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Environmental Education Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ceer20

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To cite this article: Alexandra Rocha Silva, Sónia Matos, Rosalina Gabriel, Ana Moura Arroz, Daniel Sousa, Flora Piasentin & Isabel Rosário Amorim (2023): The Field Guide audio series: mobile learning using place-based and inquiry-led approaches to promote adolescents' interest in nature, Environmental Education Research, DOI: 10.1080/13504622.2023.2216406

To link to this article: https://doi.org/10.1080/13504622.2023.2216406

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Published online: 06 Jun 2023.

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ENVIRONMENTAL EDUCATION RESEARCH
https://doi.org/10.1080/13504622.2023.2216406

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The Field Guide audio series: mobile learning using place-based and inquiry-led approaches to promote adolescents' interest in nature

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ABSTRACT

Facilitating the exploration of adolescents' questions regarding nature is vital. Research suggests that their questions are important as they can reveal their interests in particular subjects and further guide their learning process. We designed a quasi-experimental study for 68 adolescents in an outdoor and indoor setting to assess the efficacy of the audio-learning materials in promoting their interest in learning more about nature. Although we did not find differences between the two settings, results show that the audio-learning materials impacted questioning by guiding participants' focus on specific topics and promoting perceived learning. Participants also reported high satisfaction with the audio-learning materials and willingness to hear more and/or recommend them to others. As a result, we discuss the motivational role of audio-learning materials in promoting adolescents' exploration of nature and interest in learning about nature-rich environments. We believe our study has educational and design-related implications. It problematizes how audio-learning materials may bring adolescents closer to nature and tests the potential of mobile technology as a medium. Our study also builds on existing educational strategies by further adding the importance of valuing the concept of place and its ecological and social dimensions to enhance adolescents' contact with and interest in nature.

ARTICLE HISTORY
Received 16 November 2022
Accepted 11 May 2023

KEYWORDS
Inquiry-based learning; adolescent-led learning technologies; adolescents interests; exposure to nature; nature conservation; environmental education; outdoor learning; place-based learning; nature-rich environments; audio learning materials

Introduction

Growing evidence shows that spending time outdoors is crucial for developing an interest in and positive attitudes toward nature (DeVille et al. 2021; Hoover 2021). However, adolescents spend less time outdoors and more time in front of screens than their predecessors (Larson et al. 2019; Rideout 2016) despite studies showing that positive experiences in nature during childhood, especially with more "wild" natural environments, are critical for adult pro-environmental

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/13504622.2023.2216406.

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behaviors (Wells & Lekies 2006). Here, we apply the term adolescents to the stage of life between childhood and adulthood, from ages 10 to 19.

Immersion in digital technology amongst younger generations has given rise to the term 'digital natives' (Prensky 2001). It is essential to cast a critical lens on the term, given that it often presupposes that younger generations are more skillful in using technology when compared to older generations, that all children and adolescents have equal access to technology, or even that technology always has a positive contribution to add (Eynon 2020). Despite this, the term can help us describe a generation with new and specific attitudes and approaches to learning (Bennett et al. 2008). Digital natives are prone to learn by experience, multitask and search for information using information and communication technologies (Prensky 2001). Evidence suggests that young people presently prefer to learn actively, on flexible schedules and settings, and with portable and practical technological devices, such as smartphones (Muchsini & Siswandari 2018; Thompson 2015).

Our access to digital technology grows in tandem with the ever-increasing ecological challenges caused by the degradation of ecosystems and the loss of biodiversity (Bradshaw et al. 2021; IPBES 2019). Thus, it is crucial to equip younger generations with the knowledge and skills to tackle these issues through environmental education (Powell et al. 2019; Mansilla & Jackson 2011), a process that has predominantly relied on informal and outdoor learning and in direct contact with nature. The inherent portability, flexibility, and motivational capabilities of mobile technologies (Ruchter et al. 2010) are one way of harnessing the educational potential of nature-rich environments. Ruchter et al. (2010) have demonstrated that both children and adults using mobile technologies, such as mobile nature guides, can achieve similar results in environmental literacy as the ones using traditional instruments, with the addition of being more motivated to engage with their immediate environment.

Mobile technologies can effectively promote engagement with and interest in the surrounding natural environments (Kawas et al. 2019). Given the mobility of portable communications devices, they are especially relevant for place-based learning interventions since they allow the integration of location capabilities to customize the content to a particular place, improving user engagement (Kawas et al. 2019; Zimmerman et al. 2015). Place-based learning aims to help communities to learn about global and abstract concepts through the experience of local places (Smith 2002). This is of particular interest for environmental education since community-based nature conservation can be promoted through reconnecting people with their land (Dale et al. 2020; Larson et al. 2018), which is an important dimension when designing environmental education programs in island contexts as stated by Jenkins et al. (2018).

Furthermore, given that place-based learning first evolved from a desire to situate and contextualize learning within a 'community of place' (Webber et al., 2021), we ponder whether mobile technologies can enhance learning amongst adolescents living in islands where local biodiversity and habitats tend to be unique. In dealing with the concept of place within the framework of this study, we view a place not only for its ecological qualities and their potential to inform environmental education but also for its social dimensions. From a human perspective, places are also locations we have made relevant through meaningful interactions (Cresswell 2011). In positioning both ecological and social stances, we view the potential of audio-learning materials that use mobile technology to enhance our interaction with a given place and the communities that underlie its social fabric.

By combining a place's ecological and social dimensions with the situational and contextual potential of mobile technology (Kawas et al. 2019; Zimmerman et al. 2015), we may engage adolescents with their local natural environments. In addition, we can create mobile place-based learning experiences that promote the development of their interest in learning more about nature by (1) supporting their focused attention on the surrounding physical environment, (2) providing a platform where they can freely express questions of interest, whilst (3) offering

opportunities for further engagement with nature (Hidi & Renninger, 2006; Kawas et al. 2019) and their local community.

Mobile technologies to engage young people with nature

Mobile technology has grown exponentially in the last decades. As a result, scholars within environmental education and outdoor learning have explored its potential to increase engagement, interest, and learning about natural environments (Crawford et al. 2017; Santos et al. 2014; Viberg et al. 2021). Nonetheless, some authors have questioned whether mobile technology is beneficial or detrimental. We can find a recent overview of the debate in the work of van Kraalingen (2021). This systematic review addresses the advantages and disadvantages of this type of learning in outdoor education and presents strategies for the implementation of mobile technologies in outdoor learning (see details below).

Since mobile technologies allow learning across different contexts (Kumar & Chand 2019), some of its main advantages are the portability of devices and the easy access and storage of information and experiences (Midgley 2014). Learners can also achieve a more significant level of autonomy (Fauville et al. 2014). On the other hand, some of the concerns raised by several authors include its potential for distraction from the physical environment and the learning activities (Hills & Thomas 2020). The complexity of devices can also prevent educators and learners from using them (Su & Cheng 2013). The risk of technical failure of devices can also call into question the quality of the educational activities (Midgley 2014). At the same time, resource availability and the cost of mobile technology can also hinder access (Schaal & Lude 2015). These drawbacks can influence learners' direct experience with the environment and lead to a loss of experiential quality (Bolliger et al. 2021; Cuthbertson et al. 2004; Hills & Thomas 2020; Midgley 2014).

To overcome obstacles, van Kraalingen (2021) proposes three strategies for implementing mobile learning in the context of outdoor learning, *Mitigation, Intentionality,* and *Adaptation*. Educators and facilitators are advised to limit the use of electronic devices when outdoors (Greenwood & Hougham 2015), using them only when relevant to the educational objectives (*Mitigation*); the objectives of the educational activities should guide the choice and use of these devices (*Intentionality*) (Hills & Thomas 2020). In addition, mobile technologies should be adapted to make the most of their dynamic, collaborative and interactive capabilities, to engage learners with the surrounding environment and with each other (*Adaptation*), with integrated tasks, questions, and prompts to keep learners motivated and focus on the learning experience rather than on the technological devices (Anderson et al. 2015, Zimmerman et al. 2019). Van Kraalingen (2021) also emphasizes the importance of using mobile technologies to capture learners' experiences and thoughts to evaluate the educational experience and the use of mobile technologies in outdoor learning activities.

