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EXAMINING THE IMPACT OF SPHERICAL VIDEOS IN TEACHING ENDANGERED SPECIES/ENVIRONMENTAL EDUCATION TO PRIMARY SCHOOL STUDENTS

Emmanuel Fokides*	University of the Aegean, Rhodes, Greece	fokides@aegean.gr
Melpomeni Kefallinou	University of the Aegean, Rhodes, Greece	mkefallinu@gmail.com

* Corresponding author

ABSTRACT

Aim/Purpose	The study examined whether spherical videos are an effective tool in teaching primary school students subjects related to the endangered species. It also examined their feelings/attitudes towards this tool.
Background	Young students have trouble understanding concepts related to environmental education and, specifically, concepts related to the endangered species. Spherical videos constitute an interesting alternative teaching tool, applicable in diverse scientific disciplines. Additionally, research in this field is rather unsystematic and fragmented, given that the underlying technology is still an emerging one.
Methodology	A three conditions within-subjects design was applied. Forty-nine, nine-to-ten years-old primary school students attending public schools in Athens, Greece were selected to participate in the project. They had never before been formally taught subjects such as the ones included in the study and had no prior experience in using Google Cardboard compatible head-mounted displays. The participating students were taught using printed material, web pages, and interactive applications in which spherical videos were embedded. The project lasted for nine two-teaching-hour sessions (three for each tool). Data were collected using nine evaluation sheets. About a third of the questions in these tests assessed declarative knowledge, while the rest examined procedural and conditional knowledge. A validated scale was also used, designed to evaluate users' experience when using digital educational applica-

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tions. For analyzing the data (from both the evaluation sheets and the questionnaire), several repeated measures ANOVA tests were conducted using SPSS 25.

Contribution By examining the learning outcomes from the use of applications in which spherical videos were integrated, by contrasting their impact on knowledge with other tools, and by quantifying their differences, the present study extends the -rather limited- literature regarding the educational uses of this technology. Given that there is a lack of a well-defined teaching framework, the study contributes towards this end, as a modified version of Bybee's 5Es was tested, with encouraging results."

Findings Post-hoc pairwise comparisons revealed statistically significant differences indicating that students' performance when using the apps was better than their performance in the web pages and printed material. Statistically significant differences were also noted when analyzing the questionnaire's data. In detail, the analysis revealed that the apps were considered more motivating compared with both the printed material and the web pages. The same applied to students' enjoyment. Also, their sense of presence was stronger. Then again, all tools were considered as being equally useful. Finally, no usability issues were reported.

Recommendations for Educators As the development of apps requires time and effort, a large pool of ready-made apps has to become available to educators. Spherical videos have to be used in the context of a well-defined teaching framework. A familiarization period on how HMDs are used and how to run and navigate in the apps will help to avoid usability issues. Education administrators have to implement reforms in the primary school timetable and curriculum, for achieving the seamless integration of this technology to everyday teaching.

Recommendations for Researchers and Developers Motivation and enjoyment can be further enhanced by adding game-like features. Thus, software developers can consider adding such features and researchers can examine their effects. A lot more can be done for making the apps utilizing spherical videos easier to handle and navigate. For example, hand tracking can be used, which is a more natural interaction method.

Future Research Besides larger sample sizes and more interventions, future research can examine the impact of spherical videos on student misconceptions, attitudes, and behaviors towards environmental issues. It would be interesting to examine the views and experiences of educators as well. Longitudinal studies and comparison of spherical videos with other promising technologies would also be useful.

Keywords endangered species, environmental education, primary school, spherical videos

INTRODUCTION

At a time when overpopulation, biodiversity conservation, and natural resources management are major concerns, the study of the environment has become a necessity (Treagust et al., 2016). In this respect, environmental education (EE) is invaluable, since the teaching of environmental problems, especially in primary school, finds students more open to the assimilation of information about the relationship between humans and their natural surroundings (Gray et al., 2016). Also, in order for the next generation to adopt a sustainable lifestyle, students need to engage early in learning activities that allow them to explore and propose solutions to environmental issues (Franquesa-Soler & Serio-Silva, 2017; Treagust et al., 2016).

Although EE has been part of the educational practice for almost thirty years, only recently has come to the fore, due to the socio-political developments (Agbedahin, 2019; Fauville et al., 2014), as swift actions are needed to preserve the environment. On the other hand, there are many difficulties in its implementation, most of which relate to difficulties in the nature of the issues that it discusses. For example, humans have become detached from nature. What is more, most of the time, there is a considerable temporal gap between the occurrence of an incident which is harmful to the environment and the manifestation of its negative impact (Markowitz et al., 2018). As individuals are not able to immediately observe the connection between cause and effect, they get emotionally detached (Brehm et al., 1986; Elif & Muhlis, 2015). Raising students' awareness of endangered species is among the subjects discussed in EE. Then again, students face quite severe problems in this area. For example, they have several misconceptions regarding the classification of species (Chylenska & Rybska, 2018), trouble understanding the effects of the extinction of certain animals (or even of the reduction of their population) (Butler et al., 2014; Munson, 1994), and difficulties in grasping the globality of the phenomenon (Dikmenli & Cardak, 2017).

In EE, conventional teaching is not that effective in bridging the gap between theory and practice; what is missing is access to authentic learning environments, which are considerably more effective (Ateşkan & Lane, 2016). In fact, an array of tools and methods has been used in the context of EE, including but not limited to field trips (Ateşkan & Lane, 2016), videos (Kamil et al., 2020; Kleinhenz & Parker, 2017), storytelling (Lin & Li, 2018), and comics (Topkaya, 2016). The use of ICT tools/applications is also common, given that online courses (McCleery, 2015), digital storytelling (Theodorou et al., 2018), augmented and virtual reality applications (Fokides & Chachlaki, 2020; Vaishnav & Sinha, 2017) have been utilized.

An interesting emerging technology that can be used in the context of EE is that of spherical videos (SVs). In short, SVs (also called 360^{o} videos), surpass one of the fundamental limitations of regular videos, that of the single point of view, given that they are recorded using cameras able to capture images from a whole sphere. When viewing such videos, the users can freely select, at any given time, which part of the scene to view. SVs have the potential to raise viewers' awareness of major issues such as the ones related to the environment (Elmezeny et al., 2018). For the reason that they depict something real, they are preferred over other applications that are based on graphics (Queiroz et al., 2018). Such videos can immerse users in the environment they present (Slater et al., 2009), allowing them to feel present there (Argyriou et al., 2016; Higuera-Trujillo et al., 2017). Besides the positive impact on learning, positive effects on students' commitment to learning, motivation, and enjoyment were also noted (Lee et al., 2017). On the other hand, research on the educational potential of SVs is still at its early stages. This holds true for EE and, specifically, for subjects related to endangered species. Given this lack of research, a pilot study was designed and carried out to investigate whether they can outweigh, in terms of learning, other teaching tools such as printed material and web pages. At the same time, it was considered important to examine students' views on the use of SVs in terms of their sense of presence, motivation, enjoyment, whether they considered them easier to use, and whether they thought that SVs can facilitate their learning. Details for the method that was followed and the outcomes of this project are presented in the next sections.

