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The Potential of a Mobile Augmented Reality Game in Education for Sustainability: Report and Analysis of an Activity with the EduCITY App

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Abstract: The integration of augmented reality (AR) into education for sustainability curricula not only makes learning more engaging, motivating, and effective, but also equips students with the knowledge and skills to address pressing environmental challenges. This paper presents a case study of a pedagogical approach based on the exploration of an AR game in the EduCITY app and aims to analyse the potential of the 'EduCITY at the UA Campus' mobile AR game in what concerns the promotion of education for sustainability among secondary students. The game was explored in the largest annual event of the University of Aveiro—XPERiMENTA—which invited students and the wider community to participate in activities on the campuses. At the end of the activity, an individual and anonymous questionnaire to evaluate the game was applied. Students indicated that the game raises an awareness of sustainability and contributes to the development of knowledge and skills in this area. They were motivated throughout the match and managed to get a good performance out of playing. This study adds to the literature on the use of AR games in education for sustainability, by revealing that it can be an effective tool for engaging and motivating students with sustainability-related learning.

Keywords: mobile augmented reality game; education; sustainability; EduCITY

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1. Introduction

Education for sustainability should have a central role to empower learners to take informed decisions and responsible actions for environmental integrity [1] through engaging and motivating students in this issue. To achieve sustainability, education has a crucial role. An action-oriented transformative pedagogy should be developed, including elements such as self-directed learning, participation and collaboration under a social constructivism approach, problem-orientation, an inter and multidisciplinary approach, and linking formal and informal learning [2].

Currently, in today's society, data and communication technologies have become practically valuable across all social sectors, with a particular impact on education. Mobile devices offer the potential for the seamless integration of interactive digital content with the physical environment, thereby creating augmented reality (AR) experiences. This represents an innovative approach to education [3]. The combination of mobile devices and AR, coupled with gamification, proves effective in engaging learners [3,4].

Mobile AR games (MARGs) offer a unique opportunity to engage learners in immersive experiences that are valuable in an educational context. They can facilitate new experiences in non-threatening scenarios, support school learning, and foster competencies such as problem-solving and decision-making [4]. In education for sustainability, games have the potential to enhance awareness, facilitate learning, and influence behavioural change [5]. MARGs in outdoor collaborative learning activities present significant potential for educational and tourism purposes [5,6].

The objective of this study is to make a contribution to research in the field of education, with a particular focus on education for sustainability and the use of technologies. To this end, a case study has been conducted which employs the use of an AR game and an app, namely the EduCITY app. The EduCITY project is an interdisciplinary initiative that employs innovative learning strategies in the context of outdoor education for sustainability. It merges traditional teaching methods with mobile learning and AR technology in urban settings [7]. The project team developed a Smart Learning City Environment comprising four main elements: a mobile app, a web-based platform, educational games, and game creation training. The app allows access to AR content and environmental sensor data, both in free and game modes. In the game mode, users can explore the city through games designed for students and teachers at all levels, from primary to higher education, as well as the general public [7].

The aim of this study is to analyse the potential of the 'EduCITY at the University of Aveiro [UA] Campus' mobile AR game in terms of its capacity to promote education for sustainability among secondary students. To achieve this primary objective, students who participated in the activity were requested to complete a questionnaire survey at the conclusion of the activity. This was done in order to ascertain their views on the contribution of the EduCITY to the fields of education for sustainability [8]. Additionally, the automatically logged data from the EduCITY platform were triangulated with the survey results. This was done to ensure the validation of the results.

The following section outlines the structure of this paper. Section 2 presents a review of the literature on related work, organised into four sub-sections: (i) Augmented Reality in Education, (ii) Mobile Augmented Reality Games, (iii) Mobile Augmented Reality Games in Education for Sustainability, and (iv) The EduCITY Context; Section 3 presents the materials and methods employed. In particular, the procedure of the "EduCITY at UA Campus" game in the XPERiMENTA'24 activity, the participants in the "EduCITY at UA Campus" game in the XPERiMENTA'24 activity and the data collection instruments are discussed. Section 4 presents the analysis conducted and the results obtained, along with any relevant findings. The final section, Section 5, presents a conclusion to the paper, outlines the limitations of the study, and suggests potential areas for future research.

2. Related Work

2.1. Augmented Reality in Education

Augmented reality (AR) has emerged as a technology with significant potential in this society. AR is a technology that enhances the real world with virtual elements, rather than replacing it entirely [9]. Despite the superimposition of virtual objects, the user is able to perceive the real world in a more enhanced manner. The virtual elements complement reality rather than completely replacing it, making it possible to interact with the real world by accessing a virtual environment generated by electronic devices [9]. Completing this idea, the same author states that when content, such as 3D objects, videos or images, is added to conventional knowledge, it contributes to facilitate the learning process. In this regard, numerous researchers have developed pragmatic theories and applications for the integration of AR in educational settings. "In recent years, augmented reality technology has opened up new opportunities for building more attractive and pedagogical learning settings and is regarded as a type of "next generation" pedagogical media for promoting learning quality, especially for outdoor exploration activities" [10] (p. 301). The integration of AR in the educational context offers students an interactive learning environment that is more engaging and motivating. The application of AR techniques has resulted in a significant transformation of the learning process [11].

Integrating AR and engaging students with this type of visualization enhances interaction and boosts their motivation to learn [12]. The learning process becomes easier, and more accurate, enjoyable, and engaging compared to traditional methods [12]. The term "engagement" is defined in the academic literature as a constructivist "meta-construct", whereby students are deeply involved in purposeful activities that lead to

positive learning outcomes, including satisfaction, persistence, academic achievement, and social engagement [13].

The self-paced approach to learning facilitated by AR has the potential to accelerate the learning process and enhance its appeal to students. AR improves student performance, increases satisfaction and motivation for new learning, promotes collaboration and interaction between students and teachers, and stimulates imagination and creativity [14,15]. Therefore, students typically demonstrate a preference for learning environments that engage sensory stimuli and that are characterised by greater interactivity, originality, and authenticity [15].

AR applications can be classified into two different categories: image-based and location-based. Image-based AR is related to image detection and recognition, i.e., it requires specific markers which are usually artificial labels and natural graphics [16]. Artificial labels are a coded image icon. When the marker is detected, a virtual element is generated by the chosen AR software. Location-based AR, on the other hand, generates a set of information via wireless localisation or global positioning system (GPS) that identifies the location. In their study, Cheng and Tsai [16] explore the differences and similarities between the two types of AR. As far as the differences are concerned, while recognising artificial labels or natural graphics are the main characteristics of image-based AR, GPS or the wireless network are used to know the user's position/location, providing real-time information in location-based AR. In both types of AR, virtual elements such as text, audio, video, and 3D models are presented to the physical elements visible on the device's screen. In the EduCITY app, AR is produced through the interaction between the mobile phone and a board with an AR marker that is recognised by the device through its camera, i.e., AR is generated based on an image, the AR marker, recognised by the app, and this is image-based AR. The EduCITY markers have undergone changes over the course of the project, with the aim of improving their content [7,17]. These contents aim to provide information that complements the reality that can be observed at specific locations in the city and information on phenomena that cannot be observed at that time and place, as well as promoting education for sustainability [7,17,18].

2.2. Mobile Augmented Reality Games

The combination of mobile devices and AR, coupled with mobile game learning, has been demonstrated to be an effective method of engaging learners. [19]. MARGs merge the real and virtual worlds, offering a distinctive experience that differs from traditional casual games. Players can engage with virtual game objects that overlay the real environment, stimulating their imagination as if they were interacting with the real world. In mobile AR games, players tend to focus their attention on the real world rather than the screen [19]. They provide access to contextualized information, supporting situated learning [3].

The supporting technologies for the implementation of MARGs are becoming increasingly prevalent and popular, making it an opportune time for their adoption in educational contexts [20]. For this to become a reality, it is not only crucial that educators are equipped with the knowledge to utilise these technologies, but also that they have access to user-friendly software that aligns with these pedagogical approaches [21,22].