Since mobile technologies have the potential to add new interactive tasks to educational activities, the functionality of mobile devices should be considered when designing mobile learning interventions. Thus, Puentedura (2009) proposes the SAMR model (Substitution, Augmentation, Modification, and Redefinition) to classify mobile technologies' two main roles in the pedagogical design of learning activities. First, in their capacity to enhance learning activities by substituting activities without any functional change (Substitution) or by providing functional improvement (Augmentation). Second, by transforming learning activities by redesigning them (Modification) or creating new activities that could not exist otherwise (Redefinition).

However, regardless of educators' educational objectives or concerns, adolescents are increasingly using their mobile devices more when outdoors (Larson et al. 2011), and they seem to enjoy environmental educational activities better when they are coupled with mobile learning (Anderson et al. 2015; Crawford et al. 2017). Studies comparing traditional outdoor learning

approaches with approaches with mobile devices show that the latter are as effective as the former in achieving educational goals however with the additional benefit of learners' higher enjoyment and engagement (Anderson et al. 2015; Crawford et al. 2017; Ruchter et al. 2010).

Some examples of the use of mobile technologies in outdoor learning include the study from Kawas et al. (2019) that made use of an interest-centered mobile app to engage participants with nature by promoting their focused attention toward natural surroundings with the creation and sharing of photo collections. In another study, Jong (2020) used an inquiry-oriented and context-aware mobile app to promote students' motivation to learn about nature, concluding that inquiry-oriented mobile technologies are significantly stronger than traditional inquiry-oriented worksheet-supported fieldwork in promoting three of the four constructs of motivation according to Keller's motivation model (Keller 1987): attention, confidence, and satisfaction. Additionally, Zimmerman et al. (2015) studied families' exploration of a biodiversity website through mobile phones in an arboretum concluding that the website effectively promoted not only nature observation but also perceptual (identifying and describing the characteristics of something) and conceptual (making inferences using previous knowledge, explaining causal relations, and making new interpretations) conversations about it. Therefore, in outdoor learning and place-based learning, mobile technologies can serve as a medium to enhance learners' experience by promoting their motivation to learn and explore the surrounding environment and by sparking their situational interest (Chipman et al. 2006; Peffer et al. 2013; Ruchter et al. 2010; Schaal & Lude 2015).

The role of interest and questioning in the learning process

Interest can be defined as a state – situational interest – when it is a response to the environment or a trait – individual interest – when it is a personal predisposition or tendency to pay attention to certain stimuli over time (Hidi 1990). Interest and motivation are two motivational variables closely linked together (Yi 2021). According to Renninger and Hidi (2011), interest can be driven by intrinsic or extrinsic motivation and can be developed through four principles: (1) personal relevance; (2) focused attention; (3) social interactions; and, (4) continued engagement (Hidi & Renninger 2006). In the learning process, interest is particularly important since students are more likely to be focused on, engaged with, and committed to a learning activity when they are interested in the topic (Hidi & Renninger 2006; Pintrich & Schunk 2002; Yi 2021). Since interest influences both cognitive and affective functions (Renninger & Hidi 2011), encouraging interest in nature is critical to foster (1) understanding of surrounding natural environments, challenges faced, and their respective solutions and (2) positive attitudes toward nature (Monroe et al. 2008; Powell et al. 2019; Wang et al. 2022).

Students' self-generated questions can be a gateway into their interests (Baram-Tsabari et al. 2006; Chin & Osborne 2008; Swirski et al. 2018). Learners habitually ask questions to solve a knowledge gap or to extend their knowledge about something they are curious about (Berlyne 1954; Festinger 1957). Thus, questions may represent an interest in a specific topic and, at the same time, promote students' epistemic curiosity about it (Berlyne 1954). By formulating and asking questions, students practice knowledge construction, develop critical and creative thinking, and problem-solving capacities (Cuccio-Schirripa & Steiner 2000), and become more interested in learning (Chin & Osborne 2008). While bringing the role of questions closer to environmental education, recent research highlights the importance of inquiry-led approaches to foster adolescent learning processes around complex topics such as climate change (Tolppanen and Aksela 2018).

However, in a classroom setting, there appear to be few opportunities to ask questions, especially those not related to the topics on the educational curricula (Chin 2004), which leads to less intrinsic motivation and, consequently, less knowledge acquisition (Pintrich & Schunk 2002). Therefore, it is important to provide opportunities where students feel free to explore

their interests and consolidate their knowledge by posing questions that experts in the field will answer. As Baram-Tsabari et al. (2006) have analyzed, students tend to freely ask more science-related questions requesting factual-information or the explanation of causal phenomena with a focus on biology. We believe this provides an opportunity for learning-centered technological design and development with a focus on promoting questioning about nature. And while authors such as Tolppanen and Aksela (2018) pointed towards the need to improve pedagogical strategies within educational contexts, we believe that this challenge can also be the domain of mobile technology and how it is used in both formal and informal educational settings. As stated by Kawas et al. (2019), mobile learning technology has the potential to sustain the engagement needed to trigger at least a situational interest, in the sense defined by Renninger and Hidi (2011).

Research design

We developed the present study under the umbrella of Field Guide, which combines a team of researchers from different backgrounds, from biology and nature conservation, social sciences, psychology, and human-computer interaction design. The project focuses on developing, evaluating, and applying interactive mobile technologies to support place-based environmental education in the Azores Islands by promoting adolescents' exploration of nature-rich environments. In developing this study, we used questions posed by adolescents during a previous field trip on a nature trail (Matos et al. 2022) to create the audio-learning materials (an audio series). Through this process, we aimed to develop materials tailored to this age group's interests in nature. We created the audio series in response to questions posed by adolescents in an earlier moment and in collaboration with scientists whose research focuses on Azorean biodiversity and whose responses we recorded using an interview format.

Our choice of the audio series format is in debt to the general population's increased interest in podcasts. In addition, research demonstrates that when taking a place-based approach to learning, podcasts can become an opportunity to connect communities with their local heritage (Scriven 2022). Our choice of the audio series format was also in debt to the potential afforded by the stimulation of the auditory senses in nature-rich environments, which enables visual exploration of the surrounding environment. Audio learning materials can provide opportunities for learning through listening and have been recognized as valid learning objects (Cebeci & Tekdal 2006), promoting interest in learning. Given our use of an ecological and social dimension of place, we also created the audio series to connect adolescents from the island of Terceira with scientists who have devoted their work to local issues.

It is important to note that, at the heart of Field Guide is a mobile application or app that uses a geolocation positioning system to support visits to a nature park – for more details, see (Sousa et al. 2021). For this study, we adapted the app to a specific nature trail and added audio learning materials to test our hypothesis and questionnaires to collect data. For our contribution, and as indicated in previous studies (Jong 2020; Kawas et al. 2019; Zimmerman et al. 2015), our focus was on the audio-learning materials and their potential to promote adolescents' interest in nature. Here, our aim was two-fold. We wanted to assess whether adolescent-led materials concerning local natural environments could promote interest in learning more about nature and understand mobile technology's role in this process. As a result, we tested the audio-learning materials in outdoor and indoor settings using the app as the transmission medium. To guide our inquiry, we posed the following questions:

RQ1: How might audio-learning materials impact the promotion of interest in nature?

RQ2: Do adolescents perceive their engagement with audio learning materials as an opportunity to learn about nature?

RQ3: Do adolescents enjoy the use of audio learning materials to learn about nature?

RQ4: Does adolescents' interaction with audio learning materials result in a desire for continued engagement?

Materials and methods

To answer our research questions, we adopted a quasi-experimental design (Cook et al. 1979) with an embedded mixed-method approach (Onwuegbuzie & Leech 2015) that uses a qualitative methodological approach to strengthen the conclusions derived from the quantitative data. Our study uses a between-subjects design with two experimental groups and two control groups.

Participants' interest in nature was assessed through their questioning concerning the topics (Azorean nature) presented in the audio series which was developed in collaboration with local scientists and in response to a previous visit with another group of adolescents to the same nature trail. Questions were categorized according to their relation to the audio series - relation to the content provided in the audio learning materials. We also analyzed the types of objects in focus in the questions and the types of information requested**.** Additionally, to understand participants' satisfaction with the use of audio learning materials to learn about nature, we assessed their level level of perceived learning, level of satisfaction with the audio series, their willingness to hear more episodes regarding Azorean nature, and their willingness to recommend to others the audio series.

