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CurioCity: Augmented Reality Gamification to Foster Recreational Learning

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Abstract: Augmented reality (AR) has garnered significant attention in educational research due to its potential to enhance learning experiences. AR technology offers an innovative approach to interactive education by employing virtual content and dynamic interfaces. CurioCity is an AR-based educational game that aims to enhance learning experiences by combining formal education and recreational games. The game was developed for smartphones and tablets, allowing users to interact with virtual content and dynamic interfaces in real-world environments. The game design is based on the principles of intuitive learning, which emphasise curiosity, exploration, and discovery. The game also incorporates gamification elements, such as challenges, rewards, and feedback, to increase user engagement and motivation. CurioCity serves as a proof-of-concept and a preliminary investigation into the future possibilities of AR in educational game settings. Through user testing and surveys, the project evaluates the game's usability, user satisfaction, and learning outcomes. The initial usability results with expert users show that CurioCity is an effective and enjoyable educational tool that can foster learning outcomes and user engagement. The project also provides insights and recommendations for future research and development.

Keywords: augmented reality; immersive learning; AR for learning; learning technology

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1. Introduction

In recent years, there has been a growing research interest in the potential benefits of using augmented reality (AR) tools for learning [1]. Studies have suggested that the use of virtual manipulatives, either to supplement or replace their physical equivalents in the classroom, can enhance levels of engagement, excitement, and learning outcomes [2]. Furthermore, these virtual manipulatives—offered within the domain of AR—allow for a more dynamic and interactive level of engagement. Another use of AR in education is developing interactive games to aid the learning process. A recent study using a game, "ChildAR", aims to provide a multi-sensory learning experience which encourages active participation through gamification elements such as rewards and challenges. The study resulted in a significant improvement in the children's learning outcomes, along with the fostering of an encouraging approach to education as a whole [3].

The combination of utilising both virtual manipulatives and gamification elements is what drove this project, an AR educational tool in the form of an appealing and fun game. Engaging with virtual manipulatives through a phone, tablet, or head-mounted display (HMD) holds value in a classroom environment. Moreover, children have a natural proclivity towards games and play outside of academic settings, and combining these presents us with a novel opportunity. By uniting educational content with gameplay, the ambition is to not just make learning a more enjoyable endeavour but to seamlessly integrate scholastic instances into day-to-day leisure, bridging the gap between formal educational and everyday play.

The objective of this research is to develop CurioCity, an AR game designed for children using the Unity game engine. Inspired by existing AR products and their applications, we aim to introduce AR elements into traditional gaming. The idea is to provide children with a more interactive and meaningful way to learn about the world. One of the primary goals is to ensure that the AR components are seamlessly integrated into the game, offering a natural experience that does not feel like a separate entity.

2. Background

AR technology merges the digital world with our real-world environment. It achieves this by overlaying digital information such as images, videos, or 3D models—such as in Figure 1—on our environment through smartphones, tablets, or HMDs [4]. The application and usages of AR have been of interest in recent years in domains such as education, healthcare, and entertainment [5]. For our purposes, we will focus on the potential benefits of applying AR technologies to our current educational practises and how the adoption of such applications would look like in and outside of the classroom.

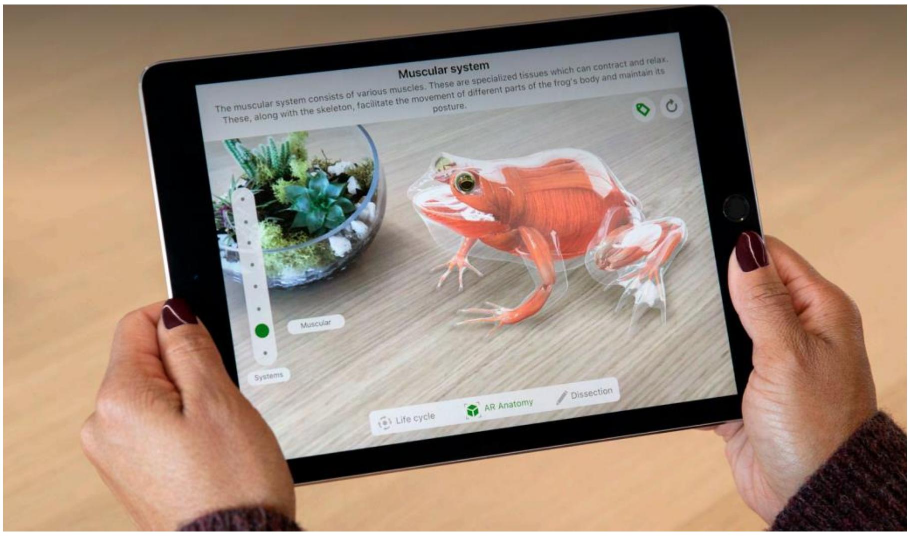

Figure 1. Example of an AR application showing an interactive 3D frog model [6].