ENVIRONMENTAL EDUCATION AND EDUCATION ON THE ENDANGERED SPECIES

ENVIRONMENTAL EDUCATION

EE treats the environment as a whole (anthropogenic and natural but also ecological, political, social, economic, technological, cultural, and aesthetic), is a lifelong process, emphasizes on problem-solving, focuses on current and future problems, examines the economic development from an environmental perspective, and promotes cooperation (UNESCO, 1975). EE includes subjects such as climate change, lack of food, risk management, biodiversity conservation, sustainable production and consumption, poverty reduction, degradation of ecosystems, water quality, endangered species, waste management, and availability of resources (Agbedahin, 2019).

However, the implementation of EE is neither easy nor always successful (C.-H. Chang & Pascua, 2016; Franquesa-Soler & Serio-Silva, 2017; Treagust et al., 2016). There are several reasons for this. Urbanization has removed individuals from nature, resulting in conceptual gaps (about the environment) (Gray et al., 2016). It is difficult to associate cause and effect, as, in most environmental problems, it takes a long time until the effects of human activities on the environment are perceived. Therefore, individuals (students included) think that there are no consequences for their actions, or they have trouble understanding how the environmental problems originated and, therefore, they have difficulties in finding solutions for them (Ahn et al., 2016; Markowitz et al., 2018). The emotional distancing of individuals from environmental problems is also an issue. This happens either because the problems are not directly observable, or not found locally, or because the individuals themselves are not directly involved (Ahn et al., 2016).

EE concepts are indeed complex and not easy to grasp. Thus, it is difficult to modify them so as to become easier for students to comprehend (Saheb et al., 2017). Students come to school full of (wrong) ideas and personal interpretations of the natural phenomena and the environment, resulting from their observations (Driver, 1985). Therefore, these wrong ideas have to be identified and remedied, as students often blindly reproduce the knowledge they are taught but do not cease to support their wrong understanding (Brehm et al., 1986). For example, they are unable to define or specify the causes and effects of key concepts such as "ecosystem", "species", "environment", "food chain", "biodiversity", "global warming", and "acid rain" (Visintainer & Linn, 2015; Yücel & Özkan, 2015). They relate "pollution" with the presence of wastes; air, soil, water, and noise pollution, as well as their impact on the flora and fauna, are rarely mentioned (Kilcan & Çepni, 2015). Students have also trouble to make the distinction between the concepts of "climate change", "greenhouse effect", and "global warming" (Boylan, 2008). They attribute climate change only to anthropogenic factors, excluding natural ones (C.-H. Chang & Pascua, 2016). The above signify problems in mastering both core and threshold concepts related to EE. The core concepts are conceptual blocks advancing the understanding of a subject, while the threshold concepts are ideas that their understanding transforms the perception an individual has for a phenomenon/subject (Meyer & Land, 2003). All things considered, it can be supported that EE is full of "troublesome knowledge" as defined by Perkins (1999).

The school textbooks deal with environmental issues rather simplistically, focusing mainly on theories (Elif & Muhlis, 2015; Kao et al., 2017). Then again, if students are not actively involved in activities, they tend to "parrot" the views of their teachers, without being able to understand their context and reasoning (Lundholm, 2006). In cases where activities are envisaged to strengthen the relationship between theory and practice, they may be difficult to implement or require infrastructure and equipment not available at school (Brehm et al., 1986; Elif & Muhlis, 2015; Stanišić & Maksić, 2014).

Educators, mainly at the primary level, are not trained to teach environmental subjects (Stanišić & Maksić, 2014) and often feel incompetent/insecure to help students understand environmental issues

(Cardak & Dikmenli, 2016; Malandrakis, 2017; Treagust et al., 2016). The lack of self-confidence is also often associated with the fact they do not have a wide range of available activities and strategies to apply during teaching (Kennelly et al., 2008). Not only that, but teachers have doubts about the exact meaning of certain concepts (Fiebelkorn & Menzel, 2013; Kao et al., 2017; Markowitz et al., 2018) and misconceptions regarding environmental issues (e.g., their causes, the mechanisms from which they arise, their results, and possible solutions) (Ikonomidis et al., 2012).

EDUCATION ON ENDANGERED SPECIES

As far as animals and endangered species are concerned, students have a considerable amount of wrong ideas. They find it difficult to classify animals into their respective vertebrae classes, often mixing mammals, reptiles, fish, and amphibians (Chyleńska & Rybska, 2018). They seem to have ideas that are incomplete and inconsistent (Dikmenli & Cardak, 2017), or ideas based on stereotypes about the animals' eating habits or how threatening they are (for example, wolfs are "bad" animals because they are dangerous) (Franquesa-Soler & Serio-Silva, 2017; Ruckert, 2016). Besides, students have several wrong ideas for animal relationships. For example, they think that all animals belonging to the same species have the same needs; they are perceived as a group with identical characteristics (Munson, 1994). Students also view animal relationships in an ecosystem as not being competitive, thinking that they have common needs (Munson, 1994). Animals are also viewed as independent organisms; any changes in their population affects only them (Butler et al., 2014). Some believe that the change in the population of an animal will affect only those directly involved with it in the food chain (Butler et al., 2014; Munson, 1994). In other cases, they believe that the impact will be minimal if the animal is not "important" (Brehm et al., 1986; Butler et al., 2014; Munson, 1994).

Students do not seem to fully understand the concept of "endangered species", or they seem to confuse it with the term "extinct species" (Dikmenli & Cardak, 2017; Ruckert, 2016). The reasons that an animal is threatened are either unclearly presented, or without coherence (Dikmenli & Cardak, 2017; Ruckert, 2016). Also, students do not seem to comprehend the secondary consequences of an animal's extinction (Dikmenli & Cardak, 2017). Their ability to understand the globality of the phenomenon is limited as well. Either they consider it to be an issue that affects only local species (Dikmenli & Cardak, 2017), or their knowledge is limited to species that receive some publicity (Giovos et al., 2018; Gomes et al., 2019). Moreover, students can usually name as endangered species animals belonging to mammals and not to other vertebrae classes (Dikmenli & Cardak, 2017).