Study setting and participants

This study was designed for the trail of Mistérios Negros, a nature trail located in a nature-rich environment in the Natural Park of Terceira Island (Azores, Portugal). The island, with only 400 km^2, is inhabited by 54 874 people, of which about 6000 are adolescents between the ages of 10 and 18 (SREA 2020). For this study, we recruited 68 adolescents from different parts of the island, 40 through local Scouts groups and 28 through local holiday camps. Ages varied from 9 to 18 (12.3 ± 2.2), and about half were female ($n = 33$). About 9% were students attending the fourth grade (age 9), 42% from fifth and sixth grades (ages 10-11), 36% from seventh to ninth grades (ages 12-14), and 14% were secondary students (ages 15-18). Most participants fall within the adolescence category with only 9% representing what is termed as preadolescence, more often popularly denoted as the 'tween' stage. In addition, and while one might argue that in working with a Scouts group the study focused on participants already inclined to nature and perhaps not representative of the whole population, evidence collected in a previous study, developed by the authors of this paper (Matos et al. 2022), suggests that in the context of the Azores, nature often serves as a backdrop to Scout led activities which are focused more on teamwork and social skills.

For sample description purposes, we assessed participants' level of exposure and connection to nature using the Nature Exposure Scale (NES; Francis 2011) and the Connection to Nature Index (CNI; Cheng & Monroe 2012), respectively. Both scales were translated into Portuguese, however, their validation for Portugal is not available yet. On average, participants scored a high level of nature exposure (13.1 ± 4.0; $N = 65$), with a minimum of four and a maximum of 20, and of nature connection (67.6 ± 8.5; $N = 66$), with a minimum of 26 and a maximum of 79.

Consent to participate in the study was obtained from all participants and their respective caretakers. Participants were informed that their participation was voluntary and that they could withdraw from the study at any time. Ethical approval from the Ethics Committee of the University of the Azores was obtained for this study.

Audio learning materials development: the Field Guide audio series

In December 2019, a group of 36 adolescent scouts walked on the same trail of Mistérios Negros. During the 'rediscovering nature' activity, adolescents were asked to perform different activities, namely, to listen to the sounds of nature, look for animal and plant species, engage in conservation actions, etc., and think and write questions related to the place and situation (Matos et al. 2022). The activities resulted in the production of 168 questions (136 different) concerning Azorean nature. About a month and a half later, in a classroom setting, the same participants ranked the formulated questions according to their interests (Ibid.). Working in groups, adolescents ranked groups of 34 questions using a paper pyramid, similar to a Q-sort, that allowed identification of the five most interesting questions for them. In the end, we collected the top two most interesting questions from each group of participants, which resulted in 18 specific questions. For each of the selected questions, we contacted experts in the field, mostly working at the University of the Azores, and collected their responses to construct an audio series targeting adolescents, specifically 16 episodes in Portuguese were created (Table 1). The audio series is now available for the public (Silva et al. 2022).

All audio series episodes followed the same structure: (1) introduction to the topic, (2) introduction of the expert, (3) posing of the question, (4) answer to the question by the expert, (5) summary and conclusions of the answer and (6) acknowledgments.

Data collection materials: the Field Guide app

Following Zimmerman and Land's (2014) guidelines for the design of place-based interventions, we combined the location-awareness capabilities of the mobile devices and the local relevance of the audio learning materials to create a learning experience that promotes: (1) discussion and questioning about disciplinary topics in places relevant to learners; (2) observation and exploration of the aspects of a place using technology to guide learners' attention; and (3) connection between learners and their community through the collection and sharing of data and the promotion of discussions about their land. To improve learners' experience, we considered van Kraalingen's (2021) strategies and recommendations by restricting the use of smartphones to only when relevant to the activity (*Mitigation*), using the mobile app to deliver the

Table 1. The Field Guide audio series episodes and the adolescents' questions that originated them (here translated from the original in Portuguese to English).

Episode	Questions
1	Do plants choose their natural habitat?
2	Is Kahili ginger edible?
3	Why is it that when we squeeze the moss and the cryptomeria water comes only out of the moss if the two plants got rain?
4	How could the water from the lagoon be used?
5	How did the volcanic eruption of Mistérios Negros take place?
6	What would happen if the insects disappeared?
7	What would happen if cryptomeria disappeared?
8	How could we currently deal with the transformations generated by a new volcanic eruption on the trail of Mistérios Negros?
9	What would happen if there were no protected areas? Why isn't all of nature preserved?
10	Why are there flies in the forest?
11	Why are mosses important?
12	Why do you think biodiversity will be lower in the future?
13	Why should we protect the short leafed juniper?
14	Why aren't there more living beings in the [Vale Fundo] lagoon?
15	Why is it important for the region's climate to have the characteristics it has?
16	Why are nature reserves important?

audio series and collect data (*Intentionality*), whilst making use of the capabilities of the mobile devices and the app - such as the geolocation capabilities and the diffusion of multimedia materials - to enrich the learning experience (*Adaptation*).

Additionally, to spark participants' situational interest and curiosity, we designed the Field Guide app according to the four principles of interest development by Hidi and Renninger (2006), adapting them to our aim: (1) personal relevance - in the sense that the questions presented in the audio series derived from other adolescents who produced them after walking in the same nature trail and were chosen by them; (2) focused attention - the stimulation of their hearing capacities allowed participants to explore the surrounding environment whilst listening to the episodes; (3) social interactions - even though indirect, the participants of the activity were interacting with the adolescents from the previous activities responsible for formulating and choosing the questions; this is also valid for the indirect interaction with the experts who answered the questions; and (4) continued engagement - our study invited participants to pose more questions after hearing each episode, allowing them to engage further with the learning materials.

For this study, conducted during the month of July 2021, we demarcated five stations with pins in the app (Figure 1) along the first kilometer of the nature trail (Azores Trails, n.d.). In the initial station, a pre-intervention questionnaire was added to collect sample characterization data (age, sex, schooling, and nature exposure and connection; see supplementary materials). And, in the final station, we added a post-intervention questionnaire with questions concerning participants' satisfaction with the use of audio learning materials and some feedback about the app (see supplementary materials).

To each of the three middle stations, we added an audio series episode chosen according to its relevance to the location where it would be listened to. Station 1 was located at a forest entrance and introduced participants to the natural park; here, we chose an episode about protected areas. For Station 2, located close to the volcanic domes of Mistérios Negros, we chose an episode that explains the volcanic eruption that originated them. And for Station 3, located in a diverse forest of *Juniperus brevifolia,* we selected an episode that clarifies the

Figure 1. The Field Guide mobile application with stations demarcated with pins.

importance of these Azorean endemic trees (Table 2). To collect participants' questions, we asked them, after every episode, what they would like to ask regarding Azorean nature and provided them space to write all of their questions freely.

We created two versions of the app, one with the audio learning materials (experimental) and one without (control). The final feedback questions concerning the audio learning materials were removed from the control version of the app.

Data collection procedure: the 'Ask a scientist' activity

The 68 participants were divided into four groups, two control groups and two experimental (Table 3). Indoor groups explored the app while performing a manual activity in a closed room (doing crafts or painting) all seated around communal tables, and outdoor groups explored the app while walking on the trail of Mistérios Negros. Because of restrictions concerning the COVID-19 pandemic and transportation limitations, sample distribution was conducted having convenience in mind. Adolescents from the same scouts' group or holiday camps would, in most cases, perform the same activity on the same day, i.e. ending up in the same sample group.

For the two groups in a nature-rich environment, participants completed the pre-intervention questionnaire (by selecting the first pin in the app) at the initial station, located at the trailhead's parking lot. Here we provided participants with initial instructions and materials (a smartphone, a smartphone case, and a pair of earphones when needed). They waited for their turn to begin the walk individually. After walking for about 700 meters, participants arrived at station 1, where they either listened to one of the audio series episodes and posed questions (Outdoor) or only posed questions (Outdoor control). They repeated this process in the following two stations by selecting the corresponding pins for each station. In the final station, participants responded to the post-intervention questionnaire (by selecting the last pin), thus completing the activity. All stations were within 90 meters of each other.

