Assessing the Impact of Transparent Display-Based Augmented Reality for Education: Insights from the ICE System Implementation

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Abstract

This study investigates the application of transparent display-based Augmented Reality (AR) in educational settings, focusing on user perceptions and media effectiveness. A classroom implementation involving 28 university students was conducted using the Innovative Cultural Experience (ICE) system, which integrates physical artifacts with interactive digital content displayed on a transparent touchscreen. The evaluation employed the Technology Acceptance Model to examine students' views on the usefulness, ease of use, satisfaction, and intention to use the system. Results show that 3D models and 360-degree media were perceived as the most effective content types. Students reported high usability, ease of use, and satisfaction, indicating strong potential for transparent AR displays to support learning. Observations and questionnaire data also revealed areas for improvement, particularly regarding textual content and interface interactions. The findings contribute to understanding how AR through transparent displays can enhance engagement and support educational objectives.

Keywords: Augmented Reality, educational technology, transparent display

Introduction

Augmented Reality (AR) technology overlays virtual content onto the real world. It can create interactive experiences that blend the physical and digital world, creating a composite view of the real world with virtual objects added in. Virtual objects can be 3D models, images, videos, or animations, and can interact with the real-world objects and respond to the user's actions and movements. AR experiences can be used in various industries, such as entertainment, gaming, marketing and in education. They offer users a new way to engage with the world around them and can provide immersive and interactive experiences that are not possible with traditional media. Recent studies confirm the growing adoption of AR in education, highlighting its potential to support engagement, interactivity, and learning outcomes across diverse contexts (Koumpouros, 2024; Pellas et al., 2019).

Currently, there are three ways to experience AR. The first and most common way is through a mobile device, such as a phone or tablet, by opening the device camera and seeing the real world with digital additions, which requires a high-quality camera and processing power for optimal results. AR experiences are usually available through mobile applications that support ARCore for Android (Google for Developers, n.d.) and ARKit for iOS (Apple Inc., n.d.) libraries. Users can also use their mobile browser for WebAR (Web-based Augmented Reality) experiences, without requiring the installation of a dedicated mobile application. WebAR uses WebGL (Web Graphics Library) to enable the display of AR content on a web page, making it accessible to a wider audience, although it currently has limited features and capabilities compared to AR through mobile applications. The second way to experience AR is through a Head Mounted Display (HMD), which is a display or projection technology integrated into eyeglasses or helmets, and displays digital content transparently, without blocking the user's view of the real world. Microsoft HoloLens (Joyjaz, n.d.) is an example of an HMD, and the cost of such devices is generally higher than that of mobile devices. The third way is through transparent screens that display dynamic or interactive content through a see-through surface. This allows viewers to see both the display and the real world through it. These screens are mostly used in product displays, museums, and theme parks, and have the potential to be used in educational settings (Suzuki et al., 2022).

The main aim of this study was to assess how effectively Augmented Reality through transparent displays can be applied in higher education. The evaluation focused on students' perceptions of the proposed system in terms of usability, usefulness, satisfaction, and intention to use. Based on this aim, the following research questions (RQ) were formulated:

- RQ1. Which media types do students perceive as most useful when using the ICE system?
- RQ2. Which interaction types are considered most effective by students in the ICE system?
- RQ3. How do students evaluate the overall usability and ease of use of the ICE system?
- RQ4. What is the level of student satisfaction and intention to use the ICE system in the future?
- RQ5. Were there any issues or usability problems reported by students during their interaction with the ICE system?

To address these questions, an interactive transparent display (HypeBox) containing a physical educational artifact was employed, allowing students to observe the real object while simultaneously engaging with the AR-based digital information.

Related work

AR is used nowadays in many fields of education including training. Rojas-Muñoz et al. (2019), propose a telementoring system based on AR for surgical purposes. The system improves the transfer of medical expertise by integrating a full-size interaction table for mentors to create graphical annotations, with AR devices to display surgical annotations directly onto the trainee's field of view. The system uses HMDs and tablets for trainees.

