribute to simplifying this task as they can effectively illustrate that evolutionary concepts apply to all living organisms via the presentation of comparable examples of evolution among diverse organisms, thereby providing tangible evidence of the process (Spiegel et al., 2012). It is important for students, who will be future active citizens, to be informed about the notion of evolution since it has been proven that various alternative ideas prevent students from understanding the concepts and mechanisms that govern it (van Dijk & Reydon, 2010). Many scientific issues that concern aspects of our everyday life, including research on diseases, the rapid evolution of antibiotic-resistant bacteria and viruses, the rapid spread of pandemics, and the impact of climate change are all based on evolutionary concepts (Spiegel et al., 2012). One of these key concepts is biological adaptation.

Indeed, if we consider the fact that teaching evolution both as a whole and/or its sub-concepts presents particular difficulties, perhaps the role of a museum is better understood as a means of offering learning opportunities relating to such concepts. In particular, it has already been found that students have difficulty understanding evolutionary concepts (Kampourakis & Zogka, 2009). The difficulties they have in understanding come from a variety of sources such as religious worldview, and misconceptions occurring from language and teleological explanations (Pobiner, 2016). Speaking more specifically about adaptation, it is already known that different definitions have been attributed to it, but a definition that includes placing adaptation within the context of evolution has been proposed (Kampourakis, 2013). This perspective highlights adaptation as an essential component of the evolutionary process of organisms (Kampourakis, 2013) separating it from any teleological connotations and, especially contrary to what students believe, adaptation occurs in populations and not in individuals (Smith, 2010). For example, when students are asked 'why do birds have wings?', they usually answer 'to fly', which indicates their belief that the reason for the existence of wings is the ability to fly, but it is not clear whether they have realized that flight was possible in birds because they had wings. In other words, both language and teleological expression are barriers to understanding adaptation and its association with evolution. One possible reason for this could be the wording of the concept presentation in the students' textbooks, whenever they exist as evolutionary concepts are not included in every school grade (Georgiou et al., 2022; Prinou et al., 2011). Students are likely to adopt similar ways of expressing themselves that ultimately create noise in the learning process. The same may be due to verbal communication and expression of teachers, who apparently play an important role in their students' understanding of scientific concepts (Kampourakis, 2013; Smith, 2016).

For all the above reasons, and considering that, among other things, evolution should belong to the cognitive field of people in the 21st century, comparative studies have been carried out to analyze the relevant content in the textbooks of several countries in order to identify similarities and differences and to design improvement proposals (Mavrikaki et al., 2023; Sá-Pinto, 2021). However, these efforts belong to the field of formal education, which is governed by its own rules and falls under the educational policy of the respective country. It is consequently extremely useful to have different learning environments to accompany the aforementioned efforts. De Lima et al. (2023) bring together in a guide a variety of activities around evolution from several European countries in the context of non-formal education, aiming to provide examples and implementation suggestions for strengthening evolutionary knowledge and scientific literacy.

Thus, although there are different non-formal education contexts, the role of the museum is evident in terms of tangible and direct clarification of the correct positioning and correlation of concepts (e.g., biodiversity and adaptation) within a wider evolutionary background. Indeed, there are museums that have already worked in this direction on various evolutionary concepts such as biodiversity (Georgiou et al., 2022), proposing their integration with contemporary approaches such as socio-scientific issues (SSI), and have made their work publicly accessible. Nevertheless, it has been found that teleological justification is still often performed both by biological educators (Nehm et al., 2010) and by visitors to natural history museums (Evans et al., 2010).

Although museums are concerned with creating interesting exhibits and programs, they rarely evaluate whether their initial educational goals are achieved (Downey et al., 2007). Most museum educators have only intuition or informal feedback to inform them about whether they have impacted student learning (Witmer et al., 2000). Most museum program evaluation studies are concerned with the thoughts and feelings of those who have visited an exhibition or have participated in an educational program. Hein (1995) has used multiple methods (questionnaires, observations, and interviews) to collect data to record visitors' behavior and knowledge gained in a range of museum exhibitions. Wilde and Urhahne (2008) have created a pre- and post-test instrument with both closed- and open-ended questions to assess the learning achieved.

In the present study, we created an educational program for secondary education students based on the biological adaptations of birds in order to

(a) evaluate the learning outcomes of the educational activities that take place in a zoological museum through its corresponding program and

(b) propose an appropriate framework to assess the learning outcomes of the educational activities that take place in a museum through its program.