For the activities in an indoor setting, after initial instructions and distribution of materials, participants responded to the pre-intervention questionnaire and, once completed, started the individual manual activity. After a while, adolescents were told to select the pin of the first station and complete the proposed task. Once the last participant completed the tasks suggested in each pin and continued doing the manual activity, we counted three minutes (approximately the same amount of time that took outdoor participants to walk from one station to another) until they were invited to select the next pin and perform the proposed tasks. This process continued until all participants reached the post-intervention questionnaire, therefore, completing the activity. Usage of the app in the indoor setting was as similar as possible to its use in a nature-rich environment.

Data treatment and analysis

Data collected with the mobile app during the interventions were transferred to Microsoft Excel software where it was synthesized and categorized.

We first established the questions' **relation to the audio series** using a four-point Likert scale, where '1' was allocated to questions unrelated to the content of the episode heard in the corresponding station and '4' to questions that referenced the same examples or concepts discussed in the episode. Three researchers with different backgrounds independently

Table 2. Stations' location and respective audio series episodes.

Station	Location	Audio series episode
1	38°44'16.69"N, 27°16'37.20"W	9. What would happen if there were no protected areas?
2	38°44'17.91"N, 27°16'40.07"W	5. How did the volcanic eruption of Mistérios Negros happen?
3	38°44'18.05"N, 27°16'43.69"W	13. Why protect the Azores juniper?

Table 3. Participants' groups and respective experimental conditions.

Groups' names	With access to Audio Learning Materials	In a nature-rich environment	Adolescents (N)
Outdoor	✓	✓	16
Outdoor control	X	✓	20
Indoor	✓	X	18
Indoor control	X	X	14

Table 4. Examples of adolescents' questions by their type of object in focus (questions were translated to English from the original in Portuguese).

Type of object in focus	Sub-categories	Questions examples
Human impacts	Human impacts	Why do people cut down trees?
		Why do people throw so much garbage on the floor?
Nature and nature protection	Protected areas	Which areas are protected?
	Nature	Is nature people's life?
Volcanic eruptions	Volcanic eruptions	What is the probability that a volcano will explode in the next 50 years?
		Did this volcanic eruption cause injuries and deaths?
Species and biodiversity	Species	How many endemic plants are there in the Azores?
	Biodiversity	Compared to Portugal as a whole, do we have good biodiversity?
Others	Terceira Island	How old is Terceira Island?
	Rocks	How many types of rocks exist in the Azores?
	Trails	How many trails are there in the Azores?
	Others	Why is the sky blue?

categorized all questions. An external judge categorized a sample of 100 questions as Bujang and Baharum (2017) recommended for Cohen's Kappa calculation for four categories. A moderate agreement was firstly obtained, $\kappa = .580$, $p < .001$, after some disagreements were solved the second inter-rater reliability test revealed a good agreement, $\kappa = .785$, $p < .001$.

A posteriori, we thematically analyzed the types of objects in focus in the questions through an inductive process that allowed categories to emerge from the data. Three researchers with different backgrounds performed the coding process, including negotiating the categories and proceeding with iterative reformulations. Initially, they were able to derive from this process ten sub-categories. An external judge categorized a sample of 50 questions as Bujang and Baharum (2017) recommended for the Cohen's Kappa calculation for ten categories, which resulted in a good agreement, $\kappa = .648$, $p < .001$. After solving some disagreements, we performed a second inter-rater reliability test, which revealed a very good agreement, $\kappa = .971$, $p < .001$. For statistical analysis purpose, these ten sub-categories were compressed into five categories (Table 4).

Lastly, to assess the type of information requested by adolescents, we adapted the categorization developed by Baram-Tsabari and colleagues (2006) that derives from Bloom's taxonomy (Bloom et al. 1956) and Bybee's classification of research questions (Biological Sciences Curriculum Study 1993). The category "general request for information" was adapted to "non-related" questions, those questions that ask for information not specific to nature; "factual" questions were operationalized as those that ask for data and/or properties of nature, natural elements, or its relations; "explanatory" questions as those that request elucidatory information about nature and/or the environment, including natural elements and its relations, with "why" and "how" questions; "methodological" questions are those that ask for procedural information related to scientific ways of producing knowledge and/or manage nature using scientific and technological tools; "predictions" questions as those that ask for possible results of a specific experiment or possible outcomes of a particular situation; and, "open-ended" questions, those that deal with opinions, controversial, political, philosophical, artistic and/or existential themes, and futuristic questions that science cannot answer for the time being (Table 5).

The same three researchers categorized all questions. Then, an external judge categorized a sample of 70 questions as Bujang and Baharum (2017) recommended for the calculation of Cohen's Kappa for six categories. A moderate agreement was firstly obtained, $\kappa = .563$, $p < .001$, after some disagreements were solved the second inter-rater reliability test performed revealed a good agreement, $\kappa = .789$, $p < .001$.

To explore differences between control and experimental groups and after the coding of all data, we performed Pearson's Chi-square tests ($\chi 2$), with a 95% confidence level ($p \leq .05$), using IBM SPSS Statistics for Windows software Version 27 (IBM Corp 2020). When more than 20% of expected frequencies were below five, we used the likelihood ratio value instead of Pearson's Chi-square value ($\chi 2$). We then carried out multiple z-tests of two proportions (with Bonferroni corrections) as *post hoc* tests with an alpha (α) level of .025 for two pairwise comparisons and .01 for five pairwise comparisons. Additionally, to explore differences between the number of questions produced by the four groups, we performed a Kruskal-Wallis test with a 95% confidence level ($p \leq .05$), assuming that the distributions of values between groups are similar. And to explore differences between sets of two groups on ordinal variables, we applied Mann-Whitney U tests (U) also with a 95% confidence level ($p \leq .05$).

Results

We retrieved a total of 150 questions: 31 from the Outdoor group ($N = 16$), 48 from the Outdoor control group ($N = 20$), 40 from the Indoor group ($N = 18$), and 31 from the Indoor control group ($N = 14$). Three participants repeated the same question in two different stations; in these cases, we only considered the question formulated in the first station and discarded the duplicate. On average, participants formulated 2.2 ($SD = 1.1$) questions, with a minimum of zero and a maximum of four questions per participant. Statistical tests showed no significant differences between the medians of the four groups, $\chi 2\ (3) = 0.520$, $p = .914$.

RQ1: How might audio-learning materials impact the promotion of interest in nature?

In responding to this question, we were keen to understand whether the setting (indoors or outdoors) had any influence on the promotion of interest. As expected, (Figure 2), when applied indoors, the audio learning materials have a significant positive impact on the number of participants' questions related to the audio series (70.0% versus 16.1%), $\chi^2\ (1) = 20.375$, $p < .001$. Similarly, in direct contact with nature, the Outdoor group also made proportionally more questions related to the audio series than the Outdoor control group (64.5% versus 6.3%), $\chi^2\ (1) = 30.985$; $p < .001$.

Table 5. Examples of adolescents' questions by their type of information requested (questions were translated to English from the original in Portuguese).