Lavrentieva et al. (2020), explores the possibilities of mobile apps with AR to qualitative update of lectures, practical and laboratory classes for specialized disciplines for students of transport area of expertise. They propose a methodology of using mobile apps with AR in students' vocational preparation process for transport industry. After testing, students' knowledge quality in specialty subjects increased by 15%.

Nowadays, there is a plethora of AR tools for every discipline. AR tools in sport activities and physical education that can improve health conditions of students at the universities are presented by Omarov et al. (2022). ARTutor (Terzopoulos et al., 2022), is a free and easy-to-use tool that can be used by educators to create augmented books and add virtual content on top of printed material. It is based on state-of-the-art technologies such as Google's ARCore and Apple's ARKit and evaluation results with pre-service teachers reveal that ARTutor is an effective tool for education and can be easily used in various educational approaches.

AR can also be used in special needs education. In a survey (Köse et al., 2021), authors conclude that AR technology is frequently used in teaching social and communication skills and AR technology is mainly used to increase the effectiveness of traditional teaching approaches and to create more interesting learning environments.

Early attempts on transparent screens (implementing AR) were performed by Hirakawa et al. (2004), by using a transparent film-type screen between the user and a target object space. The user was able to see both object and digital information. A camera was used to capture the user's gestures and estimate fingertip position. A transparent display was also used by Kim et al. (2016) in a smart-learning system combining education and entertainment to provide a rich education environment to students. The augmented reality smart learning system was using a transparent display and an education service on LMS system based on cloud service. As authors note, it was hard to provide clear transparency to users, and since the system's input device was a webcam, the marker array recognition was not stable.

The potential of incorporating transparent, handheld devices into head-mounted AR is examined by Krug et al. (2022). Authors combine a tablet-sized device with a transparent display, tracked in space, with an AR head-mounted display. Although authors provided three use cases: the exploration of 3D volumetric data, collaborative analysis of abstract data and data physicalizations, and the control of smart home appliances, the educational use of their system is not considered.

Transparent displays are also used by Suzuki et al. (2022), where they developed a system See-Through Captions, that displays the results of real-time captions (subtitles). The purpose of the system is to assist deaf and hard-of-hearing (DHH) in their daily lives and to add value to audio content provided in public facilities such as museums. The system was tested in a museum and there were many positive opinions from the participants that they could see the subtitles while looking at the contents of the exhibition.

In a previous paper (Kazanidis et al., 2022), the ICE system was presented. ICE is an AR system for promoting cultural heritage although it can be used in a variety of thematic items such as museum exhibits, in commercial and in the tourist sectors and in education. ICE uses a transparent and interactive screen attached to a metal box that contains an exhibit. The paper presented the system architecture, its components in detail and the technologies used for building it. ICE was evaluated by 12 internal users onsite, for finding possible problems and rate their experience and the application perceived usefulness and ease-of-use as end-users. Additionally, five experts (Human Computer Interaction doctors and professors, experienced programmers on identical projects etc.) checked remotely the ICE system functionality to identify strengths and weaknesses of the system. Results indicate that ICE when used in a museum setting, can provide an innovative, useful and engaging AR experience to visitors. In this paper we examine the educational use of the ICE system.

System architecture

The ICE system consists of 3 modules: Backend Management System (BMS), an AR module and the Knowledge Base. In case of the system being used for educational purposes, an educator can use the web administration page of the BMS to add the necessary for the educational scenario information that will be accessible to students. The multimedia material can be images, videos, text, audio, 360 images, 360 videos and 3D models. All this information is stored in the Knowledge Base. The educator can add multilingual content and make the scenario available in multiple languages. The educator can also add content depending on the audience, for example different content for elementary students and high school students. In this way, personalized content for each class is available. So, if for example the content is about ancient Greece, an educator can add multimedia material available for elementary students and separate material for older students. The system can be used by many educators in many schools. Each school is considered as an organization, and all material is available only for the specific school.