Consequently, the research questions that arose were:

1. Can students correlate the structure of multiple features of birds with the function of each feature after engaging in a corresponding educational program of a zoological museum?
2. Can students correlate the structure and function of multiple features of birds with the habitat they live in after engaging in a corresponding educational program of a zoological museum?

THEORETICAL BACKGROUND

Museums as Educational Environments

Museums constitute out-of-school learning environments that have the potential to engage students' interest, to teach them, to stimulate their understanding, and most importantly, to help them assume responsibility for their own future learning (Gardner, 1991). In addition, educational activities in museums engage participants in multiple ways (physically, emotionally, and cognitively), and appeal to a range of intelligences, reinforcing the participation of students with different cognitive abilities and interests (Eshach, 2007).

However, learning through museum activities is different in many respects from the methodology associated with school activities (Griffin, 1998): Museums encourage learning through stimulating curiosity, observation, active participation, a sense of wonder, speculation, and theory testing (Madden, 1985). Engagement is the key to meaningful learning experiences (Wolf, 1986), and it is dependent upon realia, which provide subjects for interpretation and sources of information for the scientific community (Achiam et al., 2016). Realia, such as animals, plants and other once-living organisms are the essence of a natural history exhibition, presented in collections or as moments-in-time in dioramas (Tunnicliffe, 2013).

Life-sized dioramas of the natural world, which portray specimens in their natural habitat contribute to teaching many aspects of biology (Tunnicliffe, 2013). Most such exhibits are supplemented by detailed studies of an organism's characteristics, often presented through interactive, computer-based learning tools, providing comprehensive background information about the subject(s) depicted. (Krombaβ & Ute, 2008).

Taking advantage of the above-mentioned opportunities offered by museums, teachers can use the educational activities to introduce students to many aspects of the real world via tangible evidence, unlike in-school learning activities that are often disconnected from real world events and objects (Ramey-Gassert et al., 1994). In addition, museum activities provide access to authentic materials and to simulated practical work, contributing to the integration of concepts, motivation for further learning, collaborative work, and the taking of responsibility for learning (Braund & Reiss, 2006).

In spite of all their advantages, museums of course cannot replace schools, but there is a need for bridging in-school and out-of-school educational activities (Eshach, 2007). By making the links between school and museum learning explicit, genuine, and continuous, students will have the opportunity for enjoyable learning experiences in both settings. In fact, studies indicate that providing opportunities for museum and school staff to learn from each other and to learn together has exciting potential (Griffin, 2004).

In addition, a museum visit can be adapted to complement lessons at school (Falk & Dierking, 2000) and give pupils the opportunity to deepen their understanding of curriculum subjects (Krombaβ & Ute, 2008). In particular, when the teacher embellishes the unit with many varied classroom activities both pre- and post-visit, the collaboration becomes fruitful, contributing to students' remembering the museum trip (Wolins et al., 1992).

Evolution Through Museum Exhibitions

During the last decade, museums have helped visitors to come in contact with difficult and occasionally controversial scientific content such as evolution, not only through specific exhibitions, but also through theatrical plays, role plays and dramas that take place at their facilities (Evans et al., 2010; Peleg & Baram-Tsabari, 2016). As a result, many participants in museum activities relevant to evolutionary theory already seem to be able to apply evolutionary principles to some organisms, suggesting that museums can contribute to reducing naturalistic or creationist reasoning patterns and reinforcing the use of scientific evidence to explain phenomena (Spiegel et al., 2006). Whatever their age and background beliefs, museums visitors may learn more about evolutionary concepts in a single visit to an exhibition focused on evolution (Spiegel et al., 2012).

The reason why museum-based activities tend to focus on the understanding of evolution is an easy one, as it is central to scientific literacy today (Evans et al., 2010). Dobzhasky (1973) stated that "nothing in biology makes sense except in the light of evolution", as this concept unifies all biological phenomena. However, evolution is rarely taught to children (Shtulman et al., 2016), even though it can be one of the best examples to illustrate the nature of science, namely the links between observations and explanations, indirect evidence and experimental results, causes and effects (National Research Council, 2012). In response to recent calls for changes in the national science standards to focus on core ideas such as evolutionary theory rather than on a sequence of disconnected topics, curriculum designers have also turned to the learning progressions approach: For each core idea, the successive steps from students' earliest ideas, which are largely based on observation and direct experience, to progressively more sophisticated models of a particular domain are depicted (National Research Council, 2012).