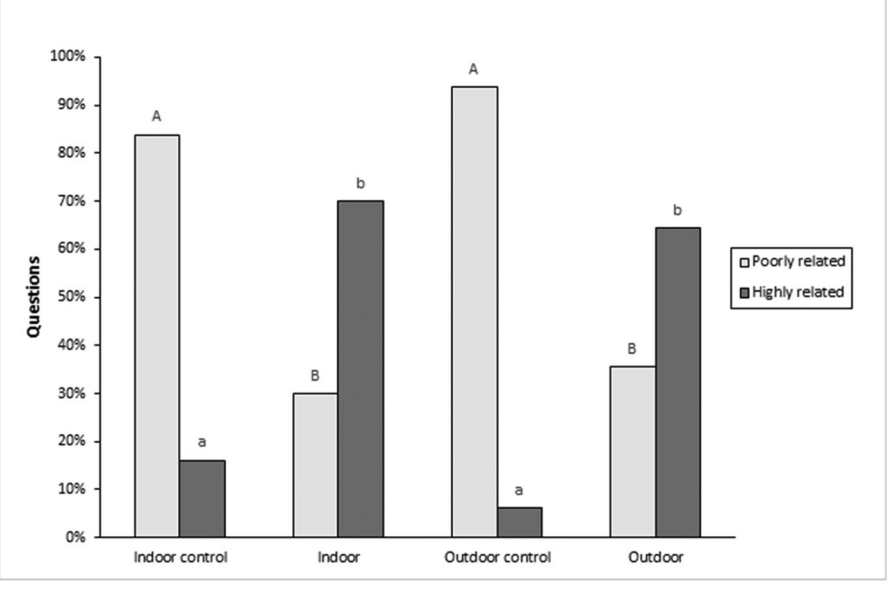
Type of information requested	Questions examples
Factual	What are the rarest plants in the Azores?
	What areas are protected?
Explanatory	Do invasive plants bring benefits to Azorean nature?
	How can we help nature more?
Predictions	Nature has to be taken care of, if we don't take care of it, what happens?
	What is the probability that a volcano will explode in the next 50 years?
Methodological	If the volcano exploded, how do we know that there are no caves or other places yet to be discovered?
	How do you manage to ensure that our protected areas are really protected?
Open-ended	How did a volcano managed to make this beauty?
	Is nature people's life?
Non-related	How long have there been no mattresses?

When analyzing the two experimental groups, Outdoor versus Indoor, no significant differences were found in terms of the questions' relation to the audio series, χ^2 (1) = .240, p = .624. Both indoors and outdoors, the audio learning materials seem to impact questioning positively.

When looking at the objects in focus in the questions (Figure 3), we find significant differences between the two indoor groups, $\chi 2$ (4) = 14.396, p = .006. *Post hoc* tests show that this difference is significant only for the 'Volcanic eruptions' ($\chi 2$ (1) = 7.327, p = .007) and "Others" ($\chi 2$ (1) = 6.940, p = .008) categories. Since one of the episodes focuses on the topic of volcanic eruptions, we expected that the group with the audio learning materials would produce more questions about it (27.5% versus 3.2%).

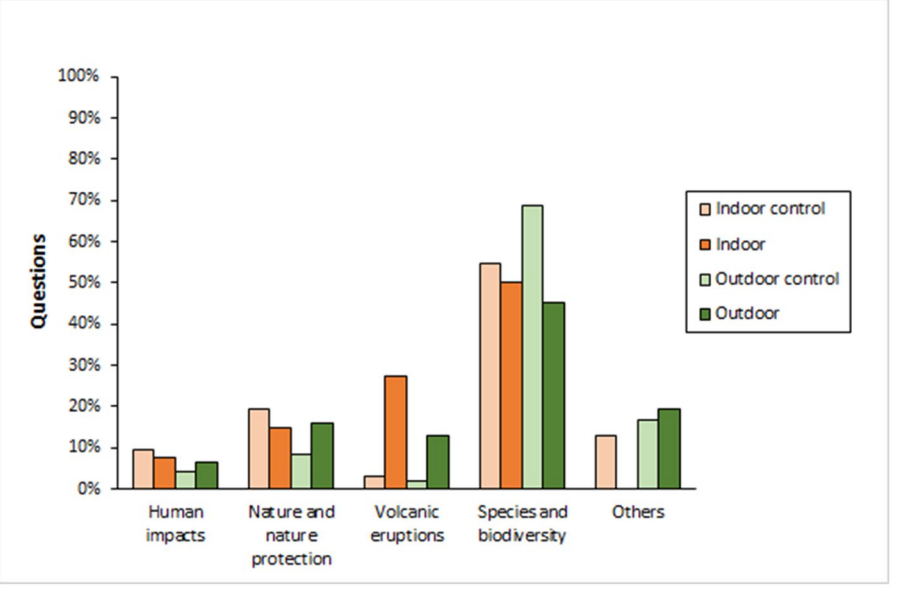
However, for the outdoor groups, even though the audio series group also produced more questions that focused on volcanic eruptions (12.9% versus 2.1%), we did not find significant differences between the two groups, $\chi 2$ (4) = 6.544; p = .162. When comparing the two audio series groups, significant differences were only found in the "Others" category, $\chi 2$ (1) = 10.667, p = .001, as revealed by the *post hoc* tests. The outdoor group has almost one-fifth of its questions (19.4%) focusing on other topics while the indoor group has none.

Finally, when we look at the distributions of types of information requested in the questions (Figure 4), we did not find significant differences between the two indoor groups, $\chi 2$ (4) = 4.961, p = .291, nor between the two outdoor groups, $\chi 2$ (4) = 5.541, p = .236. Overall, all groups made more questions requesting factual information, while explanatory information was the second most requested. Only indoor groups made predictions, and the indoor control group did not make any methodological questions. Open-ended questions represent less than ten percent of the questions in all groups. When analyzing the two audio series groups, we also did not find any significant differences between them, $\chi 2$ (4) = 3.322, p = .506.



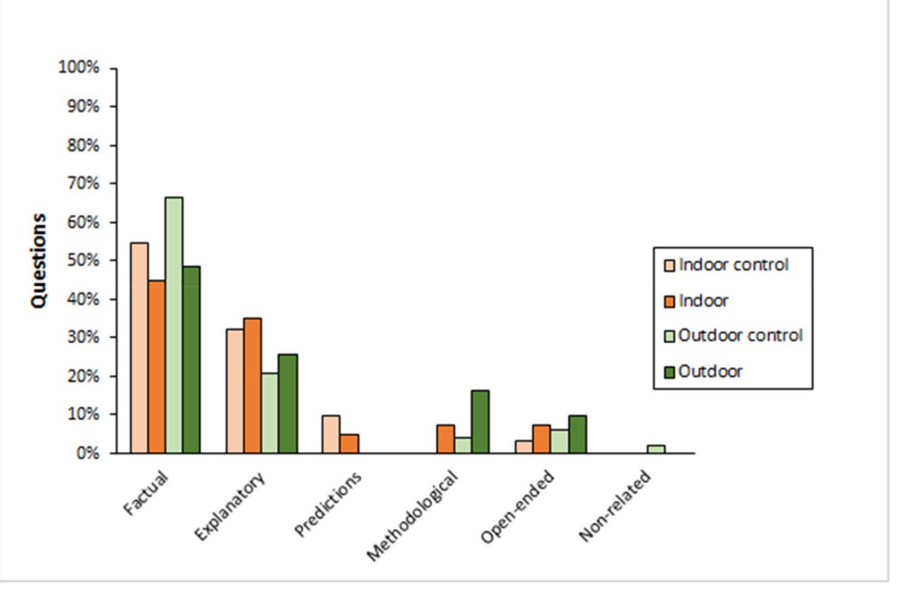
Note. N of Indoor control group = 14, N of Indoor group = 18, N of Outdoor control group = 20, N of Outdoor group = 16, total N = 68. Different letters between groups represent significantly different proportions of questions at the .05 level.

Figure 2. Relation of adolescents' questions to the audio series episodes content by groups of participants.
Note. N of Indoor control group = 14, N of Indoor group = 18, N of Outdoor control group = 20, N of Outdoor group = 16, total N = 68. Different letters between groups represent significantly different proportions of questions at the .05 level.



Note. *N* of Indoor control group = 14, *N* of Indoor group = 18, *N* of Outdoor control group = 20, *N* of Outdoor group = 16, total *N* = 68.

Figure 3. Types of objects in focus in adolescents' questions by groups of participants.
Note. *N* of Indoor control group = 14, *N* of Indoor group = 18, *N* of Outdoor control group = 20, *N* of Outdoor group = 16, total *N* = 68.



Note. *N* of Indoor control group = 14, *N* of Indoor group = 18, *N* of Outdoor control group = 20, *N* of Outdoor group = 16, total *N* = 68.

Figure 4. Types of information requested in adolescents' questions by groups of participants.
Note. *N* of Indoor control group = 14, *N* of Indoor group = 18, *N* of Outdoor control group = 20, *N* of Outdoor group = 16, total *N* = 68.

RQ2: do adolescents perceive their engagement with audio learning materials as an opportunity to learn about nature?