The HypeBox device is an interactive and transparent touchscreen that encloses the item for display and is connected to a computer that runs the ICE desktop application. A general view of the ICE system is depicted in Figure 1. In a classroom setting, students are standing in front of the HypeBox device, which enables them to see real items inside and at the same time interact with digital content displayed on the touchscreen. HypeBox is an aluminum housing box with a transparent touchscreen on one side. An educator can place an item inside the device and let students see the object and interact will all the multimedia information that is displayed on the transparent touch screen. The computer needs to have internet access to download all educational content that is stored in the Knowledge Base.

HypeBox can be placed in a classroom or in a school lab and can be easily transferred. All multimedia content is available only in a specific school although organizations (schools) can share content through the BMS. A school can have multiple HypeBox devices, and all these devices can access the content that educators of the school create. Educators can edit the content any time and add new material. ICE incorporates 2 puzzle games for gamification purposes, making learning more engaging and enjoyable.

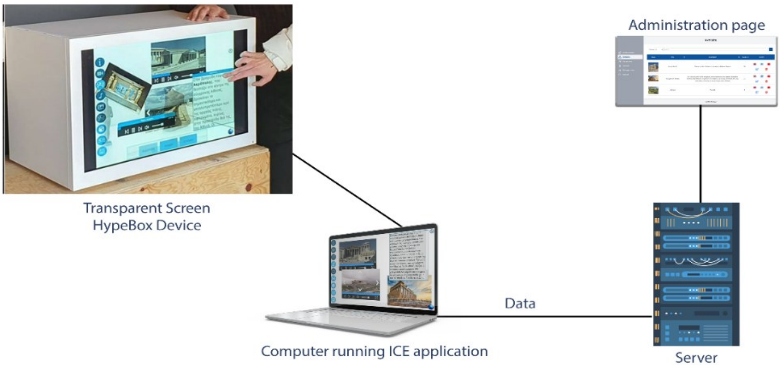

Figure 1. A general view of the ICE system

An important feature of ICE is that students can provide valuable feedback by recording an image or a video using embedded camera, or simply by text. The content is available only to the specific school and it can be used by educators to receive feedback from their students. It can also be used for dissemination purposes when displaying the school's best educational practices and approaches.

Finally, ICE can connect to other knowledge management systems like Xenagos (2023) to retrieve or to provide multimedia content through JSON. Moreover, ICE's JSON compatibility facilitates smooth communication with Learning Management Systems (LMS), including popular platforms like Moodle. This connectivity ensures that ICE becomes an integral part of the classroom ecosystem.

Research methodology

The HypeBox device and transparent displays in general, have not been widely utilized for educational purposes. Furthermore, the initial focus of the ICE system was on promoting cultural heritage. Therefore, it was imperative to evaluate its impact on educational practices, particularly in terms of students' perceptions of the proposed approach.

The main aim of the research was to assess how efficiently AR Technology can be applied to classroom through transparent screens, according to Technology Acceptance Model or TAM (Davis, 1989). TAM was chosen as the main adopted research methodology model for this study aimed at assessing the efficiency of AR in the classroom through transparent screens. TAM provides a framework for assessing the acceptance and use of technology by end-users, and this aligns with the main objective of the research. By utilizing the TAM, this study seeks to obtain evidence on the intention of use of the ICE system by the students, as well as their perception of the system's usefulness, ease of use, and overall satisfaction.

Sample

The research design chosen for this study is a pilot test with end-users (students). The design was chosen to obtain the requested information on how students perceive the ICE system for use in education. The initial sample population for the study was 28 university students. The sample was selected through convenience sampling.

Data collection instruments and data analysis

The evaluation of the system by end users was carried out through online or written questionnaires, which were sent to participants and complementary focus group discussions. A 5-part questionnaire with 19 questions was used. The first section of the questionnaire consisted of demographic questions such as participant age and prior exposure to similar applications. The subsequent two sections of the survey comprised 5-point Likert scale questions. In the second section, participants were particularly asked to rate the usefulness of the provided media and interactivity types of the ICE on a scale ranging from "1. Not at all useful" to "5. Very useful." The third section had agreement or disagreement questions with the same scale, but this time ranging from "1 Strongly disagree" to "5 Strongly agree." In this section of the questionnaire, participants were asked about perceived usefulness (Frohlke & Pettersson, 2015), perceived ease of use (Frohlke & Pettersson, 2015), user satisfaction (Abu-Dalbouh, 2013), attitude toward the ICE system (Fishbein & Ajzen, 1975), and intention to use the system (Al-Rahmi & Othman, 2013).