Furthermore, National Research Council (2013) suggests that students should develop an understanding of the form and function of living systems, ecosystems, reproduction and heredity, diversity, and adaptations of organisms during the primary education curriculum. Based on this knowledge, middle and high school students are expected to analyze and interpret data, and to apply scientific ideas to construct an explanation for the process of evolution and how natural selection works. In Europe, the presence of evolution in curricula differs among countries. For instance, in France, biological evolution is clearly present in the science curricula, starting with an introduction in primary education, further development in lower secondary education, and deeper presentation in the scientific sections of upper secondary education (Quessada & Clément, 2018). Concepts relevant to evolution, such as inheritance, are introduced into the primary science curriculum (Kover & Hogge, 2017), or in K-10 to K-12 curricula (Rufo et al., 2013). The presence of evolution in school curricula is very important, and this is why specific analytical frameworks have been suggested so that evolutionary dimensions will be clear and comparisons among various national curricula will be possible (Sá-Pinto et al., 2021).

In Greece, biology is not taught as a distinct subject in either primary school or pre-school classes; instead, all natural sciences are taught together, using one common textbook. However, curricula and textbooks for many different grades (K-2, K-4, and K-6) of primary school include only the subject "adaptation of plants and animals to their environment" (Prinou et al., 2011). According to the guidelines for K-7, K-8, and K-9, teachers are prompted to discuss aspects of evolutionary theory (such as adaptations/diversity) with their students, even though the corresponding textbook chapters do not exclusively examine evolution (e.g., chapter titles: "organization of life" and "nutrition", respectively) and they are suggested to elicit and take into consideration students' previous knowledge of evolution, and to clarify the concept of adaptation afterwards. Concepts such as inheritance, human evolution and selection are included in high school curricula (K-10, K-11, and K-12) (Sá-Pinto et al., 2021).

Creating an Educational Program About Birds in a Zoological Museum

In the educational program we designed for purposes of this study, we decided to focus on the variation of selected physical characteristics of birds and the biological adaptations, which concern flight ability, the type of vision, the anatomy of legs and feet, and the type of beak. In particular, activities focus on structure and function, key concepts in evolution, and identified as an integrative theme for science inquiry (National Research Council, 1996). According to the literature, teaching evolution and assessing a student's understanding of it should encompass both the mechanisms of evolution (such as variation, inheritance, selection) and their products (such as adaptation and trait loss) (Legare et al., 2018). However, it is difficult for a museum-based educational program to approach all these mechanisms and provide in-depth knowledge of them because of the limited time available for a school visit. Thus, we decided to focus on diversity and adaptation, using multiple examples. Moreover, research reveals that educational activities relating to evolution require examples from a range of species (Heredia et al., 2016), which would represent the advantages offered by different adaptations and how they contribute to the species' survival, particularly when compared with others (Opfer et al., 2012). Hence, we aimed to focus on different species of birds, which live in different habitats, and which deal with completely different circumstances in order to survive.

Specifically, this taxon was chosen because of the variety of distinguishable morphological adaptations they exhibit. Apart from that, current methods for assessing students' understanding of evolution are grounded in the evolution of non-human animals (Legare et al., 2018), highlighting that evolutionary processes occur in all living beings. The Museum of Zoology of the University of Athens, which hosts specimens from about 2,500 bird species and comprises the largest collection of bird species in the Balkans, was considered as an appropriate place for such an educational program and its purpose.

The development of learning through intrinsic motivation in museum settings can be obtained through "the hook", as described by Csikszentmihalyi and Hermanson (1995). The first step in this process suggests that the museum exhibition or program must capture the visitors' curiosity. Taking this into consideration, we created appropriate activities so that students would be immediately engaged to explore the exhibition: At the start of the visit, we announced that students were going to complete a mission. After a students' curiosity has been aroused, the second step in the process is to sustain their interest so that learning will take place: To accomplish this, necessary initial information was made readily available to them in the structured worksheets (in guide form) we provided.

Worksheets are often used in educational visits to museums, so that information is learned more accurately and remembered longer (Krombaβ & Ute, 2008). In groups, students use such guides to explore specific collections, objects or information, being encouraged to think, imagine, discuss and create (Nikonanou, 2015). Museum experience acquired through the use of worksheets depends on the students' ages and the composition of the group (McManus, 1985). For example, studies have demonstrated that 10- to 15-year-old students associate worksheets with in-school activities, thereby regarding their completion as a chore, without paying attention and being involved. This phenomenon can be avoided when children are working in groups, as they are more likely to complete worksheets successfully using the information from the museum experience, thereby reducing simply copying or exchanging answers (McManus, 1985).