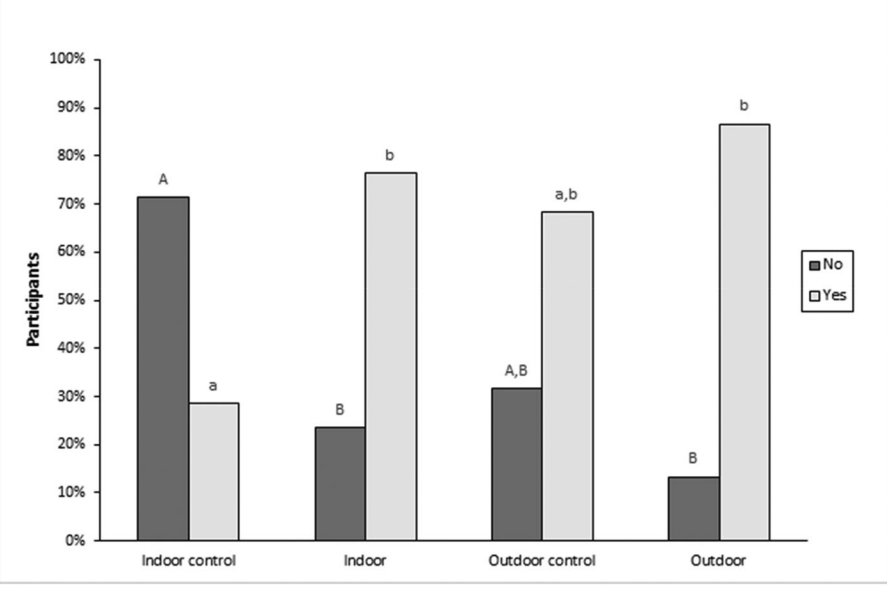
When asked if participants felt they had learned something from the experience (Figure 5), both audio series groups reported high levels of perceived learning (frequency of Indoor group = 76.5%; frequency of Outdoor group = 86.7%). In contrast, around two out of three (68.4%) adolescents in the Outdoor control group expressed perceived learning. Statistical tests show that, between the two indoor groups, the proportion of participants that reported having learned something is significantly higher for the audio series group, $\chi 2$ (1) = 7.112, p = .008. However, between the two outdoor groups, the difference in proportions is not statistically significant, $\chi 2$ (1) = 0.703, p = .402.

RQ3: do adolescents enjoy the use of audio learning materials to learn about nature?

We assessed the two audio series groups' level of satisfaction when hearing the audio series episodes during the intervention. As shown in Figure 6, in both groups, most participants report being very or very much satisfied (frequency of Indoor group = 61.1%; frequency of Outdoor group = 81.3%). Interestingly, some participants in the indoor group reported not being satisfied or only being a little satisfied. However, no statistically significant differences were found between the two groups, $U = 122$, $z = -0.789$, p = .430.

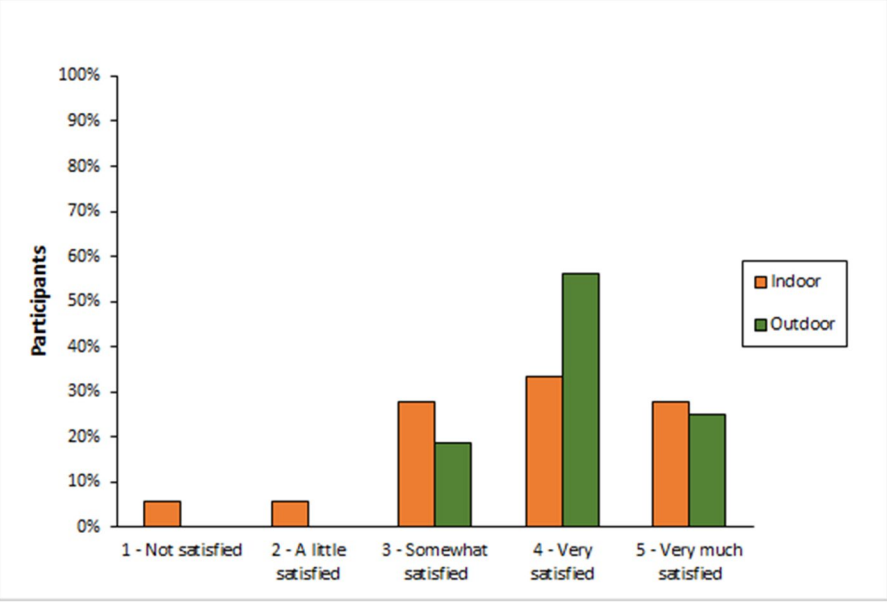
RQ4: Does adolescents' interaction with the audio learning materials result in a desire for continued engagement?

Secondly, we assessed their willingness to hear more audio series episodes about Azorean nature similar to the ones used in the activities (Figure 7). Akin to the satisfaction with the



Note. N of Indoor control group = 14, N of Indoor group = 18, N of Outdoor control group = 20, N of Outdoor group = 16, total N = 68. Different letters between groups represent significantly different proportions of questions at the .05 level.

Figure 5. Level of perceived learning after the experience by participants' groups.
Note. N of Indoor control group = 14, N of Indoor group = 18, N of Outdoor control group = 20, N of Outdoor group = 16, total $N = 68$. Different letters between groups represent significantly different proportions of questions at the .05 level.



Note. *N* of Indoor group = 18, *N* of Outdoor group = 16, total *N* = 34.

Figure 6. Level of satisfaction with the audio series episodes by participants' groups (experimental groups only).
Note. *N* of Indoor group = 18, *N* of Outdoor group = 16, total *N* = 34.

audio series, the majority of participants in both groups are very or very much willing to hear more episodes (frequency of Indoor group = 72.2%; frequency of Outdoor group, 68.8%), and only in the indoor group, some participants are not willing at all or only a little willing to hear more. However, no statistically significant differences were found between the two groups, $U = 135$, $z = -0.340$, $p = .734$.

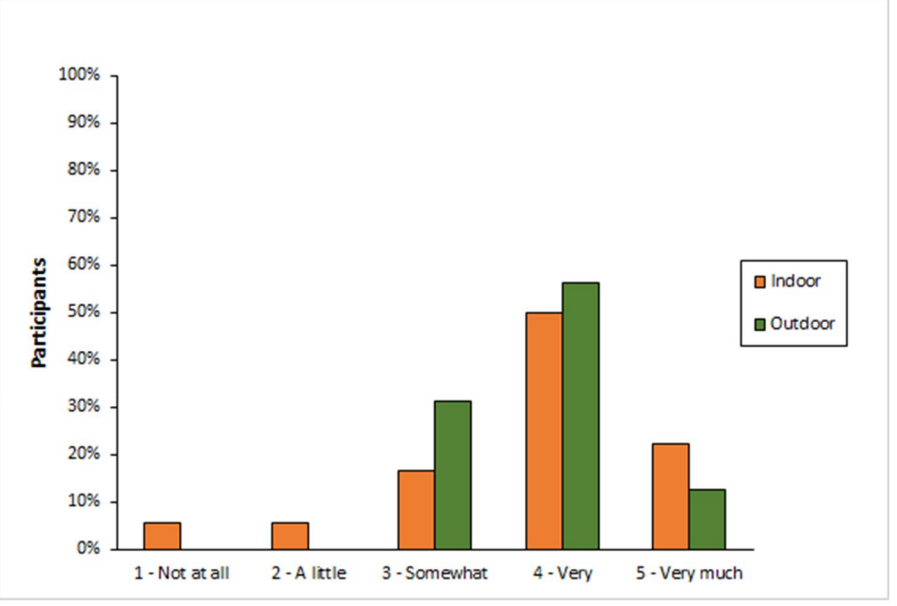
Additionally, we assessed participants' willingness to recommend the audio series episodes to others (Figure 8). For this indicator, both groups have similar proportions of participants who are very or very much willing to recommend the audio series (frequency of Indoor group = 88.9%; frequency of Outdoor group = 81.3%). Again, only in the indoor group some participants are not willing at all or only a little willing to recommend the audio series. Even so, no statistically significant differences were found between the two groups, $U = 106$, $z = -1.450$, $p = .147$.