In recent years, academic investigations have analysed the effects that AR technologies applied to educational settings have on pupil's motivation, comprehension, and attention. Examples of such uses range from geometrical manipulatives to aid pre-school learning [2] to creating dynamic learning environments on school field trips [7]. One significant advantage of using AR as a learning tool for students is the opportunity it provides for interacting and engaging with artefacts that would otherwise be inaccessible [8]. This presents to us a new method which we can utilise to help the learning process over and above the traditional textbooks and videos. The AR application outside of an academic environment, such as injecting it into educational games played on our devices, allows us to also take advantage of our natural inquisitiveness by introducing novel interactive experiences.

The future of AR is promising, but it has not been integrated into our classrooms yet, resulting in questions as to whether it is a practical proposal in the first place. The full potential of AR is dependent on hardware devices such as HMDs, which would need to be accessible to and adopted by the public or have gained institutional support [9].

2.1. AR in Education

While AR can be applied to many different fields, its utility in education can be found to hold high value [10]. Studies have widely documented the benefits of AR in enhancing learning outcomes, motivation, engagement, and comprehension across various educational contexts [11,12]. For example, a study led by Cai et al. [13] examines the effects of using AR to aid learning physics has on the students' conceptual understanding and their self-belief with respect to their academic ability. What resulted was a significant improvement in the students understanding of high-level concepts along with their self-efficacy. This may partly be due to AR allowing students to visualise abstract concepts more efficiently compared to what more traditional educational tools can offer [14]. The opportunity for students to virtually interact with typically foreign objects such as DNA structures or molecular models can provide new insights and levels of comprehension. By creating interactive digital objects for students to study, along with interfaces rich with information, educators can foster a more immersive learning environment that may enhance knowledge retention and understanding.

Adopting AR to better help students grasp high-level abstract concepts by using immersive visual aids is but one application in education. Younger students such as preschoolers will not be taught material as conceptually challenging as a high schooler will. Most of a young child's learning experience comes from various games and forms of play [15]. There is a more experiential form of schooling that teachers adopt compared to that of teaching young adults. Research has been carried out to observe the outcomes of younger children learning through AR games in the classroom, many reporting that the levels of engagement, motivation, and enjoyment were increased in the students. One example of this is a study by Zafeiropoulou et al. [16], which invited students aged 9–11 to play a treasure hunt-style AR mobile game to learn physics. This resulted in meaningfully positive feedback from both students and teachers regarding their motivations, engagement, and enjoyment. There is a trend in these studies, which is a heightened level of enjoyment and engagement when using AR tools to learn. The heightened learning outcomes and topic understanding appear to arise from both the immersive nature and enjoyment of using AR [17].

Applying AR tools to educational games and immersive classroom experiences, while seeming to have high value, do not come without its challenges and limitations. Several issues arise in including AR in a curriculum, such as the lack of devices in the classroom, technical issues around device compatibility and the rapidly growing technology and software, the training and experience of teachers to effectively integrate AR tools into their teaching methods, and economic concerns around the cost of applications and devices, potentially limiting many educational institutions [18]. While these are all concerning and somewhat limit the full potential of AR, much of the research in AR for education is one step ahead of the technology. For example, the way to appreciate the full capabilities of AR would be not to use our smartphones but to use HMDs or augmented reality smart glasses (ARSM), which are currently extremely difficult to implement in the classroom given the earlier stated economic and training limitations. However, AR is being increasingly adopted in fields such as healthcare, educational training, transport, logistics, and entertainment [19]. Furthermore, looking at the rapid development of the hardware and software, which allows AR to become more accessible and cost-effective [20], the above challenges may become less of a factor in the future. Let us now discuss how AR can be used outside of the classroom while still aiding learning.