Taking the above into consideration, we tried to develop a specific worksheet (entitled "wild flights guide"), which included a combination of activities highlighting the biological adaptations of birds and the diversity among species. Each activity was based on an educational goal; thus, each aims at developing a specific learning objective and tries to engage students in a variety of ways. According to the literature, many skills involved in scientific inquiry can be encouraged through museum activities. For instance, participants in museum educational programs have the opportunity to observe, find patterns in observation, gather information, compare, explore, raise questions, propose ways to answer questions, apply ideas in new situations, use evidence critically and logically, and communicate information in various and appropriate ways (Griffin, 1998).

At the same time, the researcher encourages students' efforts during the program by providing instruction and clues/hints. To inspire intrinsic motivation, students should feel some connection between the topic and their own lives. Thus, objects and experiences should keep up with current trends and their favorite activities. Consequently, to create the last activity of the guide, which consists of the mission announced at the beginning of the visit, we took into consideration adolescents' fondness for spending much of their leisure time with virtual playgrounds and video games (Brooks et al., 2016; Olson et al., 2007). Therefore, the mission "creating our own avatar for a video game" can be a truly engaging challenge.

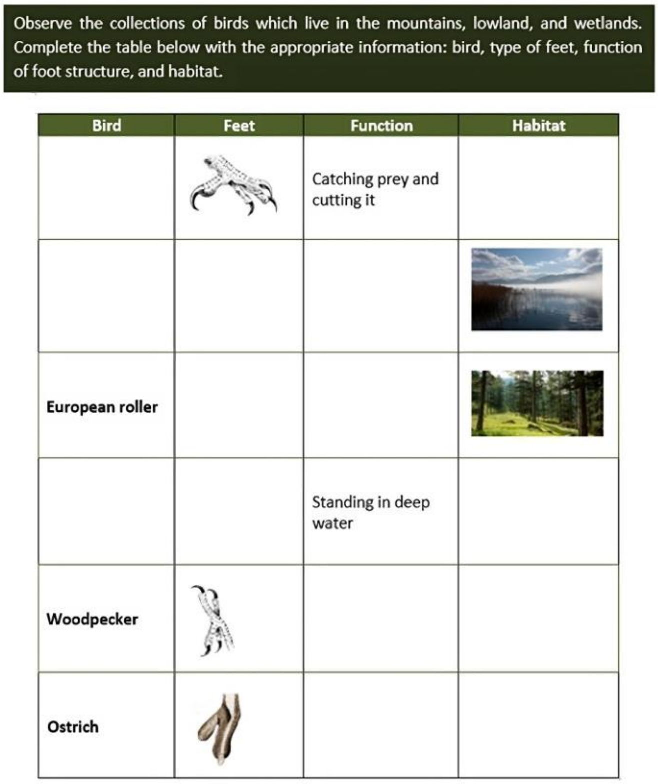
All the tasks of our educational program guide are described in detail below and aim to contribute to students' knowledge of the adaptations of birds.

METHODS

We designed a museum-based educational program for secondary school students focused on selected biological adaptations of birds. Our purpose was not only to create a museum-based educational program in terms of a simple guided tour, but also to assess the degree of achievement of target educational goals of such a program when learning takes place in an environment outside the classroom, as in a zoological museum. We created an accompanying educational guide ("wild flights guide") containing seven activities: The first six were to be completed by the students during their visit to the zoological museum and were designed to put students in contact with the target educational information contained in the guide. The seventh and final task (done in the classroom) was created to serve the evaluation part of our research: It required students to create their own bird avatar for a video game. To accomplish this, students would have to use and integrate all the information they had acquired via their worksheet during their museum visit. For this final task, we developed an analysis framework ("the analysis tool") to assess students' learning outcomes, which is described in detail in a section below. In addition, information about the procedure in the zoological museum and the content of the guide is provided below.

Wild Flights Guide

Wild flights guide served to direct the students along a route through the exhibits, which were essential to our educational goals. The guide contained activities and hints, which students were asked to complete by working collaboratively in groups. By discussing and



Observe the collections of birds which live in the mountains, lowland, and wetlands. Complete the table below with the appropriate information: bird, type of feet, function of foot structure, and habitat.