We also asked all participants what they liked most from the experience. Several topics emerged from their responses (Figure 9). About one-third of the participants that had access to audio learning materials expressed having liked everything (frequency of Indoor group = 37.5%; frequency of Outdoor group = 26.7%). Of these two groups, in the Indoor group, more participants highlighted the audio series than in the Outdoor group (50.0% versus 6.7%).

Finally, the Outdoor group seems to have enjoyed most the experience of being in nature (26.7%) and exploring the nature trail (20.0%). The same for the Outdoor control group that enjoyed nature (16, 47.1%) and the nature trail (23.5%). Control groups were the ones who highlighted the App the most, as well as the act of posing questions and the manual activities (for the Indoor control group).

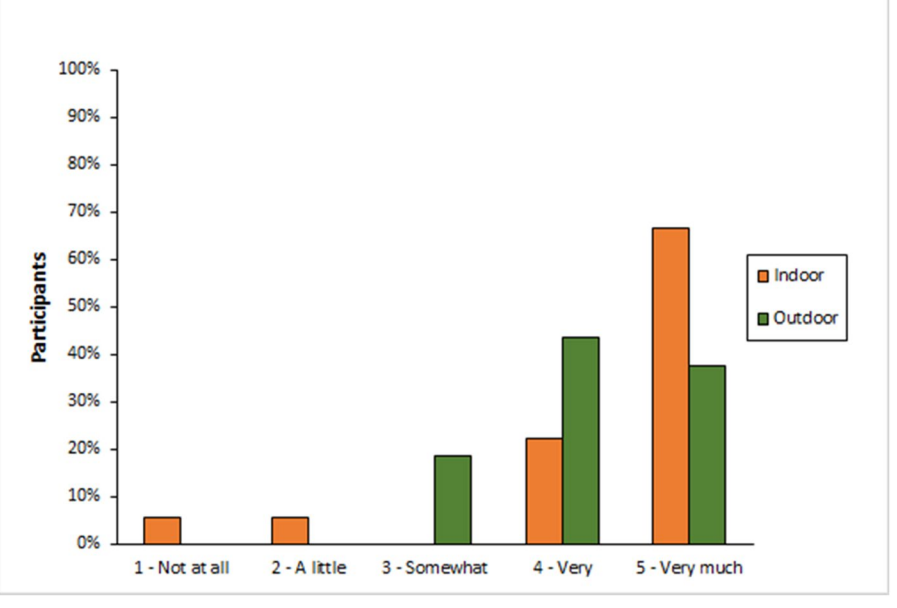
Discussion

Time outdoors is crucial in the early development of our interest in and positive attitudes toward nature (DeVille et al. 2021); however, today's adolescents spend more time indoors in front of screens instead of outdoors connecting to nature, leading to growing alienation from



Note. *N* of Indoor group = 18, *N* of Outdoor group = 16, total *N* = 34.

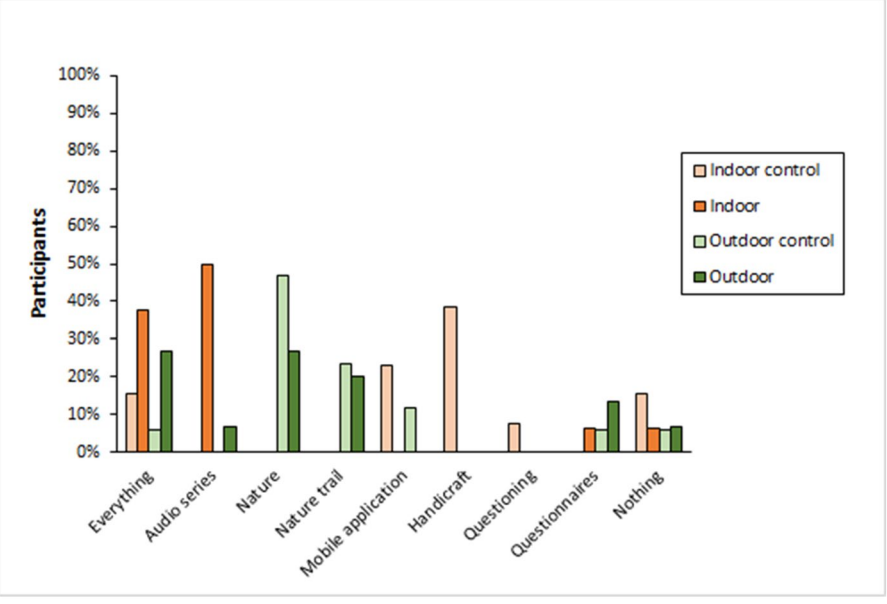
Figure 7. Willingness to hear more audio series episodes about Azorean nature by participants' groups (experimental groups only). *Note.* *N* of Indoor group = 18, *N* of Outdoor group = 16, total *N* = 34.



Note. *N* of Indoor group = 18, *N* of Outdoor group = 16, total *N* = 34.

Figure 8. Willingness to recommend the audio series episodes to others by participants' groups (experimental groups only). *Note.* *N* of Indoor group = 18, *N* of Outdoor group = 16, total *N* = 34.

nature (Larson et al. 2019; Rideout 2016). One way to overcome this is by using digital technologies' motivational capabilities to redirect our attention towards the outdoors and to the exploration of surrounding natural environments. In our study, we intersected mobile learning



N of Indoor control group = 13, *N* of Indoor group = 16, *N* of Outdoor control group = 17, *N* of Outdoor group = 15, total *N* = 61.

Figure 9. Positive highlights that were expressed by participants' groups regarding the whole activity.
N of Indoor control group = 13, *N* of Indoor group = 16, *N* of Outdoor control group = 17, *N* of Outdoor group = 15, total *N* = 61.

with place-based education to create audio learning materials tailored to adolescents. Our goal was to allow learners to explore their surroundings, learn about biodiversity by experiencing local nature-rich environments, and connect them with peers and local experts. Following Zimmerman and Land's (2014) design guidelines and Hidi and Renninger's (2006) principles fostered the creation of a learning experience enjoyed by participants that promoted their exploration of an environment and its underlying natural processes.

More specifically, we tested a mobile application to disseminate place-based audio-learning materials to spark adolescents' interest in local natural environments. Our focus was to create a community-relevant platform that allows learners to explore local natural environments while learning about more general natural phenomena and connecting with peers and local experts to develop their critical thinking and interest in learning more about nature. Creating an environmental education audio series based on adolescents' questions about nature promotes their engagement with the learning materials since they were meaningful to them. As Hidi and Renninger (2006) discuss, personal relevance is one of the critical factors for interest development.

Through this study, we wanted to understand the impact of audio-learning materials on promoting interest in nature. In addition, we were curious to learn whether adolescents perceived their engagement with the audio-learning materials as an opportunity to learn about nature. Although participants with access to the audio series did not ask significantly more questions than the control groups, their level of perceived learning was considerably higher. When analyzing questions posed by the adolescents with access to the audio series, we conclude that participants were engaged with and paying attention to the learning materials since their questions were significantly more related to the content of the audio series episodes than questions from control groups. Since individual questions can present a gateway into a person's interests (Baram-Tsabari et al. 2006; Chin & Osborne 2008; Swirski et al. 2018), we argue that the audio series effectively sparked participants' situational interests in the themes presented.

Based on the content of participants' questions, the audio series seems to have a higher impact on topics such as volcanic eruptions. Hearing an audio series episode about these topics encouraged learners to ask more questions about them. Baram-Tsabari et al. (2006) demonstrate that topics such as botany, mycology, anatomy, and physiology are among the most common in students' questions; our study corroborates this since questions focusing on species and biodiversity were also the most common in all groups of participants.

Furthermore, Baram-Tsabari et al. (Ibid.) also found that factual and explanatory questions are among the most common. While Zimmerman et al. (2015) found that perceptual and conceptual orientated dialogue are the two most common types of conversations amongst families interacting with m-Learning devices in outdoor settings. Our results agree with these studies; however, our data show slight differences between the audio series and control groups. The less complex questions (factual) are more present in the control groups, and the more complex (explanatory, methodological, and open-ended) are slightly more present in the audio series groups, but with no statistical differences. The application of audio learning materials to larger samples could reveal more significant differences. It is important to note however that we used the recommended corrections for small samples, as mentioned in the methodology section (page 14). And even though from a statistical point of view, the Pearson's Chi-square tests ($\chi 2$) test on small samples can sometimes produce falsely significant differences this did not happen.