The final section of the questionnaire consisted of optional open-ended questions on their overall experience, inquiring about what they liked and disliked about the system, as well as their suggestions for improvements.

Quantitative data was analyzed using descriptive statistics, while qualitative data from focus groups was examined through thematic analysis.

Procedure

Data was collected through a combination of techniques. Initially, the features of the ICE system were demonstrated to the students for 15 minutes. Right after, students had the time one by one to freely navigate over the ICE system and test it individually. Afterwards, students were asked to answer the research questionnaire either online (Google form) or in paper format. During the students' interaction with the system, a researcher observed the participants' actions and behaviour, keeping notes, with the aim of finding out if the experience any difficulties in specific ICE functionality. Additionally, a focus group was conducted with the students to discuss the research questions in depth. This provided additional insights into the students' perceptions of the ICE system.

Results

The research aimed to investigate the effectiveness and user perception of the ICE system, focusing on the usability, usefulness, and potential for educational application. The research was conducted in April 2023. Handmade paper artifacts, copies of original artifacts from Acropolis such as a colored printed photo of selected Parthenon sculpture, were inserted into the HypeBox. Beyond paper models, the ICE system can also host other physical objects, such as 3D-printed replicas or small-scale educational items, making it adaptable to various learning contexts. Researchers developed educational content related to the Acropolis and Parthenon using all supported media types. The content was offered in three languages (English, Greek and Turkish) through the ICE system. A sample of 28 university students were introduced to the ICE system and HypeBox before testing the system themselves.

A total of 28 university students participated in the study, with 23 completing the post-interaction questionnaire, resulting in a response rate of 82%. After a brief demonstration of the ICE system's features, each participant interacted individually with the HypeBox and responded to a structured questionnaire assessing various aspects of the system. The analysis of the demographic data revealed that the students aged 20.08 years on average and most of them had no previous experience with a similar AR system (70.8%).

Regarding the perceived usefulness of different media types, as indicated in Figure 2, 3D models were rated most positively, with an average score of 4.29 on a 5-point Likert scale. This was followed by 360-degree images and videos, which were also rated highly, averaging 4.13. Traditional media formats, such as images, video, and audio, received moderate evaluations, with scores between 3.79 and 3.83. Text-based content was rated the lowest, with a mean score of 3.54, suggesting that students found it less effective in supporting their understanding.

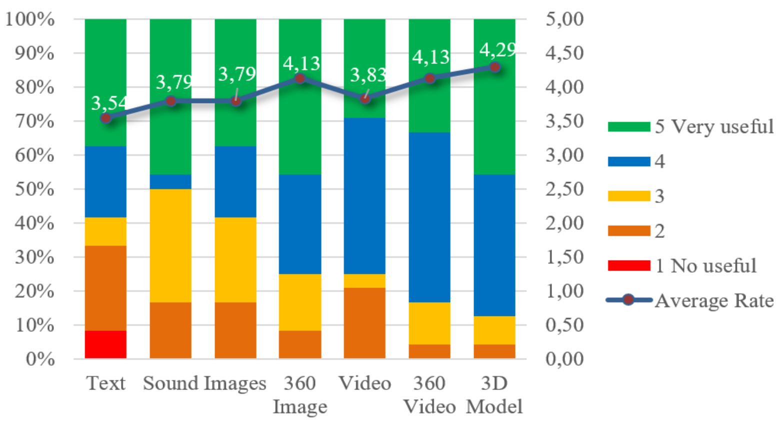

Figure 2. Usefulness of the provided media types

Figure 3 summarizes student evaluations of the interaction types supported by the ICE system. Among these, the ability to manipulate 3D models—specifically through rotation and resizing—received the highest average rating of 3.96, indicating a strong preference for interactive spatial engagement. The manual arrangement of multimedia elements was also perceived positively. Interactions involving 360-degree images and videos were rated slightly lower but remained above average. In contrast, interaction through textual content received the lowest ratings, mirroring the lower evaluations of text as a media type. These results suggest that students favor visually immersive and manipulable forms of interaction over static or text-based engagement.