Bird	Feet	Function	Habitat
		Catching prey and cutting it	
European roller			
		Standing in deep water	
Woodpecker			
Ostrich			

Figure 1. Adaptations of structure of feet of selected bird species (activity 4) (Source: Authors, original figure from the *Wild flights' guide*)

completing the worksheet activities, students gradually familiarized themselves with the target anatomical structures, functions, and biological adaptations of different bird species, which were our educational goals.

Educational and Research Goals

As mentioned previously, wild flights guide contained seven activities, each part of a progressive sequence and related to a different educational goal. Our research goal was to ascertain to what degree the completion of a specially designed museum educational program led to students' obtaining the required educational knowledge. Specifically, after the completion of the seven activities, were students able to:

- identify physical characteristics of birds, which contribute to their flight ability? (activity 1),
- observe the diversity within a species and genus, identifying similarities and differences? (activity 2),
- recognize differences in eye location and the corresponding kind of vision (i.e., straight/side vision), and correlate them with their habitat? (activity 3),
- observe leg and foot variations, and correlate them with their function and the biotope, where the birds live? (activity 4) (**Figure 1**),
- observe beak variation, and correlate them with their function and the food available in the birds' habitat? (activity 5),
- identify the physical characteristics of flightless birds, and discuss possibilities for/consequences of the loss of their ability to fly? (activity 6), and
- create a bird avatar for a video game (activity 7), which is the assessment tool described in detail below)?

Activity 7–Assessment Tool

In the final worksheet task, students had to use the information collected in the previous tasks in order to create two different bird-avatars. Students were provided with descriptions of two habitats, which differed as far as their environments are concerned: Habitat A represents a river traversing a forest and includes a diversity of animals (e.g., insects, fish, bears, and birds) and plants, while habitat B represents a desert environment, with many small animals (e.g., mice, snakes, and rabbits) and few trees. More specifically, students were asked to create two video game-type bird characters which could fit "perfectly" into each habitat.

Students were asked to describe the unique physical trait of each bird they had chosen and explain why this trait is advantageous to the bird in relation to the environment of the habitat (more than one could be referred). In other words, students were asked to support their opinion with arguments, which could reveal the level of their understanding after engaging in the educational program (Georgiou & Mavrikaki, 2013; 2017; Georgiou et al., 2020a, 2020b; Korfiatis & Georgiou, 2022; Maniatakou et al., 2020).

Consequently, students' answers were expected to reveal the correlation between the trait's structure and its function, taking into consideration the type of food available, potential predators, and the challenges presented by the environment. Among the bird's physical traits mentioned by students, flight ability, eye placement/ type of vision, beak, and the anatomy of its legs and feet were expected to be included.

As previously mentioned, this task served as the evaluation instrument. It was designed in an open-ended format, an assessment type, which permits students to express ideas consisting of both correct and incorrect elements, which is a common feature of students' progression to mastery of a domain (Legare et al., 2018). In order to avoid random responses, in our study students had to create two different avatars and give two independent explanations, thereby ensuring that they have correlated both the birds' traits they had selected and the structure of the traits to their functions in relation to the given habitat. In other words, students had to describe each bird's characteristics providing appropriate arguments.

Table 1. Analysis framework

Feature		Reasoning about …				Total score (feature + reasoning)
Name	Score	a. Structure-function correlation	Score	b. Feature–habitat correlation	Score	
(e.g., beak)						
No reference	0.0	-	-	-	-	0.0
Reference	1.0	No reasoning (simple description)	0.0	No reasoning (simple description)	0.0	1.0
				Incorrect reasoning	0.5	1.5
				Correct reasoning	2.0	3.0
		Incorrect reasoning	0.5	No reasoning (simple description)	0.0	1.5
				Incorrect reasoning	0.5	2.0
				Correct reasoning	2.0	3.5
		Correct reasoning	2.0	No reasoning (simple description)	0.0	3.0
				Incorrect reasoning	0.5	3.5
				Correct reasoning	2.0	5.0

Table 2. Total score for each feature

Derived score for each feature	Interpretation
0.0	No reference to the feature
1.0	Simple description or reference
1.5	Incorrect explanation of one criterion and no reference to the other criterion
2.0	Incorrect explanation of both criteria
3.0	Reference and correct explanation of a single criterion
3.5	Correct explanation of one criterion and incorrect explanation of the other criterion
5.0	Correct explanation of both criteria

Participants

There were 74 participants from four different Athens public sector secondary schools in areas with similar social and economic environments. It is important to note that age group (13-year-old students) was selected to fulfill the condition that participants had previously been introduced to basic biological concepts such as biological organization (e.g., cells and organisms), vital function (e.g., motion, feeding, movement, and support) in their classrooms, but had not received instruction on evolution or evolutionary mechanisms.