2.2. AR in Game-Based Learning

The access to AR tools for the classroom is, as mentioned above, highly restricted. Small numbers of students using AR results in small data pools for studies researching tools that aid learning, causing difficulties in the better understanding and the creation of such. At home, however, most children have access to either a smartphone or tablet. A 2021 study in the UK found that around 80% of young children (aged 3–11) have access to a tablet, while approximately 96% of older children (aged 12–17) have access to a smartphone [21]. Given this prevalent access to smartphones and tablets among children, AR-based learning extends itself beyond the traditional classroom. The home now opens its doors to engaging and interactive learning experiences that can complement formal education. Games in education are not a new thing; many studies have shown the benefits that digital or physical games can have for children. These include increased motivation, levels of satisfaction, and competence [22]. Many children already engage in video games of some sort that are entirely educational or include educational material. Given the educational benefits of AR, along with the levels of engagement and pleasure games bring to children, bringing the two together may allow for the greatest effects on comprehension and motivation.

Although mobile and tablet-based AR games for the home offer more inclusivity, there are certain challenges that need to be addressed if AR is to be used as a valued learning tool. One challenge is the necessity to make an AR game feel diverse in the interactions and natural to the user [23]. Many studies report that the novelty of the experience causes children to find AR learning engaging and fun, even when they only spend a short time interacting with it. However, the longevity of playing a game and remaining engaged is less certain. There is a danger that AR in games, or AR more generally, if not implemented with certain challenges in mind, may be perceived as a gimmick [24].

2.3. Requirements Overview

CurioCity is imagined as 3D mobile game aimed at young children aged four and up that seamlessly transitions between AR and non-AR landscapes. Its purpose is to bring the benefits of AR technology to learning and engagement in a domestic setting, allowing children the advantage of playing an entertaining game while seeing educational artefacts come alive in their own home. At this point, it will be helpful to give a brief overview of what CurioCity contains as a game.

We created a 3D map that a character can roam using the touch screen with missions to prompt the player to find different buildings. Once the player reaches the buildings, an AR scene will load, allowing the player to interact and find out information about different artefacts such as the solar system or the human body. At any time, the player can also load an AR scene showing a 3D model of the map they are in, allowing them another way to view it and gaining information and clues about the different buildings to help guide their way. Once all buildings in a map have been found and artefacts explored, there will be a quiz based on what they have found, and after they are successful in completing the quiz, they will unlock the next level. The levels will be based on academic subjects such as science, mathematics, and history. The specifics of features and AR elements will follow, but for now, let us consider the requirements that will be needed for an educational AR game to be a worthwhile pursuit.

In view of the background research on the topic or AR and games for education, the most important characteristics of CurioCity are outlined below. The requirements have been carefully examined considering what is needed to make an entertaining game, intuitive and easy-to-use AR components, and making the educational aspects interesting enough to keep the users engaged. The key considerations are user experience, content quality, accessibility, and engagement over time.

2.4. User Experience

This is arguably the most important requirement, as it captures a considerable number of factors that constitutes a game [25]. This requirement covers how easy, intuitive, and natural it is for the user to play and interact.

***Navigation*:** Navigating between different scenes in the game must be obvious and easy. It should be clear to the user that scene changes will occur, and all buttons or touch interactions should be clearly defined.
***UI and Design*:** The user interface should be simple yet aesthetically pleasing to children. There should be continuity in the colours, shapes, and sizes for all UI elements to keep the application from feeling disjointed.
***AR*:** Any AR scenes must sense in the context of the game. Any AR objects must be easy to interact with and be recognised as objects to explore. Any gestures used to manipulate AR objects should not be complex; they should be intuitive, taking from common gestures used on a touch screen.

Gameplay: What the game is and how it is played should be apparent before the user attempts to play it. There should be a tutorial which can be accessed at any time. Gameplay should be appropriate given the target age and it should incorporate AR elements.
Content Quality: Content quality is also a very important requirement. As this is an educational game, if there is a lack of educational aspects or a poor quality thereof, the game will lose value and meaning [26].
Accuracy: The educational content must be accurate and validated through reliable sources.
Relevance and Engagement: All content should be relevant in the context of the rest of the material and game. It should be presented in an interesting way, either through offering narrative to the content or keeping the tone and style of the content amusing and light.
Curriculum Alignment: The content should align with the current curriculum of the demographic of the users. It should not offer educational content that may conflict with their formal education, instead offering a chance to further explore areas they are in the process of learning.