We were also committed to understanding whether adolescents enjoy the use of audio learning materials to learn about nature and if their interaction with the audio learning materials result in a desire for continued engagement. Our results demonstrate that adolescents enjoyed the audio series and were willing to hear more episodes. As in the work of Hidi and Renninger (2006), we, therefore, argue that the proposed learning materials have the potential for continued engagement since participants present a willingness to hear more episodes. Participants with access to the mobile learning materials were also the ones who emphasized everything when asked to identify the most positive aspect of the learning activity (Fig. 9). The mobile learning materials seem to have improved the enjoyability of the whole learning activity, as Anderson et al. (2015), Crawford et al. (2017), and Ruchter et al. (2010) have also found.

Additionally, the indoor group highlighted the audio series more than the outdoor group. One could explain this result by drawing on the audio series' ability to redirect learners' attention to the surrounding environment since the outdoor group highlighted more nature and the nature trail than the audio series. For the outdoor group, the mobile audio learning materials served as enhancers of nature exploration, which is also in accordance with Zimmerman and Land (2014). When comparing the two outdoor groups, we observe that the control group also enjoyed nature and the nature trail; however, the audio series group enjoyed the learning activity more than the control group. The evidence we collated so far indicates that providing the audio mobile learning materials within a nature-rich environment and within the context of outdoor nature activities has greater potential to lead to an improved learning experience.

When comparing groups' satisfaction with the audio series, the indoor group shows lower satisfaction levels than the outdoor group, even though this is not statistically significant. One can explain this, considering the audio-learning materials were place-based, and only the outdoor setting expressed their characteristics, promoting more focused attention on the surrounding environment and a more enjoyable learning experience (Kawas et al. 2019; Zimmerman et al. 2015).

When applying audio learning materials to outdoor environmental education using the location-based capabilities of mobile devices, we, therefore, recommend the following points already present in the relevant literature. Firstly, evaluate the capabilities of mobile devices and platforms to make the most use of its advantages to redefine and create new learning activities that are enjoyable and keep learners engaged with the surrounding environment (Tlili et al. 2022; van Kraalingen 2021). Secondly, design mobile learning materials with community-relevant topics and tailored to local places (Zimmerman & Land 2014). Thirdly, use mobile learning with

intentionality and only when relevant, mobile learning materials should encourage the exploration of natural environments and not substitute them (van Kraalingen 2021). Finally, make use of mobile technologies' interactivity and connectivity capacities to foster social interactions and promote continued engagement (Hidi & Renninger 2006; Zimmerman & Land 2014).

We add to the above points the importance of creating audio learning materials for mobile devices to connect learners to places rich in biodiversity and to the scientific communities that contribute to the study of such places through continued research; this helps improve dialogue and interaction between different stakeholders (scientists and nonscientists), making questions about nature more approachable to adolescents. We designed the Field Guide project app to connect adolescents living within island communities while offering a platform to share their questions regarding nature with scientists. Sharing knowledge and curiosity regarding a specific place is critical to our proposal.

Recalling the words of mathematician and statistician John W. Tukey: 'finding the question is often more important than finding the answer' (Tukey 1980 cited in Bissonette 1999). We believe the lack of statistically significant data in our study begs further questioning that could set forth new hypotheses for future studies. If, on the one hand, we can conclude that the audio learning materials and the underlying mobile learning experience promoted learning, did they bring our participants closer to nature? We find voices within environmental education that recognise digital interactive technology's role in getting young people closer to nature. However, what happens when technologically-mediated experiences overlap with the nature-rich contexts we hope to make visible to a younger generation? Then it may not contribute to reapproach.

As an alternative entry point to the discussion regarding environmental education and mobile technology, we believe our contribution points towards the concept of place as a departing point for the design of learning materials, audio-based or otherwise. In the specific context of this study, we ask whether audio-learning materials that resourcefully use the location-based capabilities of mobile devices can offer access to a terrain that seeks to use technology to contribute to adolescents' renewed sense of place. By proposing both natural environments and community as contexts for learning, we ask whether technology can leverage the outdoors in ways that allow younger generations to develop what Russ (2015) describes as **'**ecological place meaning**'**, a process that presupposes a continued appreciation of the **'**ecosystem-related phenomena**'** that are key to the places we inhabit.

Conclusion

The environmental educational community has long vested energy in the debate concerning the use of mobile technologies (Bolliger et al. 2021; Cuthbertson et al. 2004; Hills & Thomas 2020; Midgley 2014). Even though a body of literature recognizes its benefits (Crawford et al. 2017; Santos et al. 2014; Viberg et al. 2021), our view was to contribute to the discussion of concrete examples and applications. In doing so, we conclude that audio-learning materials tailored for mobile devices and local communities and places can encourage adolescents to learn about nature while exploring local natural environments and sparking their curiosity and questioning concerning nature. Nonetheless, our study has pedagogical implications for how we might position the concept of place as both environment and a set of human relations within both formal and informal learning contexts. Besides the practical implications of our work, we conclude our contribution by pointing towards what authors Mannion and colleagues identify as a 'place-responsive pedagogy' (2013), whereby there is an effort to position specific environments at the forefront of teaching and learning activities "with the aim of understanding and improving human-environment relations" In addition, such an approach can potentially connect adolescents with a 'community of place', in this case, by allowing adolescents to ask

questions that scientists vested in the study of local places can answer and by creating content that draws on the interests of communities of local adolescents.

We also infer that although adequate in indoor settings, such as classrooms, audio learning materials are better enjoyed outdoors, for example, on a nature trail. This finding is particularly relevant for informal environmental education that fosters contact with nature, where the power of motivation plays a crucial role. In adopting this view, audio learning materials that make use of the location-based capacities of mobile devices, have potential as crucial mediators of experience in nature-rich contexts. We believe this dimension of interactive digital technology is particularly relevant for informal outdoor education that takes place accidentally, sporadically, and connected to places with local relevance. Since there is little research on the effectiveness of audio-learning materials in environmental education, we believe this study is particularly relevant since these materials can potentially engage adolescents with their local natural environments and promote their interest in learning more about local nature through community interaction.

Acknowledgments

We want to thank all the Scouts who participated in this study and their respective heads. Here we acknowledge the participants from the groups of Santa Bárbara (number 630), Agualva (number 154), Biscoitos (number 793), Base Aérea das Lajes (number 111), Terra Chã (number 590), and São Sebastião (number 652). As well as participants and tutors from the youth camps 'Geokids', 'O Gu e a Tita', and 'Olhar Poente'. The data collection procedure wouldn't be possible without the help of the research volunteers: Raquel Lopes Rodrigues, Ana Luísa Picanço, Enésima Pereira, Antónia Requena, Cristiana Araújo Amorim, and Miguel Ángel Gómez Molinero. We acknowledge the collaboration of the local radio station 'Antena 1 Açores' in the production of the Field Guide audio series, in particular, Lena Goulart and Carlos Sousa, as well as the participation of local radio host João Saavedra in all audio series episodes. We are very thankful for the contribution of the following scientists to the content development of the audio series: António Frias Martins, Rui Bento Elias, Alfredo Borba, Avelino Ormonde, Débora Henriques, José Carlos Fontes, Francisco Cota Rodrigues, Eva Lima, Paulo A. V. Borges, Emiliana Silva, Tomaz Ponce Dentinho, David João Horta Lopes, João Pedro Barreiros, Ana Luísa Picanço, António Félix Rodrigues, Jorge Alberto Pinheiro, Francisco Maduro Dias, and José Manuel Neto Azevedo. We thank Alexandra Baixinho for her contribution as an external judge in the inter-rater tests. At last, we would like to thank the reviewers for their thoughtful comments and for helping us improve the manuscript.

Disclosure statement

The authors have declared that no competing interests exist.

Funding

Field Guide was supported by FCT - Fundação para a Ciência e a Tecnologia a Portuguese public agency that supports science, technology and innovation, in all scientific domains. FCT project reference number: PTDC/CED/EDG/31182/2017. Author Isabel Amorim do Rosário was funded through FCT I.P., under the Norma Transitória – DL57/2016/CP1375/CT0003.

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