Data Collection

The school visits took place during the period December 2019-February 2020. The test group (n=74) completed the tasks on wild flights worksheet after participating in the museum-based program. The students had to complete the six initial tasks in one hour and had thirty minutes for the final seventh task (i.e., the evaluation instrument). The researcher facilitated the process by providing help when needed and encouraging students' efforts throughout. The students' teachers were not present during the educational program to ensure that they did not influence participants' performance.

To check long-term knowledge retention of the educational program, we had intended to repeat the final task with a larger sample two months later. However, the prohibitive conditions of the COVID-19 pandemic has limited us to the sample presented in this paper, which means that we did not gather the data necessary to evaluate the knowledge retention students' had likely gained after their involvement in our educational program.

Data Analysis

The data were analyzed by content analysis of the final worksheet task (activity 7), where specific codes were used. When evaluating students' responses, we firstly focused on the reference to the characteristics of the bird's beak, eye placement, feet and flight ability. Accordingly, we paid equal attention to the correlation between the structure and the function of each characteristic (i.e., the first criterion), and the correlation between the characteristic and the given biotope (i.e., the second criterion).

Each of the four features was analyzed individually since it is not sufficient to extract any conclusions about a student's mean score, which could occur from various combinations of responses about the features and the corresponding explanations. Consequently, we present the scores as a provisional indication of students' achievement, but in fact only high scores (>15) or low scores (<four) could reveal high level achievement of the learning goals or the opposite, respectively.

Table 1 and **Table 2** show the specific score system we created for each feature, considering the possible argumentation provided by the students for the features we had selected. The maximum score for the four target features is 20 (four features × five points each), whereas the minimum score is zero.

Table 3. Descriptive statistics for each feature's score

Variables	Mean	Maximum
Vision	1.9	5
Feet	2.3	5
Beak	2.4	5
Flight	0.7	5

Students could have developed answers, which included all the four features, some of them, or even none of them; they could have argued correctly for all the four features (i.e., fully), or for some of the features (i.e., partially), or not argued at all.

Moreover, it was possible that some answers included both correct and incorrect explanations. Consequently, responses, which neglected to mention a selected feature, for example the beak, are scored with zero points, while others, which simply mention or describe the feature are scored with one point. Responses, which provide a correct justification are scored with two points, whereas 0.5 points are awarded when the justification reflects incorrect reasoning, and zero points in the case of no reasoning at all. The maximum score for the four target features is 20 (four features x five points each), whereas the minimum score is zero.

RESULTS

Students' responses were analyzed by two independent coders who had co-configured the score system for each bird's feature. Their results were compared and when disagreements arose, coders had to discuss and re-examine their choice in order to reach agreement to assign the same code. After the results had been coded, they were quantified and statistically analyzed via the SPSS 2020 software.

After analyzing the responses, descriptive statistics derived for each feature revealed students' reasoning performance, with the highest scores corresponding to the features of birds' feet and beaks (**Table 3**). Among these responses, as regards reasoning relating to the beak feature, almost 16.7% correctly correlate both structure with function and the adaptive advantage offered relative to habitat, and this proportion increased to 20.3% as regards reasoning related to the feet feature. Typical responses were supported with accurate justifications, such as in this example:

> "I chose a raptorial bird-avatar with a sharp, hooked beak, which helps to tug away skin and tear meat into bite-sized, easy-to-swallow chunks. This choice seems to be perfect as the biotope has plenty of small animals (snakes, mice) that could be the potential prey of this avatar".

Responses, which incorporated a lot of alternative ideas and inaccuracies (12.9%) were observed in reasoning relating to the trait of eye placement/vision type. For instance, some students chose for their avatar "*eyes on the sides [of the head] that help in estimating distances when hunting*". This is an example of incorrect correlation of the feature's structure with its function. The lowest score was noted in responses relating to flight ability, since more than the half of the students (61.5%) neglected to mention it.

