Using Web 3D and WebXR Game to Enhance Engagement in Primary School Learning

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***Abstract*— Plastic recycling has been a global issue for many years. Thus, it is important to provide education to the young generation with current knowledge. However, designing an efficient learning resource for primary children (ages 5¬6) is challenging for various reasons, such as their engagement and the efficient delivery of the learning content. Web3D and WebXR are used in many educational applications. This research proposes a system that supports the combined use of Web3D and WebXR technologies to include elements of both Virtual Reality (VR) and Augmented Reality (AR) interactions to raise awareness about plastic recycling. This paper explains how Web3D and WebXR was used in this learning resource and how the mixed XR interaction was used to facilitate the game-based learning design. The results indicate that the learning session was successfully delivered within a classroom setting. Nevertheless it point to the need for further data. This project provides a case study on how to mix the use of Web3D and WebXR to enhance the engagement of pupils in primary school learning.**

Keywords—Web3D, WebXR, Extended Reality (XR), primary school education

I. Introduction

Globally, there is a growing awareness of the impact of human activities. Plastic pollution is one such world-wide problem that has been identified by the UK government as requiring immediate direct action [1]. Researchers recommend that it is important to educate the younger generation about the benefits of recycling and prepare them for sustainable living [2]. The Let's Go Green (**LGG**) project introduced in this paper aims to use recent digital media learning materials to engage with a younger audience (primary school) to increase their knowledge about plastic recycling.

Research shows that by blending the virtual world with reality, computer-simulated 3D virtual environments can enhance learning by providing richer learning resources with fewer limits in a safe learning environment [3]. The fast development of Web technology such as web-based 3D content (**Web3D**) and Web Extended Reality (**WebXR**) makes it possible to produce cross-platform and affordable 3D virtual learning content [4]. Web3D technology is reported to be beneficial for delivering learning content in some early research [5]. However, Extended Reality (**XR**) is a more recent term used to describe all immersive technologies including Virtual Reality (**VR**), Augmented Reality (**AR**) and Mixed Reality (**MR**). Therefore, compared with other digital media types, XR can blend virtual information with real 3D information naturally [6]. In other words, XR technology is capable of creating playful learning scenes while still engaging the children with the real world [7]. WebXR provides Application Programming Interface (**API**) for delivering XR content through web browsers [8]. With a promise of simplification and unification of cross-platform XR development and access. WebXR may bring a "real revolution in multimedia content for education" [8, 9]. Therefore, there is a potential that Web3D and WebXR based learning materials can be used to help the children to learn about plastic recycling.

Although some research [9-14] demonstrates the benefits of using Web3D and WebXR, it is still a challenging task to design and implement such a system especially for primary school children [15-19]. There is very little research about mixed used of XR (for example, by using both AR and VR) interaction with WebXR content and Web3D content within a classroom setting. Therefore, it is significant to explore learning content that contains a combination of media types, which then presents a research question: How to design and implement a system that can be scaled to a typical primary school classroom that supports the mixed use of Web3D and WebXR?

This paper presents a practical way to use Web3D and WebXR to create learning content. The project aims to resolve the problem of delivering content on sustainability to primary school children in the classroom. The project successfully delivered a personalised learning experience within a typical classroom (as opposed to one-to-one testing in a lab) using a combined Web3D and WebXR learning materials.

II. Background and Literature Review

A. *LGG project Challenge*

For the LGG project, children in the age range 5-6 years old were chosen. Children aged 5-6 are curious about exploring new tools which allows more effort to be put on designing the learning engagement using new technology. However, a disadvantage of using this age group is that they are generally very active and easily distracted. It could be challenging to maintain their engagement during the learning. Initially, it can be used in a classroom with a group size of 20-30 children. Aside from the characteristics of the children, there are also challenges with the learning content design and the technologies available. For example, which XR technology should be used and how to present the learning content so that the children are engaged with the learning materials. A further challenge would be how to make use of the school hardware, software and IT support that is available.