In a review published in 2012, Schmitz et al. [23] analysed eight educational MARGs using design patterns for mobile games. The review did not consider the technological aspects of the games studied and found that MARGs can have certain motivational and pedagogical effects. However, the role of AR in these results is not clear. The study by Koutromanos et al. [24] provides a comprehensive overview of the research on MARGs in education. The authors conducted a review of seven MARGs developed for use in both informal and formal learning environments. The analysis was conducted from the perspective of research design and evaluation, and the results indicated that, in some cases, MARGs can, among other things, improve learning while increasing authenticity and engagement.

Recent advancements in the field of integrating AR games into education for sustainability have led to a resurgence of interest, with predominantly positive outcomes. Findings suggest that AR gamified learning is an effective teaching platform for both real-world and classroom settings [25].

2.3. Mobile Augmented Reality Games in Education for Sustainability

Over the past half-century, the increasing demand for solutions to environmental problems and the growing interest in socio-science issues such as ecological degradation, population-resource issues, and global warming have contributed to the development of education for sustainability [26]. The concept of education for sustainability demands the creation of learning environments that can fully engage students in the learning process. These environments must facilitate a holistic and transformative approach to education, which encourages the growth of both sustainability values and the development of knowledge and competencies for action in sustainability [26,27]. To achieve education for sustainability, it is essential that educational practices and approaches guarantee the continuity, equity, and quality of the educational process over time [28]. This should be done by focusing on the holistic development of students, the preservation of resources and the promotion of a fair and informed learning environment [27,28]. Therefore, teaching sustainability principles during childhood is of paramount importance, as it serves as the foundation for the promotion of environmentally sustainable conduct throughout the lifespan among young students [29,30]. The aim of education for sustainability in K-12 education is to raise young students' awareness of their impact on the environment and to encourage them to become actively involved in its preservation. This primarily entails the dissemination of basic concepts and knowledge related to sustainability, sometimes referred to in educational literature as 'environmental literacy' [29].

In education for sustainability, games can raise awareness, facilitate learning, and encourage behaviour change [19]. In addition, AR represents a cutting-edge technology that enhances users' perception of the real world. This is achieved by blending digital information with their environment, thereby delivering contextually relevant content directly into their surroundings [9,13]. In line with the pedagogical objectives of education for sustainability, situated outdoor learning provides an authentic environment for learners to immerse themselves in the learning content, thus effectively strengthening the relationship between knowledge and real-world scenarios [22]. In several successful cases of education for sustainability that incorporate situated learning approaches, students are frequently required to engage directly in problem-solving and work towards achieving specific sustainability competences, thereby establishing a foundation for sustainability education that transcends temporal and spatial boundaries [23].

MARGs are a pedagogical strategy designed to enhance student engagement, collaboration, and the quality of the learning experience [4–6].

Bressler et al. [31] investigated the factors related to student engagement during a collaborative AR forensic science mystery game using mobile devices. They identified the main advantages and benefits of MARGs, namely, the ability to stimulate interest and motivation, promote collaboration, enhance student participation, facilitate a sense of discovery, improve performance, and facilitate teamwork. However, there are also negative effects, such as usability issues, distraction, and effective use and integration in the classroom.

In a study conducted by Al-Hammadi et al. [32], an AR game was developed with the objective of providing students with an immersive learning experience in the field of sustainability. The main objective of the game was to engage students in the task of building unique and sustainable cities with affordable and clean energy sources, thereby enhancing their knowledge and understanding of sustainability principles.

The study by Chen et al. [33] explored the impact of situated learning environments on students' motivation and learning effectiveness, contrasting those who had access to such environments with those who did not. A comparison was made between an AR

game and a standard digital game, with particular emphasis on the distinction in the immersive and engaging learning environment that was provided in the experiment. The encouraging results indicated that the AR game could be considered a superior and more effective learning tool than regular digital educational games in enhancing overall learning effectiveness, enthusiasm, curiosity, and motivation. In a recent study, Strada et al. [34] developed a sustainability serious game based on AR with the objective of contextualising sustainability-related meanings within the learning environment. This approach was found to significantly enhance users' sustainability awareness and commitment. The self-reported questionnaires completed by users demonstrated the value of integrating AR technologies into SDG learning. This integration was found to enhance users' engagement and motivation, thereby facilitating their commitment to goals consistent with education for sustainable development.

2.4. The EduCITY Context

EduCITY—'Smart and sustainable cities with Augmented Reality mobile educational games made by and for the Citizens' is a research and training project, funded by the Foundation for Science and Technology (FCT), whose feasibility is supported by a multidisciplinary team from four research units with know-how in education, training, sustainability, and AR mobile games [17].

EduCITY (https://educity.web.ua.pt/, accessed on 3 October 2024) aims to promote the development of sustainable cities through the implementation of an innovative and interactive learning environment. The challenges are contextualised in concrete and real situations. The mobile app integrates interdisciplinary challenges enriched with augmented reality educational resources, including simulations based on data from environmental sensors, 3D models, and informative content, among others. EduCITY promotes innovative interdisciplinary learning strategies in the context of outdoor education for sustainability, combining teaching, mobile learning, and AR in urban settings [17]. Considering the potential advantages of AR games in the field of education for sustainability, this study presents the development of an AR game, entitled 'EduCITY at the UA campus', which aims to facilitate a situated learning experience that can enhance students' learning effectiveness and learning outcomes, thereby improving their sustainability competences. In order to address the issues of self-awareness and interactions between authentic contexts that are lacking in traditional learning environments, the provision of situated learning environments is regarded as a crucial element in strengthening the connection between knowledge and real-world concepts. This can be achieved by involving students in ways that simulate actual scenarios, which can be facilitated by AR techniques [35].

All of the games integrated into the EduCITY app are based on the European Commission's GreenComp framework of competencies for sustainability [8]. This document defines 12 competencies under four domains, starting with an emphasis on "Being" through "Embodying sustainability values" and progressing to "Embracing complexity in sustainability, envisioning sustainable futures, and acting for sustainability" [8].

The EduCITY app represents a successful initiative in which students answer a series of interdisciplinary questions related to a given outdoor route. Such questions may involve direct observation, problem-solving, research on (AR or in videos and images), and carrying out a task in the field. Considering the current environmental concerns, there has been a recent shift in focus towards the integration of AR games as emerging tools in the promotion of education for sustainability. This approach has demonstrated positive outcomes with respect to students' cognitive and affective competencies [10,11].

The EduCITY app (Figure 1) comprises several games with distinctive objectives and target audiences (B). These games are developed collaboratively by the team and various members of the educational community [17]. The user-friendly web-based platform does not require any programming skills for those who intend to create games and AR content [17]. The structure of all games integrated into the EduCITY app is consistent and divided into four categories: spatial orientation, question introduction (D), questions

themselves (E), and answers with feedback for both correct and incorrect responses (F). Furthermore, all stages must be accompanied by multimedia resources. The process of answering questions should be repeated as many times as necessary, and the game must start and conclude with a message (C).

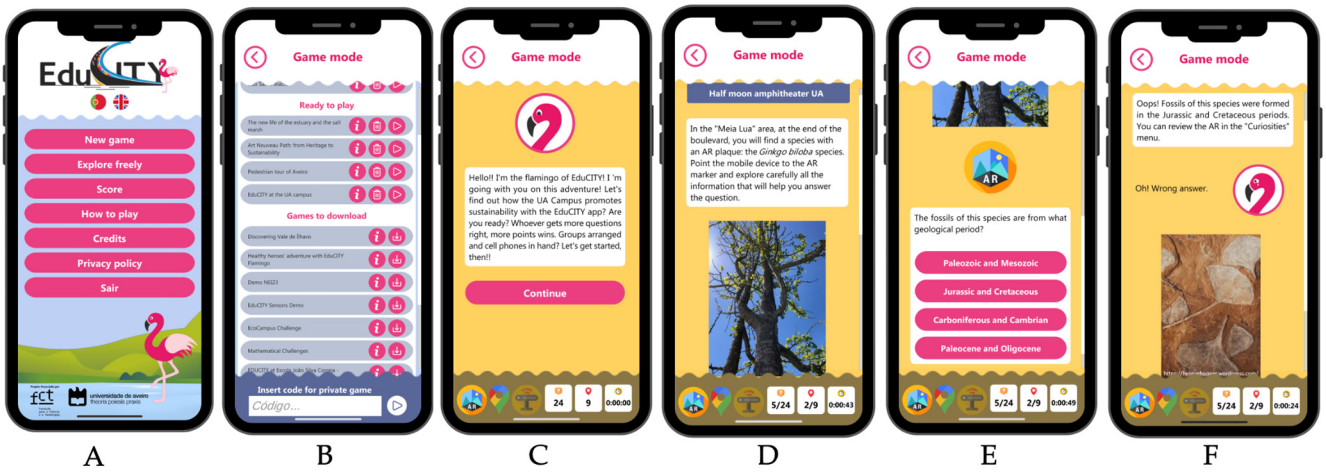

Figure 1. The 'EduCITY at the UA campus' AR game integrated into the EduCITY app ((**A**) Home menu; (**B**) Game selection menu; (**C**) Welcome message; (**D**) Question introduction; (**E**) Question and answer hypotheses; (**F**) Incorrect answer feedback).