A wide range of tools has been used for the teaching of subjects related to the endangered species and the preservation of biodiversity. Regardless of the tool, most researchers reported a positive impact on student knowledge and attitudes towards animals, or the environment in general. Even lecturing, either by itself or in combination with hands-on activities, seems to be effective (Rakotomamonjy et al., 2014). Storytelling (Lin & Li, 2018) and comics (Richter et al., 2015; Topkaya, 2016) were also utilized. Videos were also found to be effective (both in terms of knowledge acquisition and attitudes) (Kamil et al., 2020; Kleinhenz & Parker, 2017; Leeds et al., 2017), even when the audience had a little contact with the subject and did not participate in other educational programs (Breuer et al., 2017). Field trips are a commonly used strategy. They are considered highly effective as they provide authentic environments and rich experiences (Ateşkan & Lane, 2016). Despite that, field trips often entail several difficulties, including the time required to prepare the excursion and the activities that precede, take place during, or follow it. They also often require financial expenditure in order to be realized and there are cases where participants' safety is a concern (Ateskan & Lane, 2016; Coll, 2016; Jose et al., 2017). The use of printed material seems to be the most common option for the teaching of EE in schools. Studies in which printed material was used together with other means, such as videos or outdoor activities, concluded that students benefited (e.g., Kamil et al., 2020). On the other hand, studies comparing the use of ICT tools with that of printed material, concluded that the former produced better learning outcomes (Azeteiro et al., 2015; Fokides & Atsikpasi, 2016; Oluwadare, 2015). The results were attributed to the fact that the printed material did not effectively combine theory and practice (Elif & Muhlis, 2015; Kao et al., 2017). It also failed to attract the attention of students, as they considered it an outdated medium (Papageorgiou, 2015), somehow disconnected from their everyday lives (L'Astorina & Tomasoni, 2015).

To the above concerns, ICTs can provide some interesting alternatives, given that they are considered environmentally friendly (Rajput et al., 2015). With regard to EE, besides the positive learning outcomes, the use of ICTs has additional advantages such as on-demand availability of information and communication with experts and scientists. Moreover, certain technologies can simulate environments that are hard to visit or do not exist anymore, providing students with even more incentives to learn (Buchanan et al., 2019). Online courses (Azeiteiro et al., 2014; McCleery, 2015), digital storytelling (Theodorou et al., 2018), mobile devices and augmented reality (Schneider & Schaal, 2017; Vaishnav & Sinha, 2017), and virtual reality (Fokides & Chachlaki, 2020), were some of the technologies that were used in relation either to EE in general, or to the education regarding endangered species in specific. For example, when the learning content was delivered through web pages, it seems that, compared with conventional means (i.e., printed material), they are able to produce better learning outcomes and higher students' motivation to learn (C.-S. Chang et al., 2011). Students expressed the view that the web pages allowed them to easily identify the information they were looking for and in less time (C.-S. Chang et al., 2010), while their attitude towards learning appeared to be more positive (Genovia et al., 2018).

SPHERICAL VIDEOS

SVs are videos recorded by cameras able to capture images covering a whole sphere instead of the conventional limited angle of coverage (the angle range a lens can image). Users can then play these videos on their computers (changing the viewing direction using a mouse), smartphones (by moving and turning the phone), and on head-mounted displays (HMDs, by moving and turning their heads) (Siegle, 2019). There are monoscopic SVs in which everything appears to be at the same distance, as well as stereoscopic ones, in which a slightly different view is presented to the left and right eye, producing the sense of depth (Domanski et al., 2017). Hotspots can be added, allowing users to interact with the videos (e.g., loading of another scene, images, and audio) (Geng et al., 2018).

SVs are preferred when self-centered viewing is required (Queiroz et al., 2018), while their use has significantly increased in recent years because they are an easy to produce, low-cost solution (Rupp et al., 2019; Sun et al., 2018). They have been used in diverse learning subjects and scientific domains such as language and foreign language learning (Berns et al., 2018; Huang et al., 2019), chemistry and lab training (Clemons et al., 2019), education on religions (Johnson, 2018), medical sciences (Dawson et al., 2019, Guervós et al., 2019), physics (Wu et al., 2019), training on safety issues (Pham et al., 2018), and engineering (Ardjo et al., 2019), to name a few.

The theoretical framework that guides the use of SVs in education is probably identical with the one that justifies the use of regular videos, namely, the cognitive theory of multimedia learning (Mayer, 2009) and the cognitive load theory (Sweller, 2005). Mayer's theory is based on how humans process information. One of the basic assumptions of this theory, the dual-channel assumption, dictates that we have a visual-pictorial channel for processing images (as well as words displayed on a screen) and an auditory-verbal one for processing spoken words. The limited-capacity assumption, as its name implies, asserts that there is a limit on how many "chunks" of information the brain can process. The active-processing assumption suggests that learning is an active process that involves the selection of the relevant material, which is then organized into visual and/or verbal models; these models are later integrated with prior knowledge. On the basis of these assumptions, Mayer suggested that: (i) individuals learn better with graphics and narration rather than with some graphics, printed text, and narration; (ii) it is better to exclude extraneous material; (iii) cues highlighting the organization of the essential material should be added; and (iv) words and pictures should be presented near rather than far from each other and simultaneously rather than successively.

One of the instructional design's goals is to structure the learning material so as to make it appealing, maximize knowledge retention, and, ultimately, promote students' learning. Then again, as Mayer suggested, humans have limited information processing capacity. This is where the cognitive load theory comes into play. It proposed the concept of "schemas", which are organized blocks of information allowing individuals to retain, in their long-term memory, large amounts of information. Thus, the goal of instruction should be to help learners in developing these schemas (Chandler & Sweller, 1991; Sweller, 2005). In this respect, the educational material has to avoid overloading students with information, thus, increasing the chances of retaining important information. Three types of cognitive load have been identified: (i) extraneous load, that refers to the wasted cognitive effort for learning something not directly connected with the learning outcomes; (ii) intrinsic load, meaning the effort required to represent the material in working memory; and (iii) germane load, that refers to the effort required to actually understand the material. In essence, it is the germane load that leads to the development of schemas. Several solutions have been proposed for avoiding cognitive load when designing learning materials (e.g., segmenting, eliminating redundancy, pretraining, individualizing, weeding, signaling, aligning, and synchronizing) (Mayer & Moreno, 2003). Increased levels of cognitive load are likely to occur when using multimedia material (Makransky et al., 2019; Schrader & Bastiaens, 2012). However, in research related to the use of SVs (Lin et al., 2019), increased levels of germane cognitive load were noted, which is actually helpful in retaining knowledge. That is because the germane load has to be promoted in order for schemas to be acquired and transferred to long-term memory.

A positive impact on learning (e.g., Berns et al., 2018; C.-Y. Chang et al., 2019) and skills (e.g., Parmaxi et al., 2018) was noted in most SVs related studies. This holds true even for abstract concepts (Hodgson et al., 2019) and for students of lower academic achievement (Wu et al., 2019). SVs also seem to have helped in reducing the anxiety levels and negative feelings, for example, the ones associated with first-time use of chemistry laboratory equipment (Clemons et al., 2019). Yet, other studies found that the impact on learning was not that different compared to other tools (Ulrich et al., 2019) or that the results were worst (e.g., Ritter et al., 2019). Moreover, some suggested that it remains unclear whether SVs can help students' self-assessment and self-directed learning (Whittleston et al., 2018). Besides, the integration of SVs into teaching requires the development of an appropriate pedagogy but also good planning (Hodgson et al., 2019). Generally speaking, students characterized their experience of viewing/learning with SVs as positive (Fung et al., 2019; Ulrich et al., 2019), satisfactory (C.-Y. Chang et al., 2019; Huang et al., 2019), authentic, and useful (Clemons et al., 2019; Pham et al., 2018). They also reported that SVs facilitated their learning (Huang et al., 2019).