Web technology provides a good solution to most of these? IT challenges. However, when combined with XR interactions, there are other questions to answer. For example, how to select the XR technology and present the learning content so that the XR technology will engage the children with the learning materials. Therefore, such these problems need to be considered during the design phase.

B. XR technology for children's education

Other researchers have proposed or tested XR educational systems made for primary school children [17, 18, 20-25]. For example, marker tracking AR interaction is used to support children with Special Educational Needs and Disability (SEND) [24], earthquake training [25], waste management [26], recycling [27] and other learning content [23]. GPS based AR is used in recycling education [28]. Some researchers found that although there is not a significant difference in the knowledge gain between AR games and non-AR games, the AR games showed a positive impact on attitude and behaviour [27]. Some researchers found that VR can potentially be used to enhance people's interest and knowledge for environmental issues [29]. Most research, including this project found that it is beneficial to add game elements to the design [27-29]. However, unlike this research, most designs used mobile AR, which requires extra steps to work such as downloading specialist applications which can normally only be executed on mobile devices. Furthermore, other differences are that most researchers only focussed on one type of XR technology (either AR or VR). Moreover, some applications can only be used within a certain location [28]. Finally, since most AR and VR applications, for both computers and mobile devices, normally require specific development tools, it can be expensive to implement different XR technologies in to one application.

However, WebXR provides scalable and affordable solutions for XR applications. Many researchers have adopted Web3D and WebXR for education and training in areas such as science [9], engineering [10], history [11] and medical education [12]. It also supports different types of XR technology such as AR [7] and VR [11] interaction. This type of technology can be used on mobile devices which provides an affordable and scalable XR experience, including Head Mounted Displays (HMDs) [13]. Also, the web technology is sufficiently powerful to support more complicated user applications such as multiple user XR interaction [14] through a simple web browser. Therefore, WebXR provides a solution to overcome most project challenges and also provides support for different types of XR technology without involving new software and potentially complicating ICT provision.

C. Game-based learning theory

Some researchers highlighted that XR interactions (such as AR interaction) are naturally playful, but it requires the XR elements to be integral to the learning objectives to make it benefit to the learning [7]. In terms of learning designs, there have been some research about using XR in children's education [7, 15-19]. However, most research is still at an early stage of applying XR to primary school education. This means there are very few guidelines on how to design and implement educational resources using XR technology [19]. Nevertheless, it is popular to use games with XR technology to make the learning processes engaging [21, 23, 27-29]. Therefore, "game-based learning" theory [30] can be used to guide the design process. Game-based learning theory is based on the premise that knowledge can be obtained through a game play space provided [31]. Plass *et al.* suggests that game-based learning requires the designer to manipulate the game rules and activities to help achieve the learning objective(s) rather than simply applying game elements to the activities. A simple game-based learning loop includes "challenge", "response" and "feedback" which is linked through game play. Game design features are put at the centre of the learning experience to create a playful character for the learning experience [31].

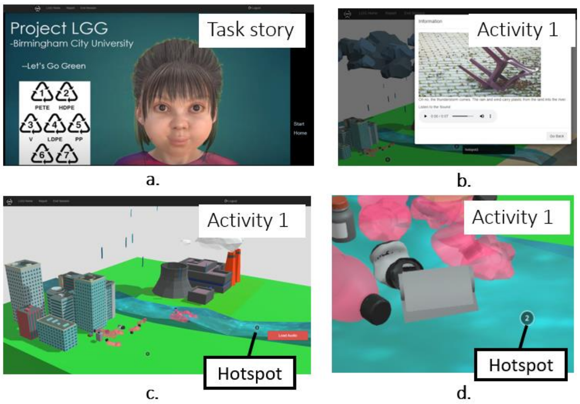

Fig. 1. Sample of storytelling with human avatar and different views in Activity 1

III. METHODOLOGY

A. "Challenge" design

Three "challenges" are designed, using the "hide and seek" game rules. Each challenge can be implemented as learning activities that allow the children to learn while playing the game. The children are challenged to find all the hidden information to be able to progress. learning objectives for each activity are described below:

Activity 1 aims to help the children explore the current problems with plastic recycling. Allowing them to access information about where to find plastics and why it has become a problem.