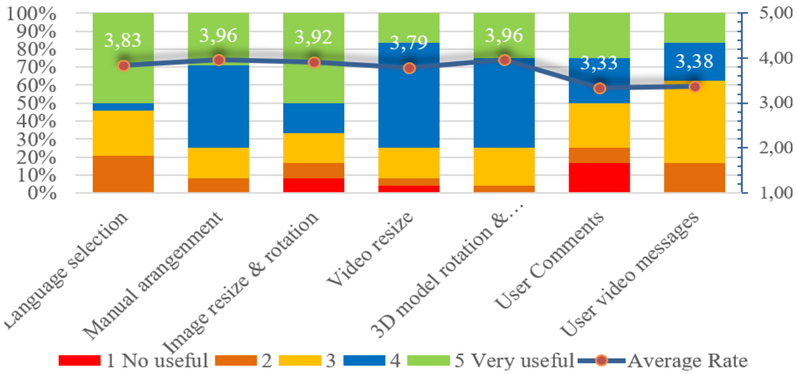

Figure 3. Usefulness of the provided interaction types

Figure 4 presents the aggregated results on system usability, satisfaction, and future use intention. Students reported a high level of usability for the ICE system. The average score for ease of use was 4.21 on a five-point scale, and 90% of participants stated they experienced no difficulty in navigating the interface or interacting with the content. These findings suggest that the system's design and interaction mechanisms were perceived as intuitive and accessible. The consistently high usability rating indicates that the system can be integrated into educational settings with minimal need for technical support or additional training.

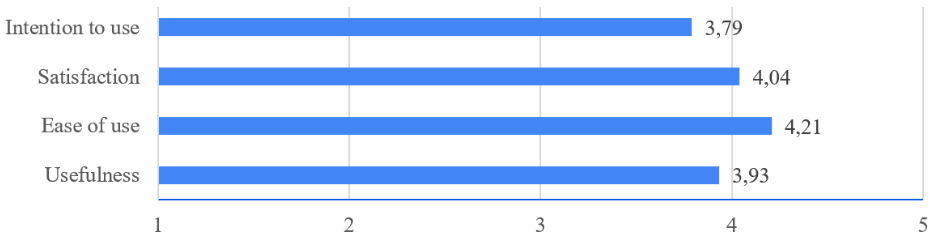

Figure 4. Students' agreement per examined variable

Overall satisfaction with the ICE system was positive, with students assigning an average rating of 4.04. The intention to use the system in the future was somewhat lower, with a mean score of 3.79. These results indicate that while students were generally pleased with their experience, their enthusiasm for repeated or long-term use was slightly more reserved. Context-specific preferences were also evident; students rated the system's suitability for museum use more highly (4.29) compared to classroom implementation. This suggests that while the system is well-received, its perceived value may vary depending on the educational context. Focus group feedback clarified these scores. Some students noted that the system was engaging but more suitable for museum-like settings than for everyday classroom use. As one participant stated, "The 3D models were helpful, but I am not sure it fits all subjects." Such comments explain the lower ratings in usefulness and intention of use, linking them to context-specific factors.

No critical technical issues were observed during the interaction sessions. However, qualitative feedback revealed areas for improvement. Several students commented on the limited responsiveness of the touchscreen interface and the suboptimal presentation of textual content, which they found less engaging compared to other media types. These observations were consistent with the lower quantitative scores assigned to text-based media and interaction. Such feedback provides useful input for further refinement of the system, particularly in enhancing content accessibility and user interaction design.