Many attributed the results (in terms of knowledge, skills, and emotions) to SVs' potential to immerse users in a realistic environment. Immersion in SVs can be spatial, temporal, as well as emotional (Elmezeny et al., 2018). Not only that, but they enhance the feeling of presence (i.e., the sense of being "inside" the digital environment) (Argyriou et al., 2016; Guervós et al., 2019; Higuera-Trujillo et al., 2017). In fact, researchers reported that many participants lost the sense of time and felt completely immersed (Berns et al., 2018). Thus, by offering realistic experiences, SVs provide students with the opportunity to better understand concepts, processes (C.-Y. Chang et al., 2019), and the problems presented to them (Dawson et al., 2019). Furthermore, others argued that SVs managed to attract the users' attention and raised their awareness of social, political, and environmental issues (Elmezeny et al., 2018). Indeed, it was observed that, when viewing SVs, students remained highly focused/concentrated on the learning content (Clemons et al., 2019; Johnson, 2018; Violante et al., 2019). Similarly, many studies concluded that the participants were highly motivated to learn and that they enjoyed using/viewing the SVs (Antlej et al., 2018; Berns et al., 2018; C.-Y. Chang et al., 2019; Huang et al., 2019; Lee et al., 2017; Violante et al., 2019), probably because of the novelty of the experience (Lin et al., 2019). Then again, others suggested that novelty can be a distraction factor, negatively affecting the learning outcomes (Rupp et al., 2016). As far as usability and ease of use are concerned, it was reported that users had no significant difficulties (Berns et al., 2018; Sankaran et al., 2019). However, others advised a familiarization period (Hodgson et al., 2019), as users might have trouble with how to use the applications or how to navigate (Antlej et al., 2018). Different target groups, in terms of age, might have resulted in these contradictory conclusions.

Research regarding the use of SVs in the context of EE is rather limited. For example, Ahmad et al. (2017) considered the development of an application in which a virtual forest environment will be presented using 360^o panoramas, for raising the awareness of endangered flora in Malaysia. Ritter et al. (2019) used an application utilizing SVs, 360^o photos, and 3D objects, for teaching students concepts related to erosion and renewable resources. Similarly, Tudor et al. (2018) used Google Expeditions (360^o virtual tours of locations around the world) for raising the awareness about the impact the large-scale development has on the environment and its implications for the ecosystem. What can be derived from these studies is that students demonstrated a significant improvement in their knowledge level regarding environmental issues. Not only that, but they also became able to suggest actions for the protection of the environment. Moreover, their responses regarding the experience they had while viewing the SVs were overwhelmingly positive. In fact, students stated that they were engaged with the learning content and reported increased comprehension and attention.

Statement of the Problem, Hypotheses Formation

As presented in the preceding sections, students, particularly the younger ones, have trouble understanding concepts related to EE in general and, specifically, concepts related to the endangered species. For example, they find it hard to associate the causes of environmental problems and their effects. They also have incomplete and inconsistent ideas about animals and their relationships. The concept of "endangered species", together with the globality of the phenomenon, is difficult to understand. Finally, it seems that their knowledge is limited to local endangered species or the ones that have received some publicity. On the other hand, SVs constitute an interesting alternative teaching tool, that can be applied in diverse teaching settings and scientific disciplines. Thus far, research in this field is rather unsystematic and fragmented, given that the underlying technology is still an emerging one. Not only that, but a considerable number of the studies presented above, suffered from methodological issues, such as small sample sizes, limited number of interventions, and lack of comparison with other tools (at least with the ones commonly used in EE). Having the above in mind, a project was implemented. It has to be noted that because EE encompasses a vast number of different subjects, it was decided the project's focus would be the study of the endangered species. Its objectives were to examine the following research hypotheses:

- *H1. Compared with other tools, such as web pages and printed material, SVs are more effective in teaching primary school students subjects related to the endangered species.*
- *H2a-e. Compared with other tools, primary school students consider SVs as (a) more useful, (b) more motivating, (c) easier to use, (d) more enjoyable, and (e) they feel more immersed when using them.*

Method

In this research, a three conditions/treatments within-subjects design was applied, meaning that the same subjects were taught using three teaching tools (printed material, web pages, and SVs). This design, compared to a between-subjects approach, is, statistically speaking, more efficient (as it requires smaller sample sizes) and powerful (Greenwald, 1976).

Sample and Duration

As the study's theme was the endangered species, it was decided the sample would consist of fourth-grade primary school students (ages nine to ten). That is because, according to the Greek program of study for primary schools, during this grade, students are taught, for the first time, subjects related to the above. Several public primary schools were contacted, located in Athens, Greece. Their fourth-grade teachers were asked to provide certain data for their students, that would help to form an ordinary and typical sample (Creswell & Poth, 2017). As a result, three classes were selected having in total forty-nine students: (i) who have never before been formally taught the same (or similar) subjects to the ones included in the study; (ii) had no prior experience in using HMDs; and (iii) the classes' average performance and boys to girls ratio were close to the national average and ratio. To ensure compliance with the ethical standards and research rules, approval was granted by the University's ethical committee. Also, students' parents provided their written consent, following a briefing on the study's objectives and methods. The duration of the project was nine two-teaching-hour sessions (three for each tool), from mid-October to mid-November 2019.

MATERIALS

The development of the project's materials was a multi-stage process that lasted several weeks. The within-subjects research design, while it allowed for more power in the statistical analysis, it posed a rather significant problem with regard to the learning material. Having the same group of participants using three different tools meant that they could not be taught the same subjects three times; each time they were going to learn more and the results would be invalid. Yet, teaching different subjects with each tool was also a threat to the results' validity, because one can argue that they cannot be compared. To overcome this problem, three measures were taken. First, given that that the study's theme was the endangered species living in land, sea, and air and that for each tool three interventions were allocated, it was decided each tool would present one animal from each ecosystem (Table 1). Second, the organization (and presentation) of the learning material was the same across the nine sessions. Thus, for each animal, students learned about its basic characteristics, population/geographical spread (past and present), habitat, feeding and mating, its role in the food chain, its importance for the ecosystem it belongs to, threats (natural and anthropogenic), and conservation measures. Also, a "what WE can do to save them" section was included. Third, great care was taken so as the cognitive load and difficulty level of the three tools would be equal. This meant that with each tool, students were to study the same amount of text, facts, figures, names, places, concepts, and so on.