3. Methodology and Implementation

The development tools used for this project are displayed in Figure 2. Unity was the chosen game engine due to the fact it is slightly more beginner-friendly than its counterpart, Unreal Engine. Visual Studio was used, as it is a powerful IDE when scripting in C# and is very compatible with Unity. During the development process, the Samsung Galaxy S22 was used as a display device, running Android 13 (API level 33) to test and run the app. In the development of CurioCity, AR Foundation was used, a cross-platform framework in Unity offering interfaces and APIs to readily take advantage of AR concepts such as plane detection, device tracking, and AR ray casting.

Figure 2. Game map overview.

The first step was to find the best way to control a character in the game. We used a touch joystick approach, as many mobile and tablet games adopt this, allowing for a familiar feel when playing. To implement this, a joystick package was used (https://assetstore.unity.com/packages/tools/input-management/joystick-pack-107631#description (accessed on 10 September 2024)), handling the user input, which was attached to the player's character object, which was also used from a package (https://assetstore.unity.com/packages/

3d/characters/humanoids/character-pack-free-sample-79870 (accessed on 10 September 2024)). The character object then has the main camera attached, along with an edited PlayerMove script from the same package (v2.3.0), handling the character's positioning and movement, camera view, and running animation.

The button UI was used to navigate the user between certain scenes, for example, the main game scene and the tutorial. The colliders were used to load an AR scene once the user reached the prompted building (encased by an invisible collider). This ensured a smooth transition from the game and the AR scenes. It also saves the player's position on the map between scene changes to ensure they can switch scenes and continue exploring from where they left off.

3.1. Game Map

In the design and implementation of the game map, a package was used to quickly and efficiently place and edit the map to our needs (https://assetstore.unity.com/packages/3d/environments/urban/city-package-107224 (accessed on 5 August 2024)). We tweaked and changed parts of the pre-set map that was offered, including changing buildings to suit our theme, removing parts of the map, adding a hard border around it so the player cannot leave it, and adding colliders where necessary to allow for the transition to AR scenes. Figure 2 shows the overall design and look of the map. The low-poly style is intended to fit in with the cartoon style design that many games adopt for our demographic. Moreover, the colourful buildings and large open roads and spaces allow the users to easily understand the map, providing easy and visually pleasing navigation throughout the game. The AR application overlays virtual content in the real world through the device's camera, but the quiz part is in 2D and does not use augmented overlays; this is a supplementary feature to enhance interaction without using AR. This combination of AR overlays and supportive 2D elements is designed to ensure a cohesive user experience within an augmented environment.

3.2. AR Objects and Interactions

The second AR scene created is a low-poly model of the solar system. We used an asset containing models of the sun and each of the planets (https://assetstore.unity.com/packages/3d/low-poly-solar-system-42713 (accessed on 10 September 2024)), then arranged and aligned them to represent the size and distance of each planet. LeanTouch (https://assetstore.unity.com/packages/tools/input-management/lean-touch-30111 (accessed on 10 September 2024)), an input management package, was used to implement several features. These include pinch-to-scale and twist-to-rotate interactions. The usability of these interactions is intuitive and simple. We implemented two additional interactions, one being a touch interaction which displays a text pop-up of fun facts about the planets selected on the screen using a ClickHandler script. The second centres the clicked planet to the camera using a CenterPlanetsOnCamera script, making it clear which object has been touched. These two separate functionalities tie together to make the interactions clearer and more user-friendly. Finally, a progress bar which unlocks the quiz was added, increasing when each planet is clicked to ensure that the user has not missed any interactions and information before proceeding.

3.3. User Interface

The user interface for the game covers every scene in the game, which are 6 in total, namely the main menu, the tutorial, the game, the AR map, the AR solar system, and the quiz. All buttons, colours, text boxes, panels, and images are all share the same design throughout, ensuring that the player has a sense of continuity, especially between the AR and non-AR scenes. Figure 3 demonstrates the UI in each scene.

Figure 3. Screenshot from each game scene. (From **top left** to **bottom right**) main menu, tutorial, game scene, AR map, AR solar system, quiz.