It is important to mention that no response included correct explanations for all features; hence, the highest total score for each habitat was 16/20. Half of the responses were supported with scientific evidence for both the relevant function and how it was beneficial to a bird's survival in relation to the challenges presented by the habitat, while others neglected the latter explanation. An example response containing all the four traits was:

> "This bird-avatar lives near the river. It will be a filter feeder with a wide beak and little grooves, which help to strain small fish and shrimp from the water. The toes of its foot will be connected with membrane, which help in swimming. Its eyes will be on the side [of its head], which help to quickly spot enemies. It will be able to fly fast, as it has hollow bones and an aerodynamic shape".

It is obvious that this student correlated the functions of the bird's feet and beak with its interaction with abiotic items (water) and other animals, mentioning that the bird's feet should be suitable for swimming, and its beak suitable for filtering water and catching small fish. As far as vision is concerned, they do not explain which animals are the potential predators in this habitat. Finally, it is not mentioned how flying will contribute to facing the challenges posed by the habitat.

The differences we observed among the different features are also confirmed by the paired sample t-test. More specifically, we noted a statistically important difference between vision type and feet ($t[73]=-3.248$, $p<0.01$), vision type and beak ($t[73]=-3.030$, $p<0.01$) and vision type and flight ($t[73]=6.641$, $p<0.01$). Statistically important differences are noted between feet and flight ($t[73]=10.283$, $p<0.01$) and between beak and flight ($t[73]=9.280$, $p<0.01$) as well. There is no statistically important difference between beak and feet, as we had expected. These differences reveal that students did not apply the same attention in reasoning to all the features, resulting in many inaccuracies in their responses relating to type of vision and flight.

Comparing Structure with Function and Advantage It Provides in a Specific Habitat

For each feature, students' explanations for structure and function were compared with those for advantage provided and habitat. Paired sample t-tests reveal statistically significant differences for vision type ($t[73]=-6.651$, $p<0.01$, for flight ability $t[73]=-4.167$, $p<0.01$, and for feet $t[73]=-3.582$). We detected no statistically significant difference in the case of beak. The results indicate that students attempt to correctly correlate the structure of a trait with the function it offers, but they failed to correlate the given advantage with the biotic and abiotic features of the habitat.

DISCUSSION

Assessment of Initial Goals

Overall, when comparing their responses for the different features, we found interesting differences and similarities in students' performance. Most of the responses include the eye location/type of vision, the morphology of the beak, and the structure of the feet and legs, and focused on how these characteristics contribute to finding food, revealing that these features are thought to be important for a bird's survival. On the other hand, more than half of the students do not mention flight ability, reflecting that they either take it for granted and do not take into consideration that there are birds, which have lost this trait, or they suggest that flight ability plays no role in a bird's survival. This finding may indicate that students tend to mention features of birds associated with feeding, neglecting other factors, which affect survival, such as reproduction, facing predators, competing for resources, and facing climate challenges. This finding is in line with the research of Shtulman et al. (2016), according to which students tend to explain adaptation in terms of individual organisms' needs.

Features successfully explained and supported with evidence were the structure and function of birds' feet and beaks: Students seemed able to recognize the variation between species and to correlate it with its function. A large proportion of the students selected the appropriate beak and feet for the specific habitat of the final task, explaining how this trait can help the bird-avatar to thrive in its environment. As already mentioned, students had the opportunity to observe a range of various beaks and feet as they walked through the museum pathway and were thus able to compare and contrast their shapes, as those features are more distinguishable and easily observed than the others.

On the other hand, type of vision is related to a bird's interaction with other animals and its habitat. Such relationships are not highlighted in the museum's exhibits, as birds are not presented in their physical environment; thus predator-prey relations and animal competition for the same resources are not depicted. This may be the reason that many students avoid mentioning or explaining why they had selected a specific type of vision (with the corresponding eye placement) or included alternative ideas, and it could be very useful to combine this museum-based program with educational field-trip activities.

Form-Function vs. Advantage Offered to Specific Habitat

An important finding was the significant difference between responses, which correlate

(i) structure with function and

(ii) the selected trait with a specific habitat.