The city is regarded as a learning laboratory, where students can develop their scientific and technological skills by exploring historic environments, contributing to urban sustainability, and inspiring other localities to adopt the ideas and solutions emerging from this project. Furthermore, it is important to emphasise that these games are co-created by the community, involving teacher training and actions for the public. They provide challenging, interdisciplinary, and active learning, and are available for any citizen to play while exploring the city. EduCITY thus offers a range of innovative, attractive educational activities, which are adapted to different age groups and levels of ability.

The EduCITY app offers two types of AR content: augmented markers and ARBook information (Figure 2) [36].

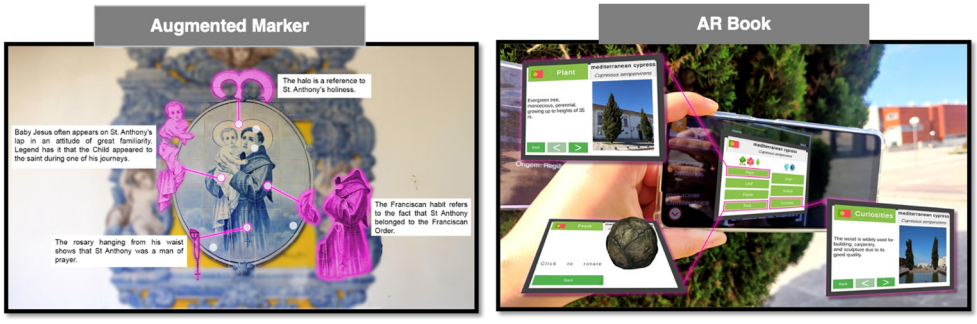

Figure 2. Example of an augmented marker and ARBook integrated into the EduCITY app.

The augmented marker is a template that employs interactive AR buttons in specific locations on an image. The objective of this AR is to enhance the user experience by prompting the display of information when the user points the camera at the selected location (via a photograph) and interacts with the interactive buttons. Consequently, a mask (2D image highlighted in pink) is superimposed over the marker, accompanied by a text balloon containing information such as text and images, as can be observed in Figure 2 [36].

The ARBook is a template for a dynamic AR menu that can incorporate 3D content and provide information that complements reality [12,36]. It provides detailed information on tree species, including characteristics such as plant, leaf, flower, fruit, origin, ecology, and curiosities. ARBook enriches the user experience by triggering AR information whenever the camera locates a marker (plaques installed with pre-defined markers in the city of Aveiro) and can integrate 3D models (see Figure 2) [36].

This paper examines the potential of the 'EduCITY at the UA Campus' mobile AR game in the context of promoting education for sustainability among secondary students.

3. Materials and Methods

A case study was conducted to ascertain the perceptions of students [37,38]. This involved the collection of data through a questionnaire, which was completed by students after they had played the game 'EduCITY at the UA Campus' with the EduCITY app in Aveiro, Portugal. The app automatically collects anonymous game logs (e.g., score) for contextual information about the activity. The aim of this study is to analyse the potential of the 'EduCITY at the UA Campus' mobile AR game in terms of its capacity to promote education for sustainability among secondary students. To address this aim, the research question is as follows: "What is the potential of the 'EduCITY at the UA Campus' mobile AR game explored in the XPERIMENTA activity to promote education for sustainability among secondary students?". The hypothesis of this study is that the MARG has the potential to motivate students to engage in education for sustainability, improving their key competencies for sustainability. The success of this activity will facilitate the pursuit of further EduCITY activities, which are aimed at promoting education for sustainability.

This section is divided into three subsections. The first subsection presents a description of the procedure of the 'EduCITY at the UA Campus' game, as part of the XPERiMENT'24 activity. The second subsection presents an overview of the participants involved in the "EduCITY at UA Campus" game in the XPERiMENTA'24 activity. The third subsection outlines the data collection and analysis approaches and tools employed.

3.1. The Procedure of "EduCITY at UA Campus" Game in the XPERiMENTA'24 Activity

The developed pedagogical approach comprises an activity framed in the XPERiMENTA 2024 event. This is one of the biggest events of the UA, directed at basic and secondary school students, as well as at the wider community. This event invites participants to explore hands-on activities, interactive projects, scientific experiments, and guided tours through the UA campuses. The context of this big annual university event facilitated the recruitment of volunteers to participate in this study.

Figure 3 illustrates the route of the 'EduCITY at the UA Campus' game on the UA campus, with a particular focus on the UA Campus Boulevard ("Alameda"). The game starts next to the UA pedagogical complex, situated near a stone sculpture created by Isaque Pinheiro (1). It then proceeds through the "Alameda" of UA which comprises the maidenhair tree (2), the well (3), the lake (4), the Mediterranean cypress tree (5), and the canteen (6), until it reaches the library (7). The game concludes with a visit to the "Sapo" sculpture by Paulo Neves (8) and a visit to the tile panel "Voar mais alto" by Zé Penicheiro (9).

The game integrates twenty-four multiple-choice questions with images, audios, videos, and AR content. These provide virtual information that complements the observable reality in each location.

In this game, AR was integrated into the questions with two main aims: (i) to promote knowledge related to natural heritage (botany), where AR markers are identification plaques for trees on the campus, in this case, the maidenhair tree and Mediterranean cypress tree (questions 2.2, 5.1, 5.2, and 5.3), and (ii) to promote knowledge related to aspects of the UA Campus, which is the case of AR markers that are art tiles of the UA (questions 9.1, 9.2, and 9.3). Table 1 serves to illustrate the questions with AR in the 'EduCITY at the UA campus' game. The table presents the number of the question in the

game, the introduction of the question, the question, and the answer hypotheses, with the correct one highlighted in bold.

Figure 3. A map representation of the 'EduCITY at the UA Campus' game route.

Table 1. 'EduCITY at the UA campus' game questions with AR.

No.	Introduction	Question	Answer Hypotheses
2.2	In the "Meia Lua" area, at the end of the boulevard, you will find a species with an AR plaque: the maidenhair tree. Point the mobile device to the AR marker and explore carefully all the information that will help you answer the question.	The fossils of this species are from what geological period?	Paleozoic and Mesozoic
			Jurassic and Cretaceous
			Carboniferous and Cambrian
			Paleocene and Oligocene
5.1	The species you are looking at is a Mediterranean cypress tree (*Cupressus sempervirens*) that belongs to the botanical group Gymnospermae. Click on AR and point to the marker on the plaque next to the tree and carefully analyse the augmented reality.	What are gables? Select the correct option.	Gables are the seeds of the Mediterranean cypress
			Gables are the flowers of the Mediterranean cypress
			Gables are the modified leaves of the Mediterranean cypress
			Gables are the pseudo-fruits of the Mediterranean cypress
5.2	Still on the subject of the Mediterranean cypress tree (*Cupressus sempervirens*). . .	What is the use of gables for the human being? Select the correct option.	Gables are used in our food
			Gables serve to calm whooping cough
			Gables are used to make tea
			Gables are of no use
5.3	Still on the subject of the Mediterranean cypress tree (*Cupressus sempervirens*). . .	This species belongs to which botanical group? Select the correct option.	**Gymnospermae**
			Angiospermae
			Moraceae
			Salicaceae

Table 1. *Cont.*

No.	Introduction	Question	Answer Hypotheses
9.1	Looking at the entire tile panel, try to figure out...	What year corresponds to the birth of the UA? Select the correct option.	1913
			1963
			1993
			1973
9.2	This panel was created by Zé Penicheiro, who represented the various areas and departments at the UA. It is called "Fly higher" because it asserts its value among the most prestigious Portuguese universities.	Identify the elements of Music and Art, respectively, on the panel. Please select the correct option.	painting of Leonardo da Vinci and cello
			moliceiro and globe
			cello and painting of Leonardo da Vinci
			book and sun
9.3	More about this panel...	Identify in the panel the elements of Biology, Chemistry, and Geosciences, respectively. Look at the AR and select the correct option.	microscope, *moliceiro*, cello
			fish, globe, waves
			microscope, test tube, globe
			book, sun, saline

The players are provided with feedback on their selected answers, whether correct or incorrect. This feedback includes explanations of the incorrect answers, or, in the case of a correct answer, additional information related to the question. This is delivered using AR and multimedia resources. According to Chen [39], immediate feedback, design principles, student involvement, and motivation to learn are considered the greatest advantages of using these resources in learning.