Table 1. The teaching/learning subjects

	Printed material (units/sessions 1, 2, & 3)	Web pages (units/sessions 4, 5, & 6)	SVs (units/sessions 7, 8, & 9)
Land	Brown bear (ursus arctos)	Golden jackal (canis aureus)	Wild goat (capra aegagrus)
Sea	Common dolphin (delphinus delphis)	Mediterranean monk seal (monachus monachus)	Loggerhead sea turtle (caretta caretta)
Air	Griffon vulture (gyps fulvus)	Audouin's gull (larus audouinii)	Dalmatian pelican (pelecanus crispus)

Strictly following the above rules, the material (texts, images, and videos) for each animal was put together and edited, coming from various, yet reliable, sources such as (i) pro-environmental organizations (WWF and Greenpeace) and (ii) national non-governmental organizations dedicated to the conservation of wildlife (e.g., MoM, the Hellenic Society for the Study and Protection of the Monk Seal; Arcturos, an NGO focusing on the protection of bears and wolfs; the Hellenic Ornithological Society; and Archelon, the Sea Turtle Protection Society of Greece). Additional details were drawn from the catalog of Greece's endangered species (Legakis & Margou, 2009). Moreover, considering that the target group was nine-to-ten-years-old students, it was important the material not to exceed their mental capabilities. Thus, when editing it, more emphasis was put on fundamental concepts and facts rather than on minor details, and, whenever possible, easy to grasp examples were included. A textbook was written, presenting the animals to be taught using printed material (units 1, 2, and 3). Because it was impossible to include videos, they were replaced by a series of screenshots and captions.

The material for the next three animals was used for developing a web site (with Google Sites). As for the SVs, several freely available on the Internet were considered, but also several video-clips were recorded using a relatively cheap 360^{o} camera. For the latter, some rather innovative solutions had to be improvised for overcoming certain problems. For example, as it is not allowed for humans to come close to areas where the sea turtles lay their eggs (for not disturbing them), the camera was attached to a remotely controlled toy car which was then put inside a turtle doll. After their initial editing (for removing the unnecessary parts and for adding voice-overs, narrations, and music), the SVs were imported to 3D Vista Virtual Tour (https://www.3dvista.com/). This software allows the development of apps which are, essentially, virtual guided tours. Hotspots were added, which allowed the transition between different scenes and the display of images, texts, and regular videos (Figure 1). There are multiple methods to trigger these hotspots. As in this study, no additional hardware was used other that a certain type of HMDs (see next paragraph), it was selected to trigger these hotspots when users focused on them and held that position for about two seconds. Three apps were developed using this software. Five fourth-grade students (who did not participate in the study), read the textbook, viewed the web pages, and used the apps. On the basis of their comments, minor revisions were made.

For viewing the SVs/running the apps, the participating students used their smartphones together with HMDs similar to Google Cardboard (provided by the project) (Figure 2). These devices are a low-cost system made out of cardboard or plastic with just two lenses and a compartment in which a smartphone is inserted. While not actual HMDs (meaning that they do not have their own displays and electronics), Google Cardboard like devices provided, thus far, easy access to SVs and virtual reality applications to millions of users. Finally, a series of worksheets was written, which included activities related to the animals each unit presented.

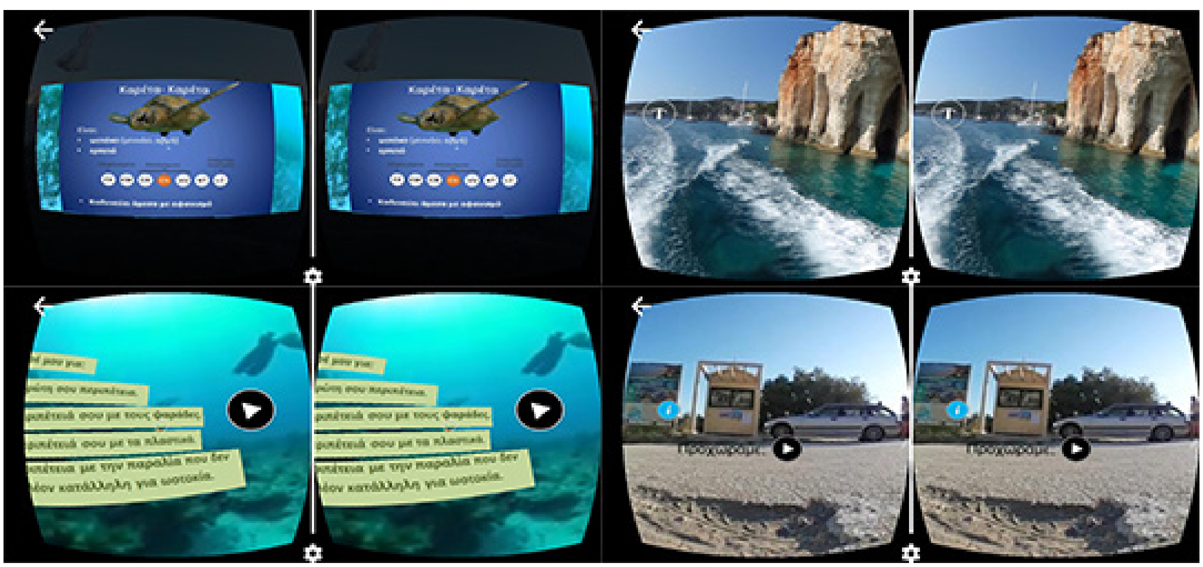

Figure 1. Screenshots from the apps

Figure 2. Students using the apps

Procedure and Teaching Framework

As the sample consisted of students attending different classes/schools, it was considered important to ensure the uniform application of the study's procedures. Therefore, the participating teachers were gathered and it was presented to them, in detail, how to implement the teaching framework described below. Following that, each was asked to simulate a teaching session, while the other teachers acted as "students."

To the first three sessions, the printed material was used, to the next three, students learned through the web pages, and at the last three sessions, they used the apps. Given that students were to use smartphones and HMDs for the first time, one teaching hour was allocated for familiarizing themselves with how to run and navigate through the apps. Additionally, it was decided to allocate two consecutive teaching-hours per session (one and a half hours). First, technical problems are always a concern; thus, it was important to make provisions for some extra time, in order to be able to deal with them if needed. Second, the teaching framework that was followed, by default, requires time for its proper application, for the reason that it includes several stages, activities, and discussions among students. Regardless of the tool that was used, students worked in groups of four (the only exception was when the HMDs were used), given that, in science-related subjects, group-work is strongly advised (Harlen & Qualter, 2014). Bybee et al.'s (2006) 5Es provided the basis for the project's teaching framework, which was modified (by removing one stage), so as to better suit the study's needs:

- As its name implies, the purpose of the Engage stage is to excite students' interest in the subject matter. Therefore, following a short presentation/outline of the topic, the teachers provided relevant examples (drawn from students' everyday life if possible) and urged them to briefly discuss the issues that were raised. This stage lasted for fifteen minutes (maximum).
- The Explore stage allows students to build their own understanding of the subject. To achieve that, students studied the relevant material by reading the textbook, visiting the web

pages, or running the apps (depending on the tool that was assigned to them). All the tools could be used multiple times. Moreover, students used the worksheets corresponding to the unit they were studying, for recording their views and opinions. The duration of this stage was around forty minutes.