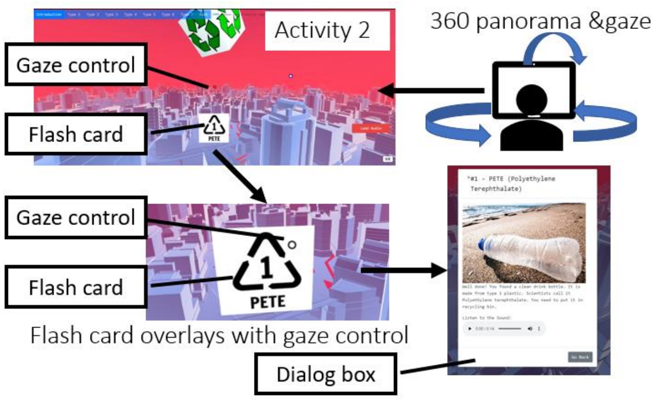

Fig. 2. The design of applying WebXR VR interaction to Activity 2

Activity 2 aims to introduce different types of plastics and the associated plastic symbols. Allowing them to access information about what the different types of plastics are and if they can be recycled.

Activity 3 aims to introduce examples of where to find plastic recycling symbols on product packaging. Allowing them to practise the recycling skills and assess their knowledge on plastic symbols.

Through this process they discover important information related to plastic recycling. They also develop problem-solving skills related to the environment. Visual game elements are used to stimulate the children's interest to exploring the learning content. A story telling style introduction using a digital human avatar helps to guide the game narratives through the learning challenges. For example, a video with a human avatar (Fig. 1. a) was made to introduce the game tasks.

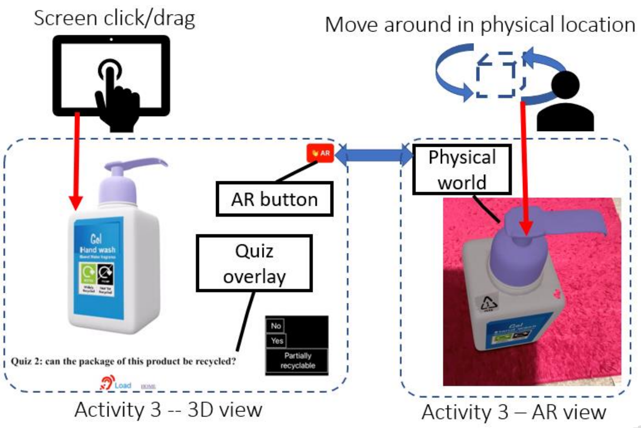

Fig. 3. The design of applying Web3D and WebXR AR interaction to Activity 3

B. *"Response" design – interaction design*

All three challenge activities require the learner to find the information through a set of game interactions. The final interaction design is described below:

Activity 1 uses screen-based 3D interaction. Fig. 1b, 1c, and 1d demonstrates some samples of different views in activity 1. The interactions include screen click and movable 3D models (Fig. 1c and 1d). Once a numbered hotspot is clicked on, a dialog box opens with the learning content (Fig. 1b). Audio recordings were made available to help read the materials. It also gave the learners a chance to learn and get used to on screen interactions with 3D objects.

Activity 2 uses mobile VR interaction. Fig. 2 demonstrates the design of applying WebXR VR interaction to the activity. The interaction utilises the built-in gyroscopes in the mobile devices and allows the children to explore a 3D space by moving the device around. There were seven flash cards with plastic symbols floating around in the 3D space. Centre gaze control (fixed in the middle of the screen) is used to trigger the hotspot flash cards containing the plastic symbols. Once the gaze control overlays with the flash card, the dialog box with learning content pops out to show the hidden information.