To illustrate, in question 2.2., if the students answer correctly, they are provided with feedback in the form of a statement of curiosity "Well done! And did you know that the Jurassic period was 205 to 142 million years ago, and the Cretaceous period was 135 to 65 million years ago?". If the answer is incorrect, the feedback presents the correct hypothesis and the statement, "Oops! The fossils of this species were formed in the Jurassic (205 to 142 million years ago) and Cretaceous (135 to 65 million years ago) periods. You can review the AR in the Curiosities menu".

3.2. Participants in the "EduCITY at UA Campus" Game in the XPERiMENTA'24 Activity

As part of the XPERiMENTA'24 event, an educational activity was created using the EduCITY app for secondary students. The students registered for and participated in the 'EduCITY at the UA Campus' game, which aims to promote education for sustainability, while touring the UA campus. The game seeks to enhance students' learning related to several key topics, including city noise, botany, and water footprint. Additionally, it articulates curricular content from various academic disciplines, including science, mathematics, education for citizenship, and cultural aspects of UA.

Twenty-seven secondary students participated in this activity, which occurred at the Santiago University Campus (UA Campus), on the 2nd of May of 2024 (Figure 4). Students were organized in 9 groups. Each group played the game for an average of one hour, using their own smartphone. At the end, symbolic EduCITY prizes were given to teams with the best performance.

Figure 4. Students in the XPERiMENTA 2024 activity.

3.3. Data Collection Instruments

The data collection process included the anonymous and automatic logging of participants' performance in the game, as well as the administration of a questionnaire immediately following the game activity. The data logs of game performance included the scores achieved, the number of correct and incorrect answers, and the time spent engaged in gameplay. The data was collected directly by the app in an anonymous way, thereby enabling an analysis of the game's capacity to facilitate learning.

After the game, students were invited to complete an individual and anonymous questionnaire. This was to ascertain their views on the contribution of EduCITY to the fields of education and sustainability.

The tool comprised three questions with different objectives. The first was an open-ended question designed to identify the key learning outcomes of the game for the students, with a focus on two or three examples. The second was an open-ended question to evaluate the students' understanding of the concept of sustainability. The third was a multiple-choice closed question to assess the potential of the AR game on the students' knowledge and skills regarding sustainability, with a particular focus on environmental sustainability. The multiple-choice question is divided into 25 lines based on the European sustainability competence framework, GreenComp [8]. The 25 questions are divided into two categories: valuing sustainability and supporting equity. For the purposes of this paper only those questions pertaining to the valuing sustainability category will be highlighted.

Concerning the open-ended questions, qualitative data analysis was completed, using the logic of content analysis, and resorted to the categorization of responses based on their answers [38]. The quantitative data were analysed through descriptive statistics and the results were triangulated to analyse the value of this game for the promotion of education for sustainability [40].

4. Results and Discussion

The results of the case study on the AR content in the EduCITY app and its value for education for sustainability, as perceived by 27 secondary school students, are presented. The findings are divided in two subheadings: the outcomes of the game and the results of the questionnaire survey.

4.1. The Outcomes of the 'EduCIYY at UA Campus' Game

Figure 5 illustrates the performance of each group in the game. It is important to reiterate that the game comprised 24 questions, seven of which required the exploration of AR content. The analysis of game logs revealed that the average number of correct answers per group was approximately 21. The questions addressed curricular content and cultural aspects of UA, including the following topics: city noise, botany, water footprint, food waste, and cultural aspects of UA. The results indicate that the majority of groups achieved

a good game performance (Figure 5). In a game with 24 questions, the students were able to correctly answer an average of 19.9 questions (ranging from fifteen to twenty-four) and incorrectly an average of 4.1 (ranging from three to nine). The standard deviation for correct answers and for incorrect ones was 2.42. The high average number of correct answers indicates that, in general, the students demonstrated a solid understanding of the game content. However, the equality of the standard deviation suggests that the difficulties encountered by the students were similar for most of the questions. Despite the overall positive performance, it is evident that a small group of students may have faced more challenges. In this regard, the subsequent analysis presents not only the questions that the students answered correctly the most, but also those that they answered incorrectly the most. A similar outcome has been observed in other EduCITY and EduPARK activities [4,6,7,18].

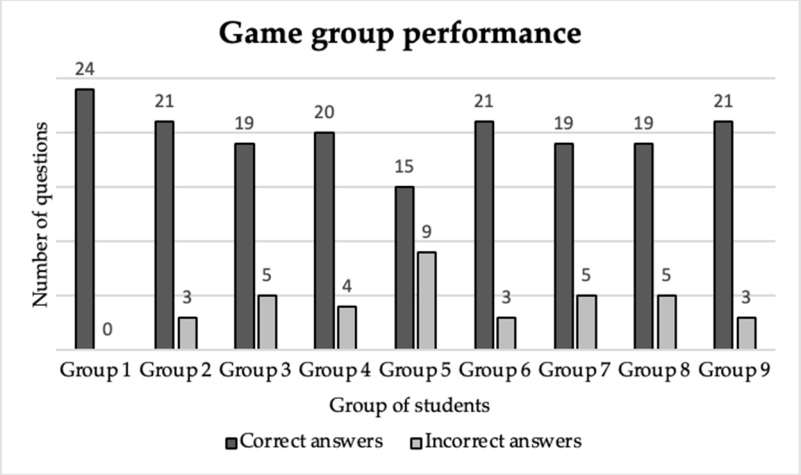

Figure 5. Number of correct and incorrect answers in the game per group.

Group 1 demonstrated the highest level of accuracy, with 24 correct responses and no incorrect answers. In contrast, the group with the lowest score was Group 5, which achieved fifteen correct answers and nine incorrect answers. Groups 2, 6, and 9 did not correctly answer three questions (Figure 5). Group 4 did not correctly answer four questions. It can be observed that Groups 3, 7, and 8 answered five questions incorrectly.

Although the average number of correct answers was higher than the average number of incorrect answers, the results indicate a modest overall performance in a game in which the multimedia content is designed to support the provision of answers. This suggests that the game could be revised to be more efficacious in promoting learning. To this end, an improvement plan for the game has been developed, which involves not only a comprehensive review of all questions in the game to improve their clarity and coherence, but also the enhancement and development of multimedia resources for the questions with the highest number of incorrect responses, which are analysed in detail below.

To analyse the students' performance in the game, the groups' answers to each question were analysed. To facilitate comprehension, the game was divided into two graphs: one comprising questions without AR (Figure 6) and another comprising questions associated with AR (Figure 7). Appendix A presents the remaining questions in the game, without the use of AR, to facilitate a more comprehensive understanding of the presented results. Table A1 presents the question number in the game, the question introduction, and the question-and-answer hypotheses, with the correct answer highlighted in bold.

Figure 6 illustrates the results of the questions in the game without the use of AR. The process of analysis began with the questions that yielded the most favourable outcomes and proceeded in a descending order of performance for those that produced the least favourable results.