It was important to design a simple UI that followed a similar sense of style. Using the same buttons, colour panels, and font throughout helped, and using a screenshot of the map as the background also brought together a city theme. We decided to also make the text boxes semi-transparent, along with the background, as it helped to create a sense of being in the game scene when you leave it, for instance, to revisit the tutorial. The main aim of the UI design was to create a sense of continuity and to help the user feel like they never really leave the game and they are just moving around it.

3.4. Additional Scripting and Features

Additional scripting was required to create the quiz, taking scores and updating the correct answers on each question, displaying a "next level" or "try again" screen upon completion. This was achieved by creating the class Quiz Manager, using arrays of public variables containing the questions and answers and displaying the next questions and set of answers while updating the position of the correct answer each time. We also added music which plays from the main menu screen and persists across all non-AR scenes, while pausing in an AR scene. A drop-down menu opens option buttons to revisit the AR city, the tutorial, and to mute the music. Figure 4 shows the flow state of the game given the different scenes. The arrows represent the possible transitions between scenes.

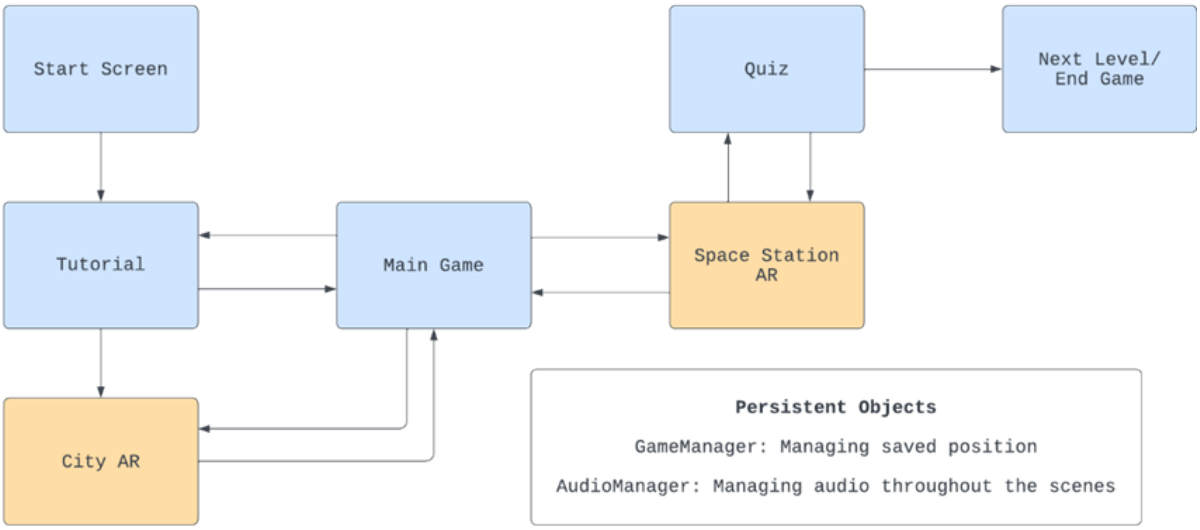

Figure 4. A diagram demonstrating the flow of the game. AR scenes are in orange and non-AR scenes are in blue.

4. Evaluation and Discussion

4.1. Testing and Analysis

The testing approach for this project comprises both expert user evaluations and play-test functionality assessments, which means to test the usability and taking feedback on the approach. By using these two approaches, we hope to gain insight into the user perceptions of the game and its AR elements and the integrity of all the implemented features.

4.2. User Evaluation

The tests were conducted with eight participants between the ages of 21 and 28, using an Android build of the game on a Samsung Galaxy S22. These participants were chosen to test the usability and quality of the application, not to evaluate the outcomes. The tests were conducted in different indoor environments, a large booth with a large open table, a smaller enclosed area with a small table, and a floor. This was to investigate if the AR features were equally effective on different surfaces and in different space confinements. None of the participants had any substantial experience with AR, which helped to slightly balance the difference in age against the target demographic. The participants were briefed about the game, being an AR educational game for children aged 4+. No tasks were assigned; instead, they were asked to load and play the game as they naturally would. The rationale behind this was to test how easy the game was to play and how intuitive the controls and interactions were. The game provides instruction throughout, and it is essential that they are clear and concise. The participants took around 5 min to play through the game, after which they were asked to fill out an anonymous survey containing eight questions with space for feedback at the end. The questions were designed to gauge the participants' experience with the game instructions, the intuitiveness of the AR interactions, the performance of the game, and its educational relevance. The results of the questionnaires are presented in Figures 5–8.