- The Explain stage provided all groups with the opportunity to openly express their ideas/opinions/explanations (as recorded in the worksheets) and discuss them with the rest of the class. The objective was to reach a common consensus for the topic of interest. The Explain stage lasted for twenty to thirty minutes.
- A last round of discussions took place during the Evaluation stage, whose purpose was to give teachers an idea of how much learning took place. It has to be noted that, in this stage, students were free to re-run the apps (or re-visit the web pages or re-read the printed material) in case they wanted, for example, to find a piece of information supporting their arguments. Around fifteen minutes were allocated for this stage.

During all stages, the teachers tried to facilitate the learning process; they guided students without manipulating or forcing their views on them, they participated in their discussions as peers, and avoided to provide direct answers to their questions.

INSTRUMENTS

At the end of each session, an evaluation sheet was administered to students (nine in total), for assessing what they were able to learn. Also, a pre-test was administered a week prior to the beginning of the project, for recording their initial knowledge level on all the subjects they were about to be taught. In all tests, about a third of the questions assessed declarative knowledge (e.g., facts and figures, definitions of terms and concepts). Most importantly, the other two-thirds examined procedural and conditional knowledge. For that matter, these questions were significantly harder to answer, required critical thinking, and bringing together different pieces of information presented throughout the session. For example, students were asked to develop their own concept maps, make suggestions for resolving problems that threaten a species, give their own opinion on a matter, and justify it. An initial pool of questions to be considered for inclusion in the evaluation sheets was formed, including questions suggested by both the participating teachers and the authors. Then, several drafts were assembled and discussed prior to establishing the final version of each evaluation sheet.

For recording students' views and feelings for the SVs (i.e., for examining H2a-e), a questionnaire was used. It included five factors (out of the twelve) of a validated modular scale designed for evaluating users' experience when using digital educational applications (Fokides et al., 2019). Three items examined motivation, four items examined presence, while ease of use, fun/enjoyment, and subjective usefulness were examined using six items. All items were presented on a five-point Likert-type scale (anchored by 1 = strongly disagree and 5 = strongly agree). The questionnaire was administered three times (one for each tool).

RESULTS

As it was mentioned in a preceding section, forty-nine students (twenty-two boys and twenty-seven girls), nine-to-ten years old, participated in the study, by attending nine two-hour teaching sessions (three for each tool). None of the participants was excluded from the subsequent data analysis given that none was absent in any session. For obtaining data, the evaluation sheets were graded on a 0-100 scale. Next, three variables were calculated, representing the average performance of each student in each of the three tools and the resulting data were inserted into SPSS 25. Table 2 presents descriptive statistics for the average scores in the evaluation sheets and the pre-test. For examining H1, a one-way repeated measures ANOVA test was to be conducted. Before doing so, it was checked whether the data met the assumptions for this analysis. No issues were found as there were no outliers, the data were fairly normally distributed, and the Mauchly's test of sphericity indicated that the variances of the differences between all possible pairs of within-subject conditions were equal (Mauchly's $W =$

.916, x^2 = 4.11, p = .128). The analysis revealed that there were statistically significant differences among the three tools [$F(2, 96) = 23.23$, $p < .001$].

For probing further into the results post-hoc pairwise comparisons were conducted (Table 3). It has to be noted that the *p* values reported below, are Bonferroni adjusted, a method that conservatively adjusts the significance levels, depending on the number of repeated analyses (Bland & Altman, 1995). The pairwise contrasts revealed that students performed better when using the apps (M = 62.05, SD = 17.23) than when using the web pages (M = 50.81, SD = 15.96, $p < .001$) and the effect size was medium to large (d_{Cohen} = 071). The same applied when the results from the use of the apps were compared with the results from the use of the printed material (M = 55.41, SD = 17.76, p = .001). The effect size, in this case, was small (d_{Cohen} = 0.37). Given the above, H1 was confirmed.

Table 2. Descriptive statistics for the evaluation sheets

Teaching tool	Evaluation sheets' scores			
	Min	*Max*	*M*	*SD*
Pre-test	13.75	76.25	40.71	15.71
Printed material	6.67	84.58	55.41	17.76
Web pages	17.50	86.67	50.81	15.96
SVs	21.40	91.08	62.05	17.23

Table 3. Post-hoc pairwise comparisons

Post-hoc comparisons							
Tool (x)	**Tool (y)**	**Mean Difference (x-y)**	**Std. Error**	***p***	***d_{Cohen}***	**95% Confidence Interval for Difference**	
						Lower Bound	Upper Bound
Printed material	Web pages	4.60	1.40	.006	0.26 (small)	1.126	8.07
	SVs	-6.64	1.75	.001	0.37 (small)	-10.98	-2.31
Web pages	SVs	-11.24	1.80	< .001	0.71 (medium-large)	-15.71	-6.78

Notes. p = Bonferroni adjusted significance level; d_{Cohen} = Effect size, Cohen's d for repeated measures

Prior to analyzing the results in the questionnaire, its internal consistency was assessed using Cronbach's alpha and it was found to be acceptable (a = .767), given that values exceeding the .700 threshold are considered adequate in most social science research situations (Taber, 2018). The reliability scores of the five factors were also acceptable (ranging from a = .758 to .803). For examining H2a-e, fifteen variables were computed representing the average scores of the factors' items (five factors X three tools) (Table 4).

Table 4. Descriptive statistics for the questionnaire's factors

Factor	Printed material		Web pages		SVs	
	M	*SD*	*M*	*SD*	*M*	*SD*
Subjective usefulness	4.07	0.73	4.14	0.64	4.19	0.54
Motivation	3.86	0.88	3.90	0.84	4.35	0.74
Subjective ease of use	3.78	1.13	3.32	0.88	3.40	0.65
Enjoyment	3.83	0.81	3.79	0.79	4.22	0.65
Presence	2.23	1.01	2.20	1.03	3.15	1.02

The data were not normally distributed and the sphericity assumption was violated in all cases. In light of the above, it was decided to conduct a series of Friedman's tests by ranks which is the nonparametric equivalent of the one-way ANOVA with repeated measures. On the basis of the results, H2a had to be rejected, as there were no statistically significant differences in subjective usefulness ($\chi^2 = 0.71$, $p = .702$). Therefore, it is concluded that students considered the three tools as equally useful in their learning. On the other hand, statistically significant differences were noted in enjoyment ($\chi^2 = 10.24$, $p = .006$), subjective ease of use ($\chi^2 = 11.66$, $p = .003$), motivation ($\chi^2 = 13.43$, $p = .001$), and presence ($\chi^2 = 27.03$, $p < .001$). As with the evaluation sheets, a series of post-hoc comparisons was conducted, for revealing differences among tools. It was found that:

- The printed material and web pages were equally motivating ($p = 1.000$). On the other hand, students thought that the apps were more motivating than both the printed material ($p = .016$, $d_{Cohen} = 0.57$-medium) and the web pages ($p = .014$, $d_{Cohen} = 0.66$-medium). Given these results, H2b was confirmed.
- Ease of use. The use of the printed material was easier than that of the web pages ($p = .009$, $d_{Cohen} = 0.52$-medium) and the apps ($p = .040$, $d_{Cohen} = 0.46$-medium). Moreover, students deemed that the web pages and the apps were equally easy to use ($p = 1.000$). Thus, H2c was rejected.
- Enjoyment. Students equally enjoyed the printed material and the web pages ($p = 1.000$). Then again, they considered the apps more enjoyable than both the printed material ($p = .022$, $d_{Cohen} = 0.57$-medium) and the web pages ($p = .040$, $d_{Cohen} = 0.70$-medium). Therefore, H2d was confirmed.
- Presence. The feeling of presence was significantly stronger in the apps than in the printed material ($p = .001$, $d_{Cohen} = 0.88$-large) and the web pages ($p < .001$, $d_{Cohen} = 0.92$-large). No differences were noted when comparing the printed material and web pages ($p = .867$). Thus, H2e was accepted.

DISCUSSION

The data analysis confirmed the most important of the research hypotheses, namely, that the viewing of SVs leads to better knowledge gains and retention versus other teaching tools. Also, some other stimulating results emerged, as discussed in the paragraphs to follow.

An interesting observation comes from students' scores in the pre-test. They were able to give correct answers to just about 40% of the questions (see Table 2). One has to be reminded that the animals included in this study were by no means "exotic;" on the contrary, they are all well-known animals living in Greece. Additionally, these animals routinely receive publicity in the national mass media. Somehow it was expected, but disproved, that students will already have an established basis of background knowledge/understanding for these animals (e.g., their habitat, the dangers they face, and preservation measures). A closer inspection of the erroneous answers revealed that, in most cases, these reflected the wrong understandings and problems reported in the relevant literature, including but not limited to, inability to connect cause and effect (Ahn et al., 2016), failure to understand the consequences to an ecosystem due to changes in the population of an animal (Butler et al., 2014; Munson, 1994), manifestation stereotypes about animals (Franquesa-Soler & Serio-Silva, 2017; Ruckert, 2016), and failure to grasp the concept of "endangered species" (Dikmenli & Cardak, 2017; Ruckert, 2016). Up to a certain degree, the above holds true for the evaluation sheets as well. Although the examination of the underlying reasons for students' limited prior knowledge was beyond the study's scope, it can be inferred that what they were able to learn by themselves (mostly outside school, as students of this age are not previously taught subjects related to the endangered species), was not enough. Thus, it is logical to assume that systematic teaching on such subjects is definitely needed. Indeed, the questionnaire results indicated that students considered all tools as equally useful. A plausible interpretation of this finding is that because students understood that they did not know much, they appreciated the chance they had to learn something by using these tools.

Taking the results in the pre-test as a reference point, the results in the evaluations sheets demonstrated that, depending on the tool, there was a small up to a noteworthy positive change in students' knowledge (24% in the web pages, 36% in the printed material, and 52% in the SVs). Unfortunately, on average, many of the questions were still wrongfully answered (38% in the SVs, 45% in the printed material, and 49% in the web pages). Whether these outcomes, as a whole, or, specifically, in relation to the effectiveness of SVs, were satisfactory or not, is a matter of deliberation. In fact, they are open to two opposing interpretations. One might support that the printed material also had an impact on students' knowledge that cannot be overlooked; therefore, it cannot be rejected on grounds of not being a useful educational tool. A skeptic might add that the rather considerable time and effort invested in the development of the apps, as well as the additional costs for HMDs, and, probably, for smartphones, outweighs their usefulness/effectiveness. In this respect, it would be wiser to reject "fancy" tools (such as the SVs) and keep using the ones that are easy to implement and have already proven their value. Still, one can counterargue that even the smallest differences count if we are to succeed in raising students' awareness about subjects related to EE. In this regard, the use of SVs is recommended. The above reflects the ongoing (and still unsettled) debate about the educational value of (almost all) ICT tools. Nevertheless, the statistically significant differences that were observed were in favor of the SVs, although the effect size was small when compared to the printed material and medium when compared to the web pages. More or less, this finding confirms the existing literature for the effectiveness of SVs both in the context of EE (e.g., Ritter et al., 2019; Tudor et al., 2018) and in the context of several other learning domains (e.g., Berns et al., 2018; C.-Y. Chang et al., 2019; Hodgson et al., 2019). Yet, the large percentage of wrong answers is a cause of concern. There are several plausible explanations for this finding. First, it would have been unrealistic to expect prodigious results with just a few interventions. Second, as presented in previous sections, EE subjects (including the ones related to the endangered species) are, by no means, simple and easy to grasp. Finally, two-thirds of the questions in the evaluation sheets were "tricky," checking not only declarative but also procedural knowledge (see section Instruments); it is logical for students to have missed some.

What remains to be discussed is why the SVs yielded better learning outcomes. In line with previous studies, it was found that the feeling of presence was stronger in the SVs (e.g., Argyriou et al., 2016; Guervós et al., 2019; Higuera-Trujillo et al., 2017; McKenzie et al. 2019; Rupp et al. 2016). This finding offers a rather convincing answer to the above question. That is because presence allows users to have more realistic/authentic experiences, giving them the opportunity to understand concepts, processes, and problems (C.-Y. Chang et al., 2019; Dawson et al., 2019). It was, more or less, expected that students will be more motivated to learn and will enjoy the use of the apps/SVs more than the other tools. On the basis of the results in the questionnaire, these assumptions were confirmed. What is of interest, is that past research in SVs has highlighted the strong connection between fun, motivation to learn, and positive learning outcomes (Antlej et al., 2018; C.-Y. Chang et al., 2019; Huang et al., 2019; Lee et al., 2017). Thus, the elevated levels of enjoyment and motivation found in this study offer two valid explanations for the better learning outcomes students had when they used the apps.

One might also suggest that the teaching method offers another probable explanation. Indeed, Bybee et al.'s (2006) 5Es and group work are highly recommended teaching approaches in science-related subjects (Harlen & Qualter, 2014). On the other hand, the same method was applied to all tools. Consequently, it can be assumed that its contribution to the results was equal across all tools. Still, the teaching framework might have had an indirect positive contribution to the results in the SVs. While the novelty of the experience increases enjoyment (Lin et al., 2019), which, in turn, might increase knowledge gains, researchers have advised caution because students might get distracted from what they are supposed to learn (Rupp et al., 2016). Then again, in the study at hand, students did not only watch some SVs but they also had to work as a team, record their views on subjects related to what they watched, present, and discuss them with the rest of the class. Presumably, as the teaching framework intertwined SVs with organized in-classroom activities, this helped students to be more focused and pay more attention, thus, avoiding distraction's negative effects.