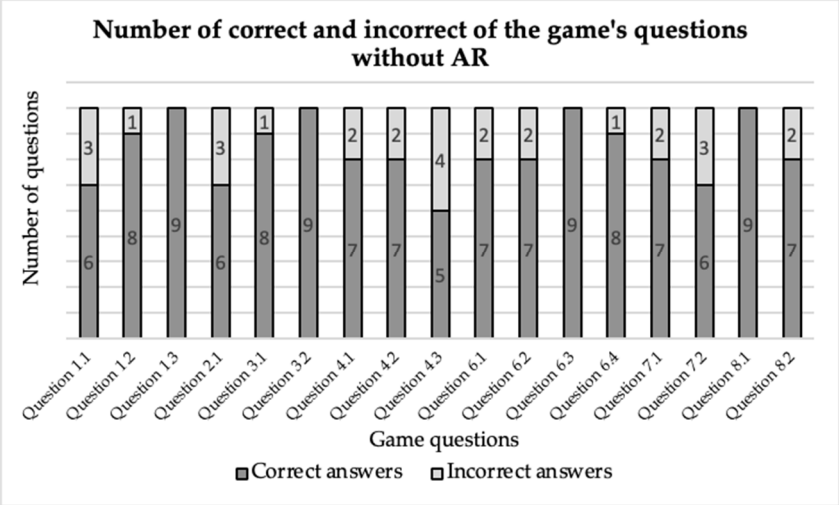

Figure 6. Number of correct and incorrect answers in the game without AR content.

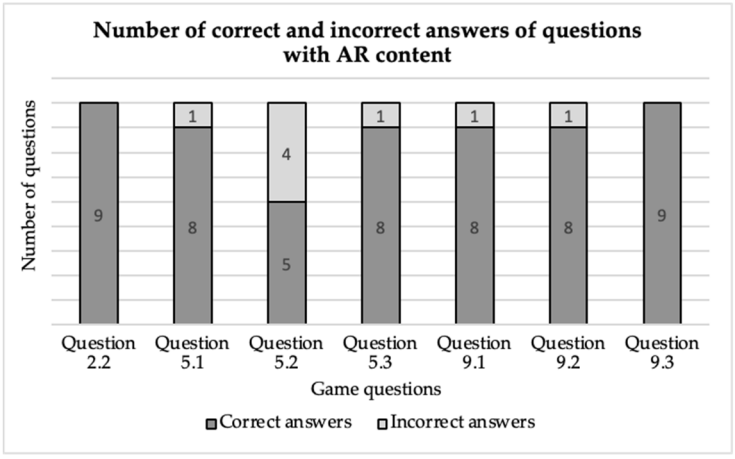

Figure 7. Number of correct and incorrect answers in the game with AR content.

A review of the results reveals that the questions without AR, which were answered correctly by all students, were questions 1.3, 3.2, 6.3, and 8.1 (Appendix A). Questions 1.3 and 8.1 required students to observe two distinct locations, each featuring a different sculpture. To respond correctly, the students were required to take a moment to observe the sculptures. This type of question was designed to foster the students' appreciation of art, thereby facilitating their engagement with the cultural and artistic aspects of the location. Simultaneously, it aimed to stimulate their creativity.

Question 3.2 presented a bar graph comparing the water footprint of various foodstuffs. Students had to observe and interpret the graph to determine which food item had the largest water footprint. In question 6.2, students had to watch the provided video in its entirety to determine the amount of food discarded in a 10 min period in the UA canteen. The fact that all groups answered this question correctly may indicate that videos are an effective educational tool, as proposed by the authors [3].

In question 1.2, the students used environmental sensors developed by the EduCITY team. These EduCITY sensors facilitate the experimental verification of learning outcomes and are designed to collect environmental data that accompanies the learning process using educational games focused on air quality or noise. In this question, the students were required to employ the noise sensor and understand the range of sound pressure levels corresponding to the noise of a quiet conversation. The groups were accompanied by the researcher responsible for the environmental sensors, who checked that all groups had

used the sensors as intended. The use was successful, as evidenced by the fact that only one group answered the question incorrectly. Similarly, one group incorrectly answered question 3.1, which required the observation of the location in order to provide an accurate response. In this question, the students demonstrated an understanding of the historical context, particularly regarding the instruments of Muslim heritage in the Iberian Peninsula. In question 6.4, only one group chose the wrong option. The results demonstrate that students are aware of the impact of consuming red meat on both the environment and their own health. These findings are consistent with those of the systematic literature review [3], which indicates that a significant pedagogical benefit of AR is its capacity to visualise abstract concepts and to motivate learners.

Question 4.1 asked students to apply the geometric concepts they had previously learned to identify the geometric solid that best represented the shape of the lake. The two groups that answered incorrectly selected the rectangle option (Appendix A), which may be indicative of a confusion between solids and geometric figures in a real-life context among the students. Additionally, at the same point of interest, the students were required to answer a question in the field of biology (4.2). In this question, which pertains to the fish that inhabit the lake, the students were required to ascertain whether the fish were typical saltwater or freshwater species, to identify their specific species, and to determine whether they were native or non-native. Both groups incorrectly identified the fish as redheads, rather than carp. One of the students suggested that the colouration of the fish had led to the misidentification.

Questions 6.1 and 6.2 are of an observational and calculative nature. These two questions required students to observe the location and estimate the total number of bicycles that could be stored in the area, as well as calculate the distance between the three UA canteens in a series of steps. Two groups responded incorrectly to question 6.1, selecting the option "between 30 and 40 bicycles". Similarly, two groups responded incorrectly to question 6.2, with one group selecting the option 1170 and another selecting the option 1300. Nevertheless, the correct responses were "between 50 and 60 bicycles" and "1270", respectively.

In question 7.1, the two groups that chose the incorrect option, "used large windows to illuminate the spaces" reviewed the video in the feedback to better understand why this was not the optimal choice. In question 8.2, the two groups that selected the incorrect option were the two groups that did not approach the UA's 'Frog' sculpture but observed it from a distance. Consequently, they did not read the phrase that represents the search engine 'Frog'. This illustrates the importance of clearly observing the point of interest in order to perform well in this game.

It was crucial to include an introductory question (1.1) at the beginning of the game, welcoming the students and promoting their connection with the mascot, Flamingo, who would accompany them throughout the game. This approach, as evidenced in the study by Paixão and Jorge [41], enhanced the students' willingness to complete the game, subsequently increasing their interest and motivation. This is because one of the key factors in the learning process is the students' willingness to learn [41]. Moreover, the use of the flamingo as a mascot was intended to foster a sense of community among the students, as there is evidence that exposure to wildlife can contribute to the development of environmentally conscious citizens who demonstrate greater awareness of species conservation and environmental stewardship. This question required them to listen to the sound and identify that it was the sound of the flamingo, linking it to the project's mascot. However, three groups incorrectly identified the sound as that of a duck, due to its similarity to the flamingo call.

Question 2.1 required students to consult the introductory part of the question to find the correct answer. This was the first question in the game, where students were required to select two correct answer options, a format that may have potentially contributed to some degree of confusion. In an informal discussion at the end of the activity, the monitors of each group reported that the students were confused when they were required to select

more than one correct option, due to uncertainty regarding the number of options that should be selected. It is thus evident that the game can be enhanced to provide greater clarity and efficacy in facilitating learning.

In question 7.2, they were directed to a video which provided the necessary information to enable them to identify the correct response. The three groups that selected the incorrect option selected the option 'he was inspired by the waves of the sea'. The students indicated that they had acted precipitously, having only observed the undulating façade and made their selection without watching the video or associating it with the Ria de Aveiro. The remaining groups (x) watched the video, where the correct answer was 'it was inspired by the natural channels of the Ria'.

By observing cultural aspects of the city, students are able to connect theoretical knowledge with real experience, thereby enhancing engagement in the learning process [17]. Moreover, students develop a deeper appreciation for the cultural diversity of their city [17,32]. Concurrently, students learn to observe and analyse their surroundings, thereby developing critical thinking skills [32].

As expected, question 4.3 (Appendix A) produced the worst results, with five groups giving the correct answer and four giving an incorrect answer. The mechanism of osmoregulation in fish is a challenging topic for students due to the complexity of the biological process involved. The image included in this question, which illustrates the differences between the osmoregulation of freshwater and saltwater fish, proved to be helpful to students in answering the question, although it is a challenging diagram to interpret. Students encountered difficulties in applying their knowledge of biology to the observations made in the field.

In addition to the game analysis, it is also essential to identify and evaluate the challenges associated with the exploration of AR content. Figure 7 presents a comparison of the number of groups that correctly or incorrectly answered each question relating to AR.

