Evaluating Knowledge Acquisition in Extended Reality (XR): HoloLearn's Conversion of Textbooks into Holographic Experience

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ABSTRACT

HoloLearn is an Extended Reality (XR) application designed to enhance traditional learning environments in classrooms. It proposes an innovative solution to enhance engagement in traditional educational settings by transforming standard textbooks into interactive, holographic experiences. This tool integrates interactive 3D models into the learner's setting, aiming to supplement traditional teaching methods and improve comprehension of complex concepts through intuitive visualization. Central to HoloLearn's approach is its alignment with contemporary pedagogical strategies that prioritize active and experiential learning. This is particularly beneficial for disciplines requiring spatial understanding and visualization of abstract concepts. The tool is designed to cater to various educational levels, aiming to enhance student engagement and retention of knowledge.This project explores the impact of HoloLearn on educational outcomes, focusing on improvements in knowledge acquisition. The research evaluates the integration of holographic technology into classroom settings, assessing its effectiveness while identifying challenges associated with technical infrastructure, user accessibility, and curriculum integration.

KEYWORDS

Mixed reality, Metaverse, Holographic Content, Immersive, Students, Knowledge Acquisition, Data Analysis, User Testing, Controlled Experiment.

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1 INTRODUCTION

Education is fundamental to societal development, providing individuals with the essential competencies required to navigate and succeed in an ever-changing global landscape. Conventional pedagogical approaches, largely centered around textbook use, have been integral to educational frameworks. However, these methods are increasingly challenged by their inability to sufficiently engage contemporary learners and sustain their attention. This paper introduces HoloLearn, a developed tool designed to augment traditional educational materials by integrating holographic technology, aimed at enhancing the learning environment. HoloLearn merges traditional textual information with interactive 3D models, offering a novel approach that seeks to invigorate the conventional educational paradigm by making learning more immersive and interactive.

The core innovation of HoloLearn lies in its transformation of static, two-dimensional instructional content into dynamic, three-dimensional holographic displays. This enhancement is designed to facilitate more effective learning by allowing students to interact with complex concepts in a visually intuitive manner. This study evaluates the effectiveness of HoloLearn in improving knowledge acquisition and retention. Utilizing a methodological framework that encompasses empirical research and data analysis, the research aims to quantify the impact of this technological integration and explore the potential challenges and opportunities for its adoption in educational settings. The overarching goal of this research is to contribute to the advancement of educational technology and to enrich the discourse concerning the integration of innovative instructional tools in contemporary educational practices.

1.1 Metaverse

The Metaverse is a concept denoting a collective virtual space where users can interact with a computer-generated environment and each other in real time. This virtual space facilitates the creation of immersive experiences and simulations accessible globally via internet-connected devices, including virtual reality headsets, smartphones, and computers. It offers transformative potential for education, work, and social interaction by enabling collaborative and experiential learning opportunities that extend beyond the limits of traditional classroom settings [9]. The educational sector is particularly poised to benefit from these capabilities, as depicted in Figure 1, which shows the perceived importance of the Metaverse across various domains.

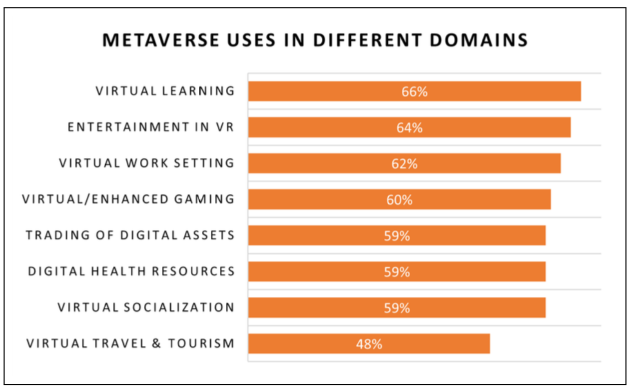

Figure 1: Human Perception of Metaverse Uses in Different Domains, May 2022 [5]

1.2 Mixed Reality

Mixed Reality (XR) integrates aspects of both Augmented Reality (AR) and Virtual Reality (VR), creating an immersive technology that blends the physical world with the digital. The development of an XR framework is pivotal in building a decentralized Metaverse that supports AR and VR devices, facilitating the creation of applications using open-source tools and engines. Considerations for developing such a framework include technology integration, hardware compatibility, visualization techniques, and client-server communication protocols [9]. In XR environments, the focus is often on rendering objects within the user's immediate perception rather than the entire scene, optimizing interaction and immersion in Metaverse applications.