Activity 3 uses Simultaneous Localization and Mapping (**SLAM**) AR interaction. Fig. 3 demonstrates the design of applying Web3D and WebXR AR interactions to Activity 3. Initially, the learner can load the 3D view of the object. Using click and drag to rotate the object (Fig. 3 3D view). Once the AR button is clicked, the learners can use the mobile device camera to scan an available space (such as a desk or floor surface), the digital 3D model is placed on the scanned surface as if it was put there in the real world (Fig. 3 AR view). After that, the learner is able to observe the object from different angles (move around in the physical location) to look for the plastic symbols. Once the observation is finished, the learner can return to the main screen and complete the quiz. The correct answer will lead to the next question. Once the final question is completed it will end with a celebration page to finish the learning journey.

C. *"Feedback" design*

Instant multimedia feedback can be triggered as soon as the learner interacts with the application in all three activities. For example, in Activity 1, the learner can get different 3D views by rotating and moving the Web3D models or clicking on the hotspots. In Activity 2, if the screen centre gaze control is over-laid on to a flash card, it will trigger an animation of card disappearing. In Activity 3, the AR 3D model can be observed from different angles once it is anchored to a physical location. Apart from 3D models, rich multimedia content including audio, video and expressions of reward are also added to the learning journey to help give feedback to the learner. For example, at the beginning of each activity, there was an audio summary of the last activity and the new tasks in the current activity with hints. In Activity 3, instant quiz feedback will be delivered through audio recordings.

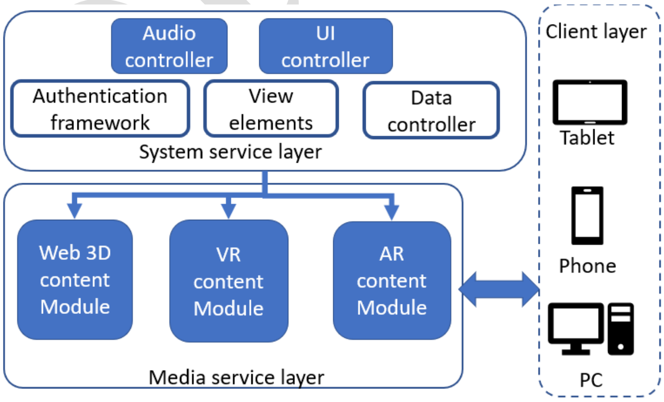

Fig. 4. System Architecture

IV. SOFTWARE SYSTEM DESIGN AND IMPLEMENTATION

One of the challenges for the system is how to integrate the required WebXR technologies together, instead of simply connecting them with hyperlinks. The design needs to reuse the resources and maintain use and user data. The project is based on a previous project [32] and most of the Web3D functions have been reused. However, as this project needs to integrate more media types, the framework was extended to facilitate video streams and WebXR content. The detailed design is shown in Fig. 4. The high-level architecture design is based on a Client-server model and the final results are Web3D and WebXR content. There are three layers aimed at building different functional stacks to achieve the systems goals. From the top to the bottom, these layers are called "Systems service layer", "Media service layer" and "Client layer".

The "System service layer" is the basic layer that contains all sharable functions that can be re-used by all the media applications on the "Media service layer". For example, audio controller controls the audio resources that load at the beginning of every activity scenario. The view elements are a set of multimedia resources that can be used by the web application to deliver content to the users. In Fig. 4, the white boxes represent the function blocks that use server-side functions such as database connections, and the blue boxes represent reusable client-side functions.

The "Media service layer" is a layer where all function modules are implemented for different Web3D and WebXR content. It currently consists of three different modules. The "Web 3D content Module" provides functions to generate web 3D applications. The detailed structure is explained in a previous paper [32]. The VR content Module provides functions to generate VR interaction content. It implements frameworks that support scenarios that require the mobile gyroscope. The AR content Module provides functions to support the AR interaction. It implements frameworks to be able to use the mobile camera and sensors to render the AR content.