Figure 7 demonstrates that the two questions with AR that were answered correctly by all students were questions 2.2 and 9.3. In question 2.2, students were required to explore the maidenhair tree ARBook and select the "curiosities" button to find the answer. The geological period of fossils is new content for the students as it is not included in the biology and geology or science curricula. Despite the new content of this question, all groups got it right, showing that AR, and the ARBook in particular, helped them to answer the question. In question 9.3, students were asked to observe the tile panel and identify in augmented marker the elements of biology, chemistry and geosciences (Figure 8). The fact that all groups answered this question correctly demonstrates that the students had correctly used the full functionality of the augmented marker. This was evidenced by their successful exploration of the marker and their ability to locate the requisite information to answer the question correctly. As Floricel [5] asserts, the incorporation of augmented reality features facilitates the illustration of the consequences of sustainability-oriented practices in comparison to existing practices. This approach encourages a more sustained engagement of individuals and groups in observing and immersing themselves in nature, comparing observations, and implementing and testing the effects of interventions.

Figure 8. Examples of AR included in the 'EduCITY at the UA campus' game.

Figure 7 also indicates that in questions 5.1, 5.3, 9.1, and 9.2, only one group selected the incorrect answer.

In question 5.1, Group 5 selected the option "Gables are the seeds of the Mediterranean cypress", while in question 5.3, Group 2 selected the option "Angiospermae". In these two questions, students had to use the ARBook to find the information they needed to give a correct answer.

In question 9.1, Group 5 incorrectly identified the tile panel and selected the correct option, 1993. The group did not explore the Augmented Marker, but focused their attention on the panel that could potentially induce errors. As illustrated in Figure 8, the digit nine (the second digit displayed on the panel) is strikingly similar to the digit 7 (the third digit shown on the panel).

In question 9.2, Group 6 chose the option "painting of Leonardo da Vinci and cello". The students' response to this question indicates a misunderstanding of the instructions. They were asked to identify the elements of music and art, respectively, but answered in the reverse order.

Regarding question 5.2, four groups selected the incorrect option "Gables are used to make tea". In order to answer this question correctly, the students had to consult the ARBook, where they found the information, they needed on the "curiosities" button on page 2. This research question is more challenging to answer, as the information is not readily apparent. It is notable that all four groups gave the same incorrect answer, which lends credibility to this hypothesis. This is probably because the students' initial response was influenced by their preconceived notion that tea comes from plants.

The data collected through the game integrated into the EduCITY app suggests that the students performed well. However, it would be wrong to claim that AR is 100% effective, as some groups gave incorrect answers to questions that required the use of AR content. Furthermore, this project is still in the data collection phase, and the results are still limited by the small sample size, which may affect the generalisability of the results.

As mentioned, after the 'EduCITY at the UA Campus' game, students were invited to complete an anonymous questionnaire survey, to ascertain their views on the contribution of EduCITY to the fields of education and sustainability.

4.2. Results of the Questionnaire Survey

An overall view about the answers to those topics indicates that students considered the EduCITY app to have positive potential for education for sustainability. The students indicated that the content they found most valuable was related to the cultural aspects of the UA and the trees on campus. It is noteworthy that all students responded to the question "For me, sustainability is. . ." which indicates their interest in the subject. All students responded to the questionnaire voluntarily and successfully completed the 'EduCITY at the UA campus' game. A similar approach was employed by Chen, with the administration of the questionnaire occurring after the activity. This method proved effective in maintaining student motivation and ensuring the integrity of the data, as evidenced by the absence of incomplete or invalid questionnaires [28].

Students in the first question of the questionnaire had to identify two or three key insights learned from the game (Table 2).

The feedback was analysed using inductive categorical content analysis [42]. The unit of analysis was the main themes of the questions, and all answers were analysed as no sampling was conducted. The coding scheme was developed based on the questions' themes: noise, botany, food waste, curricular content, cultural aspects of UA, and other (students' answers not aligned to the questions in the game). Table 2 summarises the students' answers, with a total of 62 statements regarding the knowledge and skills they gained from the game.

Table 2. Examples of content that students reported having learned from the 'EduCITY at the UA Campus' game, which is integrated into the EduCITY app.

Category	Sub-Category	Citation Example	Frequency	
Noise	Flamingo noise	*I learnt what a flamingo sound like.*	7	
Botany	Mediterranean cypress tree	*I learnt what a galbula is.*	6	10
	Not specified	*I learnt about plants.*	4	
Food waste	-	*I learnt about food waste.*	4	
Curricular content	Science	*I learnt that carp are freshwater fish and fish don't drink water.*	7	8
	Mathematics	*I learnt what a parallelepiped looks like.*	1	
Cultural aspects of UA	UA's date of birth	*I learnt the date on which the UA was founded.*	19	33
	"Sapo" sculpture	*I learnt when the search engine "Sapo" was created.*	3	
	Library	*I learnt that the architecture of the UA library is inspired by the currents of the estuary.*	5	
	Solar panels installed at UA	*I learnt about the complexity of the solar panels in front of the rectory.*	1	
	The well	*I learnt what a "nora" is.*	1	
	Not specified	*I learnt some curiosities about UA.*	2	
Other	Teamwork	*I learnt to work as a team.*	2	

The majority of students (33 answers) indicated that they had acquired knowledge about a range of topics and curiosities related to the UA. The most common was the date of the UA's birth. This question (9.1) was associated with an augmented marker, and upon exploring this AR, the students noted the highlighted date. The students enjoyed the opportunity to learn about the curiosities of the UA, as many of them had previously expressed an interest in studying there. This activity gave them insight into some of the cultural aspects of the area. As evidenced by the results of the game, only one group gave an incorrect answer to this question, indicating that the students made effective use of the UA Panel augmented marker.

The second most frequently mentioned category was botany (10 responses). The students indicated that they had acquired knowledge about the Mediterranean cypress tree, particularly the characteristics of the galbula, through observation in both the real world and in the 3D model associated with ARBook. Furthermore, the students indicated that they had generally acquired knowledge about plants. This finding is supported by the results of the 'EduCITY at UA campus' game, where all groups chose the correct answer to question 2.2.

Although the results of the game did not demonstrate the absolute effectiveness of AR, when triangulated with the responses to this survey question, it can be concluded that the two subjects most frequently mentioned by students were those with AR questions, which may indicate effective learning. Furthermore, the students' willingness to engage with the game and their active exploration of AR to answer the questions was a significant contributing factor in their successful completion of the game with dedication and concentration.

The category that received the third highest number of citations was "Curricular content", with eight mentions across two dimensions of analysis. Students indicated that they had acquired knowledge about science, which was mentioned on seven occasions. Additionally, one student noted that they had gained insights into mathematics. These findings are in line with those of D'Ambrósio [43], who asserts that examining local mathematical understandings and integrating them into the school curriculum can facilitate

more meaningful and contextualised learning, promote an appreciation of cultural diversity and stimulate students' interest in mathematics.

Table 2 illustrates that the students also acquired knowledge about the flamingo's sounds, food waste, other aspects, and curiosities of the UA ("Sapo" sculpture, library, solar panels, and the well), and emphasised that they had benefited from collaborative learning as they engaged in team-based activities. These findings are corroborated by prior research wherein students collaborate to address a challenge with the support of an AR environment. The studies highlight the value placed on teamwork and communication, as well as critical thinking and problem-solving [28].

In the second question, students were required to complete the sentence, "Sustainability for me is…". In this question, the students opted to answer collectively, stating: (i) "…thinking and being responsible"; (ii) "…preserving the environment"; (iii) "…guaranteeing the needs of this generation without compromising future ones"; (iv) "…fulfilling the 3 Rs"; (v) "…being responsible"; (vi) "…a way of living"; and (vii) "…balance between humanity and nature". Students' answers demonstrate a broad understanding of the fundamental principles of sustainability. They recognise the significance of environmental protection, intergenerational equity, individual responsibility, and a holistic approach to sustainable living. These findings are encouraging and suggest that the students have a solid comprehension of sustainable practices and the capacity to promote them effectively.

The third question of the questionnaire comprised 25 lines, subdivided into two categories: valuing sustainability and supporting equity. As previously stated, only those questions pertaining to the valuing sustainability category were considered for this paper.