2 LITERATURE REVIEW

2.1 Effectiveness of AR in Enhancing Learning Outcomes

Augmented Reality (AR) has shown a remarkable capacity to transform learning experiences, particularly in primary education. The study by Contero and López (2013) emphasizes AR's potential to improve kinesthetic learning and sensory engagement, making it a highly interactive and visually rich alternative to conventional educational tools. AR's ability to facilitate the manipulation of 3D models offers students a unique level of control and interaction with the learning material, leading to notably higher knowledge retention rates. This study's validation protocol, involving initial assessments and subsequent follow-ups, provides evidence that AR-based learning outperforms traditional methods in specific educational contexts, such as the study of the digestive and circulatory systems. [4]

2.2 Navigating Challenges and Accessibility in XR Learning

XR technology, while innovative, presents its own set of challenges in educational contexts. The work of Pimentel et al. (2022) highlights crucial considerations such as cognitive load, time constraints, and issues of accessibility and affordability. The study stresses the importance of inclusive design and the need for high-quality learning content tailored to the learners' needs. To mitigate potential pitfalls and ensure a productive learning environment, adopting Universal Design for Learning frameworks is essential. These frameworks play a significant role in ensuring all learners can access and benefit from XR technologies, addressing critical concerns like privacy and data security. [7]

2.3 Integrating XR in Higher Education: Strategies and Considerations

Introducing XR into higher education requires a thoughtful and well-planned approach. The insights from Rana, Hossain, and Hossain (2021) provide valuable guidance on designing successful XR experiences in this context. Key factors include extensive user testing to ensure that XR interactions are engaging and action-oriented. Additionally, this study underscores the necessity of informing users about data collection and privacy measures within XR platforms. These considerations are vital in aligning XR experiences with broader educational goals, such as those outlined in the UN's Education for Sustainable Development Initiative, ensuring that XR applications in higher education are both effective and ethically sound. [8]

2.4 The Impact of Augmented Reality on Student Attitudes, Motivation, and Learning Achievements

A comprehensive meta-analysis was conducted to assess the impact of Augmented Reality (AR) technologies on educational outcomes. The findings revealed that AR-assisted education significantly enhances student attitudes and learning achievements. This analysis, encompassing a wide range of studies, highlighted the consistent positive effects AR has on the way students perceive and engage with educational content. However, it was noted that while AR improves attitudes and achievements, it does not have a marked impact on students' overall motivation levels in the learning process. This insight is crucial for understanding the multifaceted influence of AR in educational settings. [2]

2.5 Mixed Reality and Education Transformation

Mixed Reality using HoloLens 2 is revolutionizing educational innovation and transformation. The Forrester report emphasizes its role in enabling teaching scale, supporting remote learning, and improving student knowledge retention. It highlights the significant reduction in training and instruction time, fostering more efficient and engaging learning environments. This technology's versatility in lab work and complex tasks positions it as a future-ready tool for educational advancement. It notes a 30% reduction in training time and a 15% decrease in instruction time per instructor, demonstrating significant efficiency improvements. These metrics underscore the technology's impact in creating dynamic, engaging learning environments and enhancing educational outcomes. [3]

3 DEVELOPMENT PROCESS

3.1 Tool Selection and Preliminary Research

The initial phase of our project involved an evaluation of development tools suitable for creating an augmented reality (AR) educational application. We focused on comparing the Meta Oculus and Microsoft HoloLens development platforms. After research, we selected Microsoft's Mixed Reality Toolkit (MRTK) and the HoloLens 2. The MRTK offers a versatile development environment, providing essential freedoms crucial for our application's needs, such as the ability to access the camera feed for QR code detection. The HoloLens 2 enhances these capabilities with its advanced mixed-reality features, integrating the virtual and real worlds to foster an immersive educational experience. This technology alignment is intended to create a dynamic and interactive learning environment that utilizes the strengths of mixed reality to improve educational outcomes. The pilot project was implemented in the field of biology, a discipline that benefits significantly from XR technology for visualizing complex biological structures, facilitating virtual dissections, and supporting memorization assessments [11]. We anchored our content development around a standard human biology textbook to ensure curriculum relevance. To further refine content applicability, we consulted with biology educators and students.Asset arrangement was planned to ensure an ergonomic and user-friendly interface. We applied best practices in UX/UI design specific to XR environments and adhered to ergonomic principles to optimize the interface design [1].

3.2 Application Development

Figure 2: HoloLearn Dashboard

3.2.1 Architecture and Design. The architecture of the HoloLearn application was designed to be modular and scalable, utilizing the capabilities of the Unity Engine in conjunction with the Mixed Reality Toolkit. This setup supports a wide range of interactive and immersive educational content. The design principles emphasized user-centric navigation, hand tracking and seamless 3D model manipulation, as well as responsive design to accommodate different learning scenarios. A central feature is the use of QR codes to facilitate the activation of 3D models within the application.