Existing WebXR software packages such as Aframe VR and Google Model-viewer are used to render the XR content in Activity 2 and Activity 3. Aframe VR allows the VR content to be rendered on mobile devices and it uses the mobile gyroscope sensors to allow the users to explore the 3D panorama. Model-viewer allows the user to use the AR function ARCore-supported Android devices and ARkit-supported iOS devices. Both technologies can be embedded with existing software frameworks using HTML, CSS and JavaScript code. The web application is deployed on a windows server and two databases are implemented. One database (SQL) maintains all user information, and another database (No-SQL) is used to collect the interaction data.

TABLE I. TEST HARDWARE AND SOFTWARE LIST

Hardware	Software	Usage
iPad	iOS, Safari browser	Used by the children to load the programe. One iPad is used for demonstration
Laptop with big in classroom monitor	Microsoft, Microsoft Edge	Used by the teachers to give Software demonstration
Server	Microsoft server	Web application content host

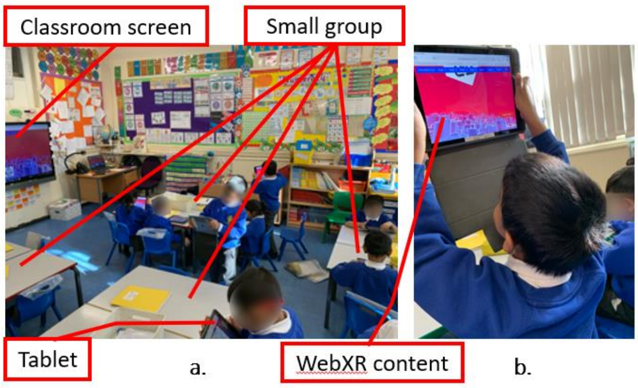

Fig. 5. Test environmetn in classroom settings

V. TEST RESULT

The research had ethical approval and followed ethical guidelines [33]. The experiment was conducted in 2022 with 17 recruited participants. All participants were aged 5 - 6 years old and from the same year group (Year 1) and same primary school in the UK. They were asked to participant in a lesson in their usual classroom. The learning environment was set up as shown in Fig. 5. A classroom with good lighting was used. Small groups (4 to 6 children) were setup and sufficient space was provided around the groups for each child so that they could walk around and observe the 3D objects using XR interaction. A few books were put on the table to make the WebXR tracking work better. All the main devices used in the experiment are explained in Table I. The session was successfully delivered and the learning activities took approximately 50 minutes. Their classroom teacher and the two researchers supported the process. Three students left for short period during the experiment, but the other children remained engaged throughout the whole process.

Prior to the session there was communication with the school ICT staff to check the school devices supported WebXR. Once compatibility was confirmed there was little ICT involvement as the learning content was online and only the latest Safari browser was required to render the content. At the start of the session there were a few settings to change, such as manually logging in to the system and turning off screen rotation permissions.

VI. CONCLUSION AND FUTURE WORK

Applying XR technology to teach about the environment related topics is not new and has been shown to have a positive impact on the learners' attitude and behaviour. However, applying the XR technology, especially WebXR, to primary school level children is still at an early stage. The challenges faced included:

- lack of design guidelines
- lack of consideration of scalability for school classrooms and
- a lack of research on the mixed use of XR interaction.

This paper contributes to this area of research by introducing a learning system which supports different 3D based media content, including Web3D and WebXR (including both AR and VR interactions). The system is used to implement the learning content designed for plastic recycling for children in year one, UK (5 - 6 years old). This paper introduced the LGG project as well as the project methodology, learning design and overall project process. The learning design is guided by game-based learning theory. The system software design focused on using reusable modules to facilitate the Web3D and WebXR learning content. The implementation chose web technology which is proven to help the project scalability and provide better reuse of existing school resources. The session was successfully delivered in a UK primary school classroom. There was very little ICT involvement apart from the need of some pre-session settings on the tablet.

However, future work is required to evaluate the system using the data collected during the process. Detailed data analysis such as pre-session and post-session test and questionnaire data is required to find how the use of Web3D and WebXR affected the young learners' engagement level and learning outcomes, especially when using mixed use XR interactions. Further research is also required to obtain evidence from a larger sample size with a wider age range and over a longer time period. For example, this project can be scaled up to other age groups in the future. Meanwhile, further work is needed to improve learning content design, interaction design and system design based on the feedback from this research.