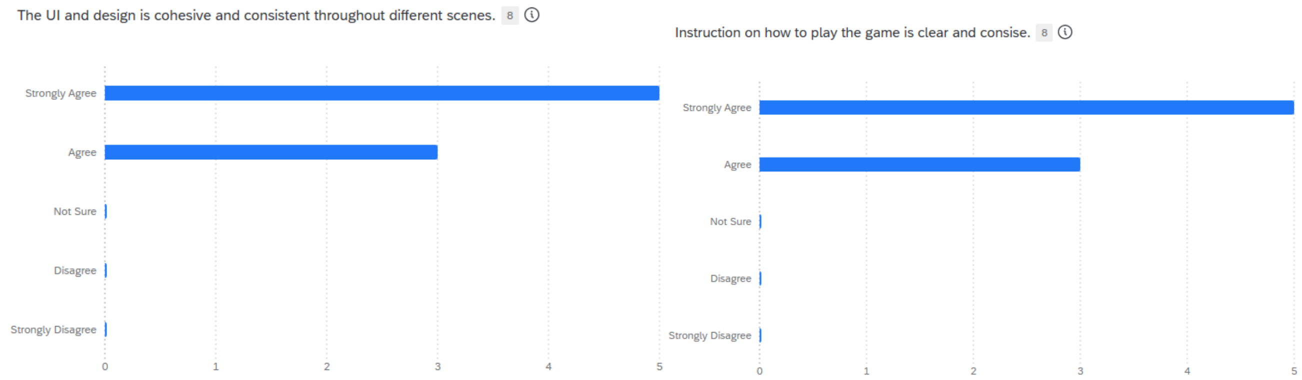

Figure 5. Results of the evaluation questionnaire for design consistency and instructions for users.

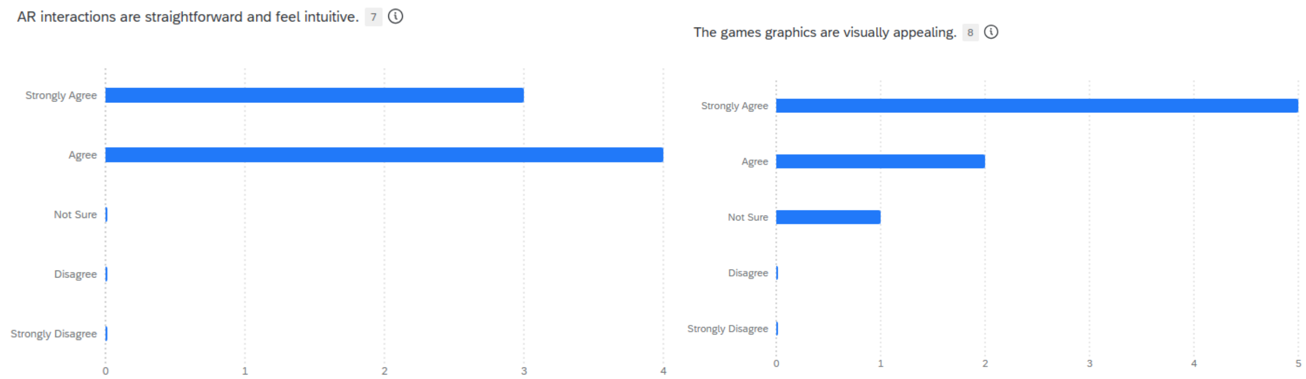

Figure 6. Results of the evaluation questionnaire for interactions in AR and visually appealing graphics.