3.2.2 Development Process. During the iterative development of HoloLearn, we conducted initial tests using Unity's in-app game mode. Subsequent testing phases involved hands-on device trials alongside frequent consultations with our academic advisors. These interactive sessions were critical in pinpointing necessary improvements and expanding the application's functionality. In the end, we found that the most intuitive and user-friendly application design would be a holographic dashboard that can overlay a student's desk space [See Figure 2].

3.2.3 Features and Functionalities. HoloLearn includes several features aimed at enriching the educational experience. These include interactive 3D models, QR code scanning, a PDF reader, an AI-powered chatbot, and a Note Pad integrated with a virtual keyboard, as shown in Figure 3. The application also includes an adjustment feature allowing users to customize the dashboard to their preferences, enhancing user interaction and accessibility. We also added a hand menu, a menu that shows up on the user's palm itself, which was an intuitive way of allowing users to access menu settings without adding additional buttons to the virtual dashboard itself [See Figure 4].

Figure 3: Application Keyboard

Figure 4: Hololearn Hand Menu

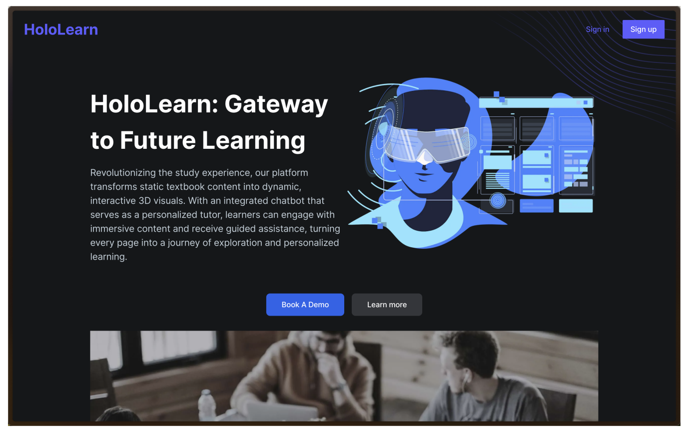

Figure 5: Landing page for the HoloLearn Website

3.2.4 User Interface (UI) and User Experience (UX). Considerable attention was given to the UI/UX design of HoloLearn to ensure an intuitive and engaging user experience. Firstly, all the components of the app were set up on a curved dashboard that surrounds the user's view in XR and ensures that all interactions with the app are always within hand's reach. The interface was crafted to be user-friendly: hand tracking for all user interaction, voice-to-text integration for ease of typing on the virtual keyboard, intuitive 3D model manipulation controls, and a hand menu in XR.

3.3 Web Application

3.3.1 Development Process. We developed a comprehensive full-stack web application using Next.js and React for the front end, paired with an Express.js server connected to a MongoDB database for backend operations. This technology stack was chosen for its scalability and ease of integration, allowing us to create a visually appealing and user-friendly site [See Figure 5]. The development of our full-stack web application was underpinned by a rigorous process, starting with the establishment of a backend using Express.js. We carefully designed the RESTful API endpoints to facilitate efficient communication between the client and server. This would also serve for our extension to other platforms by having a central backend for fetching data. Each endpoint was thoroughly tested for functionality and security, ensuring reliable and secure data transactions.

Our database schema, structured in MongoDB, was devised to optimize data retrieval and storage processes, enabling swift and consistent access to educational materials. We implemented comprehensive user authentication, incorporating session management and encrypted credentials to protect user data. In a move to streamline the user experience, we developed a dual authentication system. Our custom authentication was built with security best practices involving salting and hashing of passwords. Alongside this, we integrated Google Authentication, providing users with an alternative option to access our platform using their Google accounts. This dual approach not only offered flexibility and ease of use but also adhered to high-security standards, giving users the choice and assurance they need for a safe and reliable sign-in experience.

3.3.2 Managing and Uploading Assets. The web platform features an asset management system that enables the uploading, deleting, and downloading of educational assets. It also includes a QR code generation feature for each asset, streamlining the incorporation of these resources into educational materials by educators. These QR codes can be easily integrated into teaching material to trigger the spawning of 3D assets. [See Figure 6]

3.3.3 Content Management System. Alongside asset management, the platform is equipped with a versatile content management system that provides comprehensive support for an array of content types, including documents, slides, and images. This system is tailored to facilitate an organized and streamlined distribution process, thereby significantly reducing the administrative burden on educators.