To respond to the question "This activity allowed me to…", the students were required to complete the table and use a Likert scale, with responses ranging from one (strongly disagree) to six (strongly agree). The findings of the survey presented in Figure 9 suggest that students perceived the EduCITY app to be a valuable educational tool for sustainability. It is notable that no student indicated that they strongly disagreed with any of the statements.

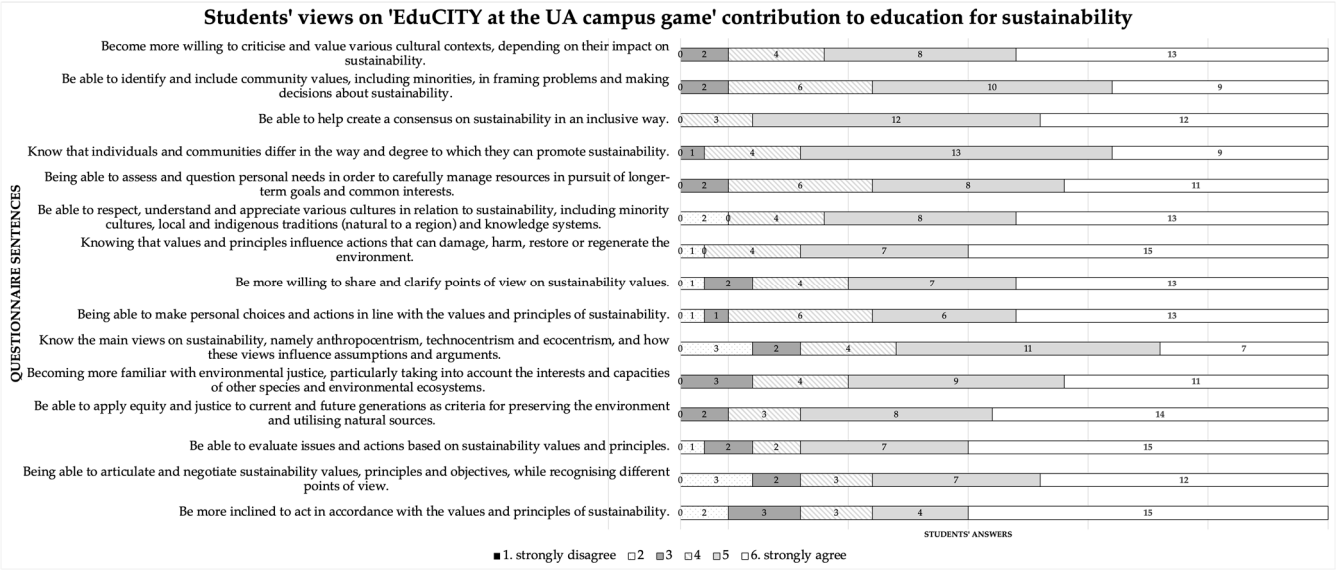

Figure 9. Students' views on 'EduCITY at the UA campus' game's contribution to education for sustainability.

As illustrated in Figure 9, the students' most highly valued outcome of the activity was the awareness that values and principles can influence actions that may cause damage or harm to, or the restoration or regeneration of, the environment. This was indicated by fifteen students who identified level 6, seven students who identified level 5, four students who identified level 4, and only one student who identified level 2. As Redman and Wiek

assert, forward-thinking skills, values, and strategies are fundamental to facilitating change and enabling individuals to envisage sustainable futures and develop effective and efficient strategies to achieve them [27].

Furthermore, the considerable number of students (15) who selected option 6 (strongly agree) in the statement "be able to evaluate issues and actions based on sustainability values and principles" indicates that the game is an effective tool for students to evaluate sustainability issues. In the statement "be more inclined to act in accordance with the values and principles of sustainability", 15 students also selected option 6, which is defined as "strongly agree".

In the statement, "be able to apply equity and justice to current and future generations as criteria for preserving the environment and using natural sources", fourteen students indicated a strong agreement with option 6, eight students selected option 5, three students selected option 4, and two students selected option 3. No students expressed disagreement with the statement (options 1 and 2).

With 13 students selecting option 6, the following statements stand out as particularly noteworthy: "become more willing to criticise and value various cultural contexts, depending on their impact on sustainability", "be able to respect, understand and appreciate various cultures in relation to sustainability, including minority cultures, local and indigenous traditions (natural to a region) and knowledge systems", "be more willing to share and clarify points of view on sustainability values", and "being able to make personal choices and actions in line with the values and principles of sustainability".

With a reduction in the number of students selecting option 6, the following statements are particularly noteworthy, "being able to articulate and negotiate sustainability values, principles and objectives, while recognising different points of view" and "be able to help create a consensus on sustainability in an inclusive way", with 12 answers.

With 11 answers in option 6 (strongly agree), the statements are as follows: "being able to assess and question personal needs in order to carefully manage resources in pursuit of longer-term goals and common interests" and "becoming more familiar with environmental justice, particularly taking into account the interests and capacities of other species and environmental ecosystems".

The statements with the worst results were "be able to identify and include community values, including minorities, in framing problems and making decisions about sustainability" and "know that individuals and communities differ in the way and degree to which they can promote sustainability", with a total of nine students answering strongly agree.

The results of the study suggest that the 'EduCITY at the UA campus' game was well received by the student cohort, with the majority of students expressing strong agreement on its contribution to understanding and acting on sustainability principles. The game is particularly effective in enabling students to evaluate sustainability issues, understand the influence of values, and motivate sustainable actions.

Nevertheless, there is a clear need to enhance the skills required to negotiate sustainability values and to develop the ability to critique and value different cultural contexts. Furthermore, while there is a strong grasp of concepts, such as environmental justice and anthropocentrism, these areas could benefit from further reinforcement.

5. Conclusions

The aim of this study was to analyse the potential of the 'EduCITY at the UA Campus' mobile AR game in terms of its capacity to promote education for sustainability among secondary students. This MARG has been designed with the objective of promoting education for sustainability, while touring the UA campus, and seeks to enhance students' learning related to several key topics, including city noise, botany, water footprint, and cultural aspects of UA, and articulates curricular content including science, mathematics and education for citizenship. This paper presents the findings of an activity conducted at the XPERiMENTA event. The results of the game demonstrated a high level of engagement and performance across all groups, with the majority of questions answered correctly.

Based on the data collected, students unanimously consider the EduCITY app to have high educational value as a pedagogical strategy in education for sustainability. The study's results answer the research question, "What is the potential of the 'EduCITY at the UA Campus' mobile AR game explored in the XPERIMENTA activity to promote education for sustainability among secondary students?". According to the students, the 'EduCITY at the UA campus' game has the potential to be an effective educational tool for sustainability, as it addresses issues of considerable relevance to the area, including city noise, botany, water footprint, food waste, and cultural aspects of UA. Furthermore, the integration of AR plays a key role in exploring this new content.

The majority of students indicated that they had acquired knowledge about the cultural aspects of UA and the botanical aspects, particularly about trees, with the ARBook.

In addition, the students identified curriculum learning, the sound of the flamingo, and food waste as areas of learning that they had found particularly valuable. It is also noteworthy that some students emphasised the value of teamwork. Outdoor group activities have been demonstrated to foster the development of essential teamwork and communication skills, which are crucial for the effective navigation of complex sustainability challenges.

The results of the questionnaire indicated that, following the game activity, students demonstrated greater awareness of the environmental issues presented and a greater capacity to act in accordance with the principles of sustainability. The fact that the game is conducted in an outdoor environment provides students with a tangible, real-world context in which to observe and interact with sustainability issues in a first-hand capacity. This direct connection to the environment makes the concepts of sustainability more pertinent and meaningful to students.

This study emphasises the importance of integrating innovative technologies, such as AR, into educational contexts to facilitate the promotion of sustainability and nature conservation. The findings of the study demonstrate that AR is an efficacious instrument for addressing sustainability-related content, particularly in relation to cultural and natural heritage. It can consequently be posited that the use of AR in this game facilitated the visualisation of complex new concepts, making them accessible for comprehension and recollection. This can be corroborated by the responses to the questionnaire survey. The exposure of students to AR experiences can play a pivotal role in influencing their attitudes towards the conservation of cultural and natural heritage, as well as fostering a sense of responsibility towards nature.