In our study, the majority of students were able to accurately explain how the morphology of each feature contributes to the survival of a bird, confirming that students can successfully match shape with function when they work with actual specimens (Rule, 2008). The zoological museum's exhibits permitted students to observe a range of bird species, with different morphological features grouped according to the habitat in which they live. Consequently, students can recognize motifs presented more frequently in a specific kind of biotope, compare them, and connect them with their function through hints given from the worksheet. However, the fact that biotopes are presented as images in museums prevents students from recognizing the interactions between biotic and abiotic factors. This may be the reason why few students correlated the advantage offered by the feature with the potential predators or prey. For example, although students mentioned the advantage of a feature, they neglected to explain how the presence of other animals, plants, or water can influence and challenge a birds' survival. This shortcoming may be overcome when such educational programs are combined with fieldtrip activities in authentic natural surroundings. Fieldtrips in nature contribute to the teaching of concepts that govern ecosystems, permitting students' interaction with both living and non-living organisms (Beery & Jørgensen, 2016; Minteer et al., 2018). Hence, students would have the opportunity to observe populations and to investigate interactions among different species with the natural resources in the habitat. In that way, students may correlate how certain traits confer advantages to organisms, leading to differential survival and to the passage of these traits to a new generation, an important concept in teaching adaptation (Shtulman et al., 2016).

Assessment of Total Responses

Assessment of the total responses showed that the maximum score was 16/20. In this case the responses included most of the information required relating to the structure and function of the features, and arguments were mainly supported by evidence, although some elements had been neglected. Findings revealed that the bird-avatars had all the traits, which correspond to the specific biotope. As far as the function of a trait is concerned, half of the responses were supported by scientific evidence, while explanations for how the function can benefit a bird's survival in relation to challenges posed by its biotope were neglected.

Assessment of Educational Program and Evaluation Tool

In general, the outcomes of the study indicate that students who participated in the educational program were actively engaged in the activities. Furthermore, they could apply the knowledge gained to new situations, supporting their choices with evidence. However, students' difficulty to correlate type of vision and flight ability to the features of a habitat indicates the weakness of some of the worksheet tasks. Consequently, these tasks should be modified or reinforced with a combination of activities so that students will approach the tasks more seriously, as they tend to consider museum educational programs done outside of the classroom as a simple school outing, or even as a day of respite from their studies.

Regarding the use of the final task as an evaluating tool, we suggest that activities, which require students to apply the information gained from their investigations be included in museum-based educational programs. Such activities have two diverse aims: On the one hand, students are guided to approach the central theme from various perspectives, thereby creating a holistic view of the subject, an experience, which can serve as a reminder of what they learned from the museum program. On the other hand, museum educators have the opportunity to re-assess the initial goals of the program and can identify problem areas in order to modify and improve them in terms of producing the most beneficial program for achieving students' learning goals. The assessment tool we created could be useful to other science educators as well. Furthermore, the final assessment task provides a means of estimating students' engagement in, and knowledge gained through the museum educational program intervention. Results from such an evaluation could be more fruitful when the assessment task is repeated after a period of time. This procedure could provide an estimation of students' retention of the knowledge gained through the educational program. Thus, a limitation of our study is the inability to realize the repetition of the final task due to factors beyond our control: Having prepared the initial design of this repetition, we were unable to conduct it because of the pandemic and the restrictions affecting both in-school and in-museum procedures. Moreover, the importance of supplementing such an educational program by activities focusing on evolution in order to shed light into any teleological beliefs of the students should be noted. Hence, our next steps will focus on the repetition of the museum-based educational program with a second implementation of the assessment task and some additional activities relating to the process of evolution.

CONCLUSIONS

In this research we designed an educational program for a class visit to a zoology museum that we accompanied with a corresponding activity worksheet on bird adaptations (wild flight guide). Our aim was to evaluate the program based on the knowledge that students could ultimately gain in such a non-formal education environment, and for this purpose we constructed an appropriate assessment tool.

What we have found is that although encouraging results emerge regarding students' knowledge around bird adaptations (i.e., beak, feet and habitat correlation), this is not the case for all the trait categories (i.e., flight ability, eye position) that were tested. In light of these findings, we intend to enrich the program with additional activities and possibly a field trip. In a future step, we intend to repeat our research, increasing our sample and reinforcing it with results on knowledge retention after a certain period of time.

Moreover, through this research we have focused on evolutionary adaptation and not on all aspects of evolution, which means that there are still steps to go before we can consider that students are fully familiar with all evolutionary dimensions. However, it is undoubtedly an important step outside the context of formal education by using the museum, which we hope will provide insights for other researchers both/either in terms of designing a similar educational program and/or in terms of utilizing the proposed assessment tool.

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

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