Discussion

The findings of this study provide insights into the educational value and usability of transparent display-based AR through the ICE system. Regarding RQ1, students identified 3D models and 360-degree media as the most useful content types, highlighting a preference for visual and spatially rich representations. These media formats were perceived as more effective in supporting engagement and understanding than traditional formats such as text or static images, suggesting the importance of media richness in AR-enhanced educational environments.

For RQ2, interaction types that enabled manipulation of 3D models and control over content layout were rated most favorably. These results underscore the role of interactivity in fostering learner engagement, particularly when students can actively explore and customize digital content. In contrast, interactions involving text were rated lower, indicating a need for more effective integration of textual elements in transparent AR systems.

In response to RQ3, students evaluated the system as highly usable, with most reporting no difficulties in navigating the interface. The intuitive design of the touchscreen and the clarity of content presentation contributed to these perceptions, reinforcing the potential of the system for use with minimal technical support.

As for RQ4, students expressed a generally positive attitude toward the system, with high satisfaction ratings and moderate intention to use it in future educational activities. Interestingly, participants indicated that the system is particularly well-suited for museum-like settings, where the integration of physical artifacts with digital overlays is most natural. This suggests that context plays a role in perceived relevance and applicability.

Regarding RQ5, no major technical problems were reported during the pilot sessions. Nonetheless, qualitative feedback highlighted specific areas for improvement, including touchscreen responsiveness and the visual presentation of textual content. These suggestions align with the lower ratings assigned to text-based media and interactions, pointing to design aspects that warrant further refinement.

These results are consistent with recent TAM-based studies. For example, Shyr et al. (2024) demonstrated that perceived usefulness is a strong determinant of students' acceptance of AR, while Celayir et al. (2025) confirmed the importance of both usefulness and enjoyment in shaping behavioral intention. Such evidence reinforces the notion that interactive and visually immersive formats are more likely to support learner engagement.

Overall, the study supports the view that transparent AR displays can effectively support educational objectives, particularly when they emphasize visual interactivity and intuitive design. The positive student evaluations of 3D models and 360-degree media, combined with favorable assessments of usability and satisfaction, indicate that such systems have the potential to complement or extend conventional teaching methods, especially in settings involving tangible objects or spatial content.

However, the study has several limitations that should be acknowledged. The sample size was relatively small and restricted to university students, which may limit the generalizability of the findings to other educational levels or disciplines. Additionally, the evaluation focused on a single educational context—cultural heritage content related to the Acropolis and Parthenon—thus further research is needed to examine the effectiveness of transparent AR displays in other subjects such as science, engineering, or language education. The system was tested in a controlled environment, and long-term adoption effects, including learning outcomes and engagement over time, were not assessed.

Future work should address these limitations by including larger and more diverse participant groups, conducting longitudinal studies, and expanding the range of learning domains evaluated. Technical improvements, particularly in the responsiveness of the touchscreen interface and the presentation of textual content, are also essential for increasing usability and engagement across a broader spectrum of learners.

In terms of implications for practice, the findings suggest that educational institutions considering the integration of AR technologies should prioritize content types and interaction modes that are visually rich and interactive. Teachers and instructional designers should be supported through training and authoring tools that allow them to develop content suited to transparent AR displays. Moreover, such systems may be particularly effective in informal or hybrid learning environments such as school exhibitions, laboratories, or museums, where physical-digital convergence can be naturally integrated into the learning experience..

Conclusions

This research presented how transparent displays can be used for educational purposes showcasing the ICE system integrated with the HypeBox, a transparent display device. The findings from the study shed light on the positive impact of transparent display technologies on the learning experience with historical artifacts from the Acropolis and Parthenon. The study demonstrated that a substantial portion of students expressed an intention to use the ICE system in the future, indicating its potential for sustained engagement beyond the scope of the research. This positive outlook suggests that the transparent displays and specifically the ICE system holds promise in fostering continued interest and learning in school environments.

In conclusion, the ICE system represents a promising tool for educational organizations seeking to enrich their students' learning experiences. Building on its insights, educators and institutions can effectively leverage transparent displays and interactive technologies to promote a deeper understanding of educational content.

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