References

[1] UK backs ambitious global action to tackle plastic pollution, https://www.gov.uk/government/news/uk-backs-ambitious-global-action-to-tackle-plastic-pollution, updated on 25/08/2022

[2] Oluwadipe, S., Garelick, H., McCarthy, S. and Purchase, D., 2022. A critical review of household recycling barriers in the United Kingdom. Waste Management & Research, 40(7), pp.905-918.

[3] Correia, A., Fonseca, B., Paredes, H., Martins, P. and Morgado, L., 2016. Computer-simulated 3D virtual environments in collaborative learning and training: meta-review, refinement, and roadmap. Handbook on 3D3C Platforms, pp.403-440.

[4] Rodríguez, F.C., Dal Peraro, M. and Abriata, L.A., 2021. Democratizing interactive, immersive experiences for science education with WebXR. Nature Computational Science, 1(10), pp.631-632.

[5] Chittaro, L. and Ranon, R., 2007. Web3D technologies in learning, education and training: Motivations, issues, opportunities. Computers & Education, 49(1), pp.3-18.

[6] Bailey, J.O. and Bailenson, J.N., 2017. Immersive virtual reality and the developing child. In Cognitive development in digital contexts (pp. 181-200). Academic Press.

[7] Oranç, C. and Küntay, A.C., 2019. Learning from the real and the virtual worlds: Educational use of augmented reality in early childhood. International Journal of Child-Computer Interaction, 21, pp.104-111.

[8] Pomykała, R., Cybulski, A., Klatka, T., Patyk, M., Bonieckal, J., Kedzierski, M., Sikora, M., Juszczak, J. and Igras-Cybulska, M., 2022, March. "Put your feet in open pit"-a WebXR Unity application for learning about the technological processes in the open pit mine. In 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) (pp. 493-496). IEEE.

[9] Rodríguez, F.C., Frattini, G., Krapp, L.F., Martinez-Hung, H., Moreno, D.M., Roldán, M., Salomón, J., Stemkoski, L., Traeger, S., Dal Peraro, M. and Abriata, L.A., 2021. MoleculARweb: A web site for chemistry and structural biology education through interactive augmented reality out of the box in commodity devices. Journal of Chemical Education, 98(7), pp.2243-2255.

[10] Liarokapis, F., Mourkoussis, N., White, M., Darcy, J., Sifniotis, M., Petridis, P., Basu, A. and Lister, P.F., 2004. Web3D and augmented reality to support engineering education. World transactions on engineering and technology education, 3(1), pp.11-14.

[11] Luigini, A., Fanini, B., Basso, A. and Basso, D., 2020. Heritage education through serious games. A web-based proposal for primary schools to cope with distance learning. VITRUVIO-International Journal of Architectural Technology and Sustainability, 5(2), pp.73-85.

[12] Al Hafidz, I.A., Sukaridhoto, S., Al Rasyid, M.U.H., Budiarti, R.P.N., Mardhotillah, R.R., Amalia, R., Fajrianti, E.D. and Satrio, N.A., 2021, September. Design of collaborative WebXR for medical learning platform. In 2021 International Electronics Symposium (IES) (pp. 499-504). IEEE.

[13] Sobota, B., Korečko, Š., Hudák, M. and Sivỳ, M., 2020. Collaborative virtual reality usage in educa-tional and training process. In XI International Conference of Information Technology and Development af Education, Itro 2020. Proceedings of Papers (pp. 242-247).

[14] Huh, S.; Muralidharan, S.; Ko, H.; Yoo, B. XR Collaboration Architecture Based on Decentralized Web. In Proceedings of the, 24th International Conference on 3D Web Technology (Web3D '19), Los Angeles, CA, USA, 26–18 July 2019; Association for Computing Machinery: New York, NY, USA, 2019; pp. 1–9.