It is noteworthy that all students successfully completed the activity and that there were no dropouts, which may indicate that students felt interested and motivated while engaging in the activity. These findings corroborate the hypothesis that was initially postulated.

The results of this case study may provide insight into the educational value characteristics of the EduCITY app. Consequently, the case study demonstrates that students are interested in this teaching strategy, not only because all students completed the game and solved the quiz voluntarily, but also because they claim to have developed knowledge, skills, and attitudes with the game integrated into the EduCITY app. Thus, it can be concluded that the game facilitated the generation of new knowledge for the participating students, enabling them to reinforce certain concepts and expand their understanding of sustainability. Experiencing sustainability concepts in a natural environment has the potential to foster a deeper appreciation of the environment and an increased sense of responsibility for its protection. Nevertheless, it is believed that in order to gain meaningful insights, it is necessary to conduct a greater number of activities with students to increase the sample size.

Overall, these results are in line with other studies that indicate that the combination of outdoor environments and cutting-edge technologies, such as augmented reality, can exponentially increase the educational effect and result in greater student engagement in sustainability education [3,24].

In this regard, it is important to emphasise the specific contributions of this study, which are as follows:

- Highlight the importance of deploying an MARG in the educational sector.
- Publish the 'EduCITY at the UA Campus' game questions, which serve as an illustrative example of an AR game.
- Publish part of the questionnaire survey developed based on the European sustainability competence framework, GreenComp [8], and the results obtained. The aim here is to encourage other educational research to use GreenComp.
- Encourage future research to use MARGs as a means of addressing content related to education for sustainability, based on the results of this case study.

One of the main challenges facing those engaged in educational research is to ensure that the results obtained can be generalized to a wider population. The limited representativeness of the sample used in this study constrains the scope for drawing inferences and conclusions. Nevertheless, there is some evidence that could potentially inform conclusions. A further limitation of studies with small samples is that they may not accurately reflect the experiences of students from different socio-economic backgrounds. The results of a study conducted in a particular cultural or educational setting may not be directly applicable to other contexts. Consequently, as future work, the EduCITY team will focus on developing more activities with students and the community in general to play with the EduCITY app and explore AR content to gather more information about the potential of this smart learning environment for learning gains, namely for both sustainability education and student motivation and understanding. This approach will provide valuable insights into the effectiveness of the smart learning city environment in enhancing education for sustainability, student motivation, and understanding, which will inform future developments.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Aveiro University (protocol code 07473848, 6 March 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available upon request to the authors.

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Appendix A

Table A1. 'EduCITY at the UA campus' game questions without AR content.

No.	Introduction	Question	Multimedia Content	Answer Hypotheses
1.1	Shhhhhh!!" Someone is trying to talk to you. Hear the sound…	What bird is this you are listening to?	Audio	Swallow
				Seagull
				Flamingo
				Duck
1.2	Cities are full of noise. This has several effects on human health, and it is measured in terms of sound pressure. Sound pressure is the pressure variation in the atmosphere caused by sound waves, and it is measured in decibels (dB).	Using the noise sensor, try to understand the range of sound pressure values to which the noise of a quiet conversation corresponds.	Environmental noise sensor	40–90 dB
				40–60 dB
				60–70 dB
				80–90 dB
1.3	Look around and find a stone carving.	What is the organ of the human body that is irreversibly damaged when the noise is above 90 dB?	-	Head
				Heart
				Eyes
				Ear
2.1	In the half-moon facing the Alameda da UA, we can observe green spaces, important in promoting environmental sustainability on the campus. Plants help to fix the soil, reduce temperatures and the effects of wind, absorb carbon dioxide and release oxygen.	Urban green spaces are important because they promote… (Select all the correct options.)	-	The incidence of winds
				The aesthetic value of the city
				The hunting of wild animals
				Environmental sustainability
3.1	What is most essential to life on Earth sometimes comes from the deepest places. Do you know what I'm talking about?	Inside this well you can see a device that was used to collect water. These devices were discussed in History classes, when you learned about the Muslim heritage in the Iberian Peninsula. What is the name of this device?	Image	Picota
				Nora
				Lifting system
				Aquifer
3.2	The Water Footprint is an indicator of the use of fresh water per unit of time, per person, product or service. For example, a smartphone consumes 12,760 L of water in its production. Water consumption occurs from the production of raw materials to the washing of vehicles used in transport.	Which of the following products have the highest water footprint? Select the correct option.	Bar graph	1 kg of peach
				1 kg of walnuts
				1 kg of red meat
				1 pair of jeans
4.1	The lake you are looking at is a way of bringing people closer to natural elements, such as water and fish, in addition to providing an aesthetic value for the campus.	What is the name of the prism shaped by the lake?	-	Cube
				Parallelepiped
				Tetrahedron
				Rectangle
4.2	Still about the lake…	Are the fish living in this lake typical of saltwater or freshwater? Can you recognise the species? Will it be a native or exotic species?	Image	**Carp, an exotic, freshwater species.**
				Sardines, an exotic species, from salt water.
				Redfish, an exotic, freshwater species.
				I don't know, I didn't taste the water.
4.3	Still about freshwater fish…	Do freshwater fish drink water?	Illustrative diagram	Freshwater fish do not drink water. It enters through the skin and gills.
				Freshwater fish drink water. It enters through the skin and gills.
				Freshwater fish drink water. It comes out through the skin and gills.
				Freshwater fish do not drink water. It comes out through the skin and gills.

Table A1. *Cont.*

No.	Introduction	Question	Multimedia Content	Answer Hypotheses
6.1	Near the access stairs to this canteen, you will find a bicycle park. The UA bike program is dedicated to the use and importance of bicycles for a healthier environment!	Looking at this park, estimate the total number of bicycles that can be safely stored.	Image	Between 10 to 20 bikes
				Between 30 to 40 bikes
				Between 80 to 90 bikes
				Between 50 to 60 bikes
6.2	Find the UA Canteen Social Action Services signboard.	How many steps do you have to take, at least, to get to know the 3 canteens?	Image	1300
				1170
				1400
				1270
6.3	The amount of food wasted worldwide is 1.3 billion tons, which corresponds to approximately one third of the food produced for human consumption annually. In addition to the waste that is produced when food is thrown away, there is also waste of energy, water and materials for its production, transport, processing and storage until consumption.	Watch the video. In 2017, in this UA canteen, how much food was wasted in 10 min?	Video	6 soups, 30 dishes, 5 fruits
				7 soups, 36 dishes, 8 fruits
				10 soups, 33 dishes, 3 fruits
				6 soups, 35 dishes, 9 fruits
6.4	In addition to waste, we have other food-related issues. Livestock, for example, produce 16% of the world's greenhouse gas emissions in the form of methane through the digestion. We must reduce the consumption of red meat for ecological and health reasons.	How can you reduce meat consumption? Select all the correct options.	-	**Increase the consumption of vegetables and greens, in a varied way**
				Consuming pre-made meals sold in supermarkets
				Plan meals to avoid eating unwanted foods
				Consume carbohydrates to replace meat
7.1	The Library of the University of Aveiro was designed by the architect Siza Vieira. The façade facing the Ria is wavy, allowing sunlight to enter continuously, but indirectly. The library's roof has cone-shaped windows facing north, making for constant lighting, thus reducing lighting costs.	What was the architect's main concern when designing this library? Select the correct option.	Video	He took care to create many shelves
				He used effective lighting solutions
				He used large windows to brighten up the spaces
				He was concerned about the noise inside the library
7.2	Still on the library...	This building appears as a parallelepiped and its façades are all different. The façade facing the Ria presents an undulating form, linking it to the place where it was built. What could have been the source of the architect's inspiration?	Video	He was inspired by shells and conch
				It was inspired by the natural channels of the Ria
				He was inspired by the waves of the sea
				He was inspired by the open pages of a book
8.1	This sculpture that features a human figure with a frog's head is a work by Paulo Neves. It is a tribute to a tool that, along with books, allows us to obtain knowledge! Watch it very carefully!	The internet search engine "Sapo" was developed at the University of Aveiro. What year was it created?	-	1985
				1975
				1965
				1995
8.2	More about the "frog"...	What sentence represents the "Frog"?	-	"The Future (still) starts here"
				"The Future (also) started here"
				"The Future (also) will start here"
				"The Future (also) starts here"

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