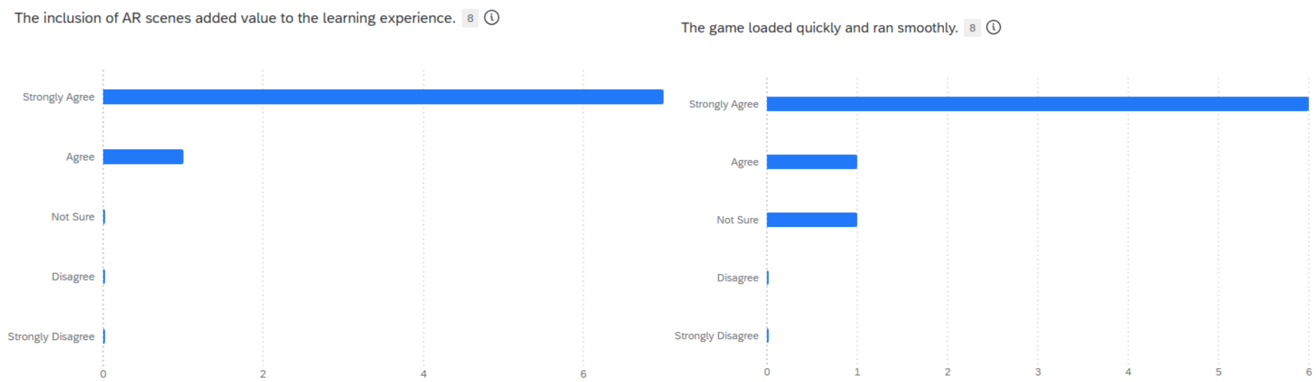

Figure 7. Results of the evaluation questionnaire on the use of AR scenes as learning content and the responsiveness of content.

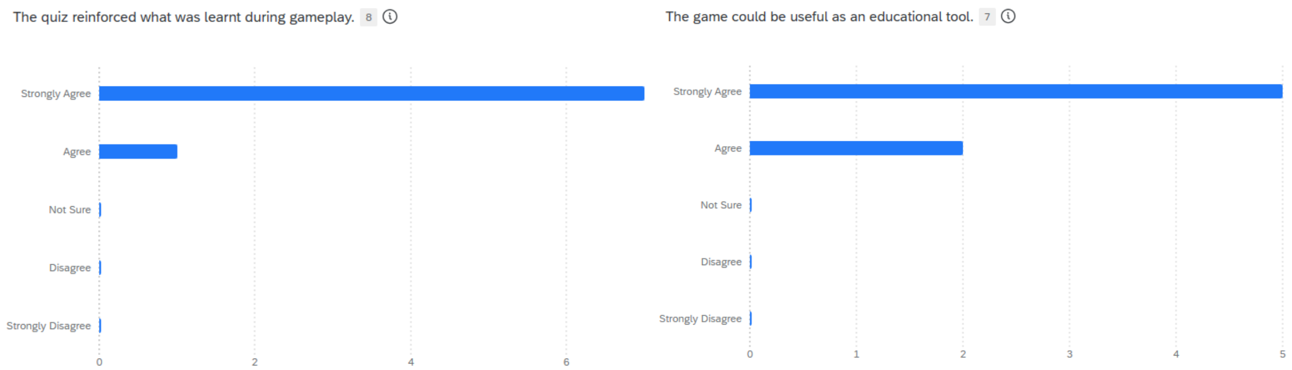

Figure 8. Results of the evaluation questionnaire about the quiz and the overall potential of the game as a learning tool.

4.3. User Feedback Analysis

The overall survey results and feedback were extremely positive. The application received high ratings and positive feedback for consistent design across all scenes and the clarity of instructions provided for interacting with the application. The approach ensures a smooth and intuitive user experience, making it easier for users to engage seamlessly with each part of the application. This consistency in design and clear instruction set has contributed significantly to the overall quality and usability of the application, reinforcing the user's commitment to excellence in interaction design. The users provided good feedback on graphics quality, responsive speed, and intuitive interactions. These attributes minimise cognitive, physical, and mental workload following the NASA Task Load Index [27], creating a more accessible [28] and enjoyable user experience.

The participants considered the AR elements intuitive while adding value to the educational experience. The consistency and aesthetic of the design and UI was well received, along with the tutorial and instructions on how to play and interact with the game. One user commented explicitly on their "*enjoyment of interacting with the 3D model of the same city in which the game is played*". As for the other positive feedback, it all followed a trend of the *enjoyment, educational value, and intuitiveness* of the game.