Finally, another indirect positive contribution to the results comes from the lack of usability issues. The mean of students' responses in the questions regarding ease of use (M = 3.40, SD = 0.65), pointed towards the conclusion that there were no overt problems. Moreover, it was found that the web pages and the apps were equally easy to use. In general, users find relatively easy to use and navigate in apps in which SVs are integrated (Berns et al., 2018; Sankaran et al., 2019). On the other hand, given that the sample was primary school students without any prior experience in using such apps (and HMDs for that matter), it was decided to allocate a teaching hour for familiarization purposes, as advised by others (Hodgson et al., 2019). By doing so, it was theorized that the quality of students' experience would be positively affected. The quality of user experience is known to affect motivation, enjoyment, and learning outcomes in many types of ICT applications (Fokides & Atsikpasi, 2018).

IMPLICATIONS FOR PRACTICE

It can be argued that the present study extends the -rather limited- literature regarding the educational uses of SVs as it (i) examined the learning outcomes of this technology in relation to EE and (ii) contrasted SVs' impact on knowledge with other tools and quantified their differences. Furthermore, a number of the study's findings might have interesting implications that researchers, software development experts, and educators should consider. For example, it was found that students regarded the SVs as a motivating and fun experience. While these two findings are not uncommon when ICT tools are used for educational purposes and their link with positive learning outcomes is well-established, one should probably consider how both can be further enhanced. A way to achieve that, applicable to most ICT tools, is to add game-like features (Fokides et al., 2019). In this respect, software developers can consider adding such features in apps utilizing SVs and researchers can examine their effects. Then again, caution is advised, because there is always the chance students to be overwhelmed by the novelty of the experience that the SVs provide and ignore the learning content (Rupp et al., 2016). Thus, by adding game-like features to the equation, the effects might be even more adverse. It was found that students considered the apps and web pages as equally easy to use. On the other hand, a lot more can be done in the field of usability, which might make these apps even easier to handle and navigate. For example, instead of focusing on the hotspots for triggering them, hand tracking can be used, which offers a more natural way to interact (Miller & Bugnariu, 2016), although the trade-off is that this feature is harder to implement and requires additional hardware.

Coming to education per se and on the basis of the results, the integration of SVs into everyday teaching practice seems to be an appealing path. Still, it is wise to take into account several constraints that might affect their successful integration. First, the availability of ready-made apps utilizing SVs is limited. It is true that numerous SVs can be found on the Internet, covering a wide range of subjects, but there is a considerable distance between them and well-organized apps in which additional information and material have been added. On the other hand, on the basis of the experience gained in this study, it can be argued that it is not that hard for an average user to develop such apps. Alas, it is questionable whether educators have the will and the time to do so. Therefore, actions at a higher level are required, so as a large pool of ready-made apps to become available to educators. Second, the tool, by itself, does not guarantee positive learning outcomes. It has to be used in the context of a well-defined teaching framework. The study suggested and tested one such. While far from being perfect, it can be probably used as the basis for the formation of a more robust instructional framework. Third, as with most ICT tools used by (young) students, a familiarization period on how HMDs are used and how to run and navigate in the apps is a prerequisite. Finally, probably the most significant consideration is time availability. Each intervention lasted for two consecutive teaching hours and a total of nine interventions had to fit into an already full and -up to a certain degree- inflexible timetable. Lessons had to be rescheduled or even skipped in order to find the needed hours. As this was a temporary measure, it was accepted -not without reluctance- from the participating teachers and their colleagues, whose schedule was also affected. Yet, if the use of SVs (or of any other ICT tool that requires time for its proper use) is to become common practice, education administrators have to implement rather bold reforms in primary school's timetable and program of study.

LIMITATIONS AND FUTURE WORK

Although the data analysis demonstrated, quite clearly, that SVs have a positive impact on learning, there are limitations to the study that bear consideration. The sample size, even though adequate for the statistical procedures that were followed, could have been larger and more diverse (e.g., in terms of age range). Moreover, the study focused on the endangered species, covering just a fraction of EE subjects. Quite logically, there are reservations for the results' generalizability. EE is not just about knowledge; attitudes and behaviors are, probably, more important. Alas, the impact of SVs on the above was not examined. Neither did the project examine how misconceptions can be eased. Then again, the study was highly exploratory in nature, given that SVs are an emerging technology, not to mention that research on their educational uses is still at its infant stages. These limitations can be used as guidelines for future research endeavors. Additionally, it would be interesting to examine what the educators think about SVs and what are their experiences after using them in their everyday teaching. Longitudinal studies and comparison of SVs with other promising technologies (e.g., fully immersive virtual reality) would definitely be useful.

CONCLUSION

The study of the environment and of the impact that human activities have on it has become a priority. Yet, EE, in general, and, in specific, education on endangered species, are troublesome learning domains; primary school students have several difficulties in understanding key concepts related to both. More than a few conventional and ICT related teaching methods and tools are utilized with the intention of achieving better learning outcomes and for infusing, to students, environmentally friendly behaviors. Among them, videos are quite commonly used. In this respect, SVs, an alternative form of video offering a 360^{o} field of view, constitute an interesting alternative teaching tool. Indeed, past research has indicated that they can be applied in diverse teaching settings and domains. On the other hand, research on their use in the context of EE is rather limited. In order to address this research gap, the study at hand examined the use of SVs in the context of the education on endangered species, by comparing their impact on learning with that of printed material and web pages. For that matter, a project was implemented, that lasted for nine two-teaching-hour sessions (three for each tool), having as a target group forty-nine, nine-to-ten years-old primary school students. The results indicated that the learning outcomes from the use of SVs were better compared with the other two tools. On the basis of the results, it can be concluded that SVs are, under certain circumstances, effective in promoting primary school students' knowledge on the above issues. In short, their effectiveness can be attributed to the fact that they offer an immersive, pleasant, and motivating environment. An instructional framework for integrating SVs into teaching was also proposed and tested. While the study and its findings might prove useful to both educators and researchers, several implications were identified. These were related to the design of applications, the features that need to be included, and their usability. A number of issues related to the primary school timetable and program of study also need to be addressed. In conclusion, there are still unresolved issues regarding SVs' educational potential, leaving room for many future studies in this field.

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BIOGRAPHIES

Dr Emmanuel Fokides is an Assistant Professor in the Department of Primary School Education, University of the Aegean, Greece. His courses focus on the educational uses of emerging technologies, virtual reality, digital storytelling, augmented reality, and serious games. Since 1994, he is involved in a number of research projects regarding distance and lifelong learning and the educational uses of virtual and augmented reality. He is also the founder of the Emerging Technologies in Education initiative (ETiE). His work is published in several conference proceedings, chapters in edited books, and journals. He is also the co-author of two books.

Melpomeni Kefallinou holds a Master's degree in ICT in Education. In addition, she holds a Master's degree in special education. She is interested in the educational uses of immersive technologies and motivated in integrating ICTs into her teaching, in order to accomplish inclusive education and for the students to get inspired in setting and achieving higher goals. She is currently employed as a special education teacher at a primary school in Athens, Greece.