[15] Araiza-Alba, P., Keane, T. and Kaufman, J., 2022. Are we ready for virtual reality in K–12 classrooms?. Technology, Pedagogy and Education, pp.1-21.

[16] Elmqaddem, N., 2019. Augmented reality and virtual reality in education. Myth or reality?. International journal of emerging technologies in learning, 14(3).

[17] Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Alzahrani, A.I. and Sarsam, S.M., 2020. Challenges and prospects of virtual reality and augmented reality utilization among primary school teachers: A developing country perspective. Studies in Educational Evaluation, 66, p.100876.

[18] Bistaman, I.N.M., Idrus, S.Z.S. and Abd Rashid, S., 2018, June. The use of augmented reality technology for primary school education in Perlis, Malaysia. In Journal of Physics: Conference Series (Vol. 1019, No. 1, p. 012064). IOP Publishing.

[19] Yang, K., Zhou, X. and Radu, I., 2020. XR-ed framework: Designing instruction-driven and Learner-centered extended reality systems for education. arXiv preprint arXiv:2010.13779.

[20] Kerawalla, L., Luckin, R., Seljeflot, S. and Woolard, A., 2006. "Making it real": exploring the potential of augmented reality for teaching primary school science. Virtual reality, 10(3), pp.163-174.

[21] Mahadzir, N.N. and Phung, L.F., 2013. The use of augmented reality pop-up book to increase motivation in English language learning for national primary school. Journal of Research & Method in Education, 1(1), pp.26-38.

[22] Demitriadou E, Stavroulia KE, Lanitis A. Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education. Education and information technologies. 2020 Jan; 25(1):381-401.

[23] Muhammad, K., Khan, N., Lee, M.Y., Imran, A.S. and Sajjad, M., 2021. School of the future: A comprehensive study on the effectiveness of augmented reality as a tool for primary school children's education. Applied Sciences, 11(11), p.5277.

[24] Gybas, V., Kostolányová, K. and Klubal, L., 2019, November. Using augmented reality for teaching pupils with special educational needs. In ECEL 2019 18th European Conference on e-Learning (p. 185). Academic Conferences and publishing limited.

[25] Mitsuhara, H., Iguchi, K. and Shishibori, M., 2017. Using Digital Game, Augmented Reality, and Head Mounted Displays for Immediate-Action Commander Training. International Journal of Emerging Technologies in Learning, 12(2).

[26] Sulistyowati, P., Ananda, N.S. and Hudha, M.N., 2021, March. Developing an instructional media based on Augmented Reality animation for 3R topic (Reduce, Reuse, and Recycle) of thematic learning. In IOP Conference Series: Materials Science and Engineering (Vol. 1098, No. 3, p. 032111). IOP Publishing.

[27] Juan M, C., Furió, D., Alem, L., Ashworth, P. and Cano, J., 2011. ARGreenet and BasicGreenet: Two mobile games for learning how to recycle.

[28] Annetta, L., Burton, E.P., Frazier, W., Cheng, R. and Chmiel, M., 2012. Augmented reality games: Using technology on a budget. Science Scope, 36(3), p.54.

[29] Scurati, G.W., Bertoni, M., Graziosi, S. and Ferrise, F., 2021. Exploring the use of virtual reality to support environmentally sustainable behavior: A framework to design experiences. Sustainability, 13(2), p.943.

[30] B Plass, J.L., Homer, B.D. and Kinzer, C.K., 2015. Foundations of game-based learning. Educational psychologist, 50(4), pp.258-283.

[31] Anzai, Y. and Simon, H.A., 1979. The theory of learning by doing. Psychological review, 86(2), p.124.

[32] Guo, X. Rees, D. and Richards, M., A Scalable Interactive Mixed Reality Escape Room Simulation for Anatomy Learning, International Journal of Modeling and Optimization, 2020.

[33] British Educational Research Association. 2018. Ethical Guidelines for Educational Research, BERA: London. 4th edition. https://www.bera.ac.uk/publication/ethical-guidelines-for-educational-research-2018, updated on 25/08/2022.