From the feedback, there were also several issues that the participants found with their experience of the game, one being that there were *UI inconsistencies, pointing out that one of the text boxes, which the user can close once reading*, clashed with other textboxes if not closed when interacting with the solar system model. This meant the user could not read the educational content and struggled to close the text box due to the UI components overlapping. Another criticism was that the pulsing animation on the "Start Game" button while reading the tutorial slides was found to be quite distracting. A similar distraction was observed during the quiz, as the game's theme music played during it. All of these observations are easily resolved, requiring small UI and code snippet changes. However, two more concerning complications were observed.

The application's design efficiency not only enhances ease of use but also contributes to smoother engagement, reducing the effort needed to navigate and interact effectively. This user-centred approach has led to higher satisfaction and engagement ratings, affirming the application's strengths in usability and performance.

Of the complications, the first was that it was awkward and tricky to navigate and interact with the 3D city model when in a more confined space. As the size of the city was set to load quite large to allow for a more immersive view and easier gaze interactions, without an appropriate physical space, this could hinder the users' overall experience of the game. If it were necessary for the game to be played in more confined spaces with smaller areas, the city AR scene would likely need to be redesigned in a way that does not require a minimum area to appreciate. Finally, saving the characters' position in the game between scenes did not work. Each time a user manually loaded another scene and the game scene was reloaded, the player character was back at the map's starting point.

Most of the participants commented that it did not hinder their experience; however, it highlighted an important issue that will need further investigation.

The consensus of the participants' experience with CurioCity was that it serves as a fun and intuitive educational tool. This follows from previous research on utilising AR and games for educational purposes. Although not tested on the target demographic, the tests provided valuable feedback on the overall experience and engagement that the game could offer. The quiz module received outstanding feedback as an educational tool, praised for its clarity and engagement, which effectively supported the learning process. Users appreciated the thoughtfully structured questions, which reinforced key concepts and encouraged active participation. Overall, the participating users were highly satisfied with the application's strong graphics quality, interaction intuitiveness, and responsive speed. This design reduced cognitive and physical workload, enhancing both the quiz module and the application's effectiveness as a learning tool.

5. Limitations

One of the limitations of this study is that the evaluation of the AR game for learning was conducted solely with expert users. While expert feedback provided valuable insights into the usability and effectiveness of the approach, the findings may not fully reflect the experiences of actual end-users, i.e., children or students in a real-world educational setting. Future work should involve conducting evaluations with real end-users to obtain more relevant and diverse feedback, ensuring that the AR game meets the needs of the target audience in terms of usability, engagement, and learning outcomes.

6. Conclusions

Immersive technology in its different forms with gamification is an exciting and innovative research field with many applications in education. They can enhance learning outcomes and increase learners' motivation, self-efficacy, and engagement by providing interactive and immersive experiences that appeal to different learning styles and preferences. Children naturally drawn to games can benefit from the intersection of education, AR, and games, which offers a unique opportunity to create a fun and engaging educational tool accessible to almost everyone with smartphones or a tablet. CurioCity is a project that explores this potential by developing an interactive and immersive educational AR game that allows learners to explore different aspects of a city, such as its history, culture, landmarks, and environment. The outcome of the project demonstrates the value of AR in creating meaningful and intuitive learning experiences that can foster curiosity, creativity, and critical thinking. The game design is consistent and delivers educational content in an immersive way that aligns with the learning objectives and outcomes. CurioCity is a proof-of-concept that showcases the possibilities of AR in educational gaming environments and provides insights for future research and development in this domain.

7. Future Work

Looking forward, several functions could be taken to extend this project. Given more time and resources, further sensory and immersive features, a more exhaustive narrative, gamification elements such as rewards and a collectibles system, and additional AR scenes could all be added to enrich the game with more playability, engagement, and immersion. Furthermore, further testing with actual end-users and research would provide a more comprehensive analysis of the future benefits of such an approach to learning.

This project has provided a framework for an AR-based educational game; the development has provided invaluable insights into AR technology and its application in education. Future iterations supported by more structured methodologies could see it becoming an essential tool for experiential learning. In summary, while the full potential of AR learning tools is still being discovered, developers need to attempt to showcase the best of what they offer. The more AR tools and applications are developed, the more we can test and refine them and their uses. AR could be a powerful instrument in education, just as it is proving to be in various other fields. This project has demonstrated one way in which AR can demonstrate itself to be a valuable addition to our current educational practises.

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