3.3.4 Dashboard Interface. This dashboard provides an accessible overview of assets and instructional materials, which in turn helps educators plan, execute, and assess their educational strategies. Additionally, we enhanced the platform with HoloTutor, a personalized chatbot powered by the GPT-3.5 API, which is available on both the website and the XR application. This feature supports interactive learning by providing instant answers to student inquiries and facilitating a more engaged and personalized educational experience.

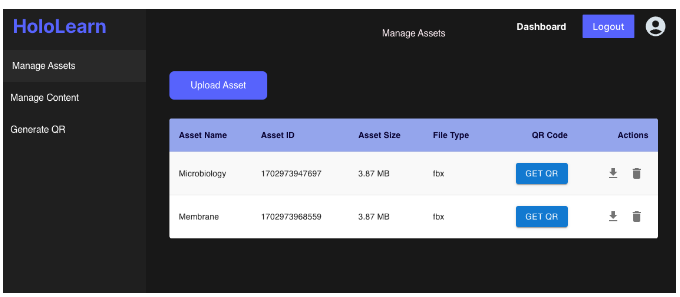

Figure 6: Dashboard of the HoloLearn Web Application

4 USER TESTING PHASE

User testing of the HoloLearn application involved a pilot study with 7 participants to assess the usability and effectiveness of the educational tool. Key findings indicate that users found the hand-tracking controls intuitive and the overall user experience positive, enhancing engagement with educational content. Challenges were identified with the virtual keyboard, particularly voice-to-text functionality, which varied in effectiveness due to environmental factors. Through the user testing surveys, we found that HoloLearn has potential across various educational fields, notably in science and history, with unexpected applicability in art and finance.

For a comprehensive review of the user testing methodology, detailed feedback, and full analysis, refer to Appendix A.

5 RESEARCH STUDY

5.1 Research Overview

With the app development completed and a successful pilot study, we continue our investigation of the app. The core objective of our research was to evaluate the efficacy of the HoloLearn application in enhancing knowledge acquisition among university students. This study was designed to test the following hypotheses:

Null Hypothesis (H0): There are no significant differences in knowledge acquisition between students who learn using traditional methods (textbook only) and those who learn using the XR-enhanced method (Textbook + XR app).

The research adopted a random experimental design with two distinct groups: a control group that utilized traditional textbook-based learning methods, and an experimental group that engaged with the same educational content enhanced through the HoloLearn XR application. To minimize variability between the two groups and isolate the impact of the XR-enhanced method from other potential confounding factors, the HoloTutor feature of the application was turned off during the study. This design enabled a direct comparison of educational outcomes between the traditional and augmented reality-enhanced learning experiences.

5.2 Study Design

The experimental setup involved a single-session study where participants were randomly assigned to one of the two groups to ensure the mitigation of potential biases and preexisting knowledge differences:

- The control group studied educational material presented in a conventional textbook format.
- The experimental group interacted with the same textbook material enhanced by XR technologies via the HoloLearn app.

Each session was structured as follows:

(1) Pre-Study Survey (5 minutes): A survey was administered to assess the participants' initial knowledge and their familiarity with XR technology.
(2) Introduction (5 minutes): Participants were briefed about the study without revealing specific research questions to avoid influencing their responses.

(3) Learning Session (25 minutes): Participants engaged with the study materials as assigned to their respective groups.
(4) Post-Learning Content Test (15 min): Both groups were administered a standardized test to evaluate immediate knowledge acquisition.
(5) Post-Study Survey (5 minutes): After the test, participants completed surveys designed to evaluate the learning material, following the criteria outlined by Keller (2010) [6]. Additional questions, specifically tailored to the experimental group's experience with the XR application, were incorporated. The assessment of the application's performance was guided by the Mobile Application Rating Scale (MARS) [10].

5.3 Content Development

The content of this study was designed to align closely with the curriculum of introductory university-level biology, focusing on providing a deep understanding of human anatomy. The development of the instructional materials was guided by the goal of ensuring parity between the control and experimental groups in terms of the content's depth and complexity but differing in the mode of delivery. We generated learning material 9 pages long that was split into 3 chapters: heart biology, digestive system, and muscular systems. This material also contained labeled diagrams for each of the chapters.

- **Traditional Learning Materials** For the control group, the instructional materials were printed out. This traditional format was chosen to reflect the common method of study in current university settings, providing a solid baseline against which to measure the effectiveness of the XR-enhanced learning experience.
- **XR-Enhanced Learning Materials** For the experimental group, the same textbook content was used; however, it was supplemented with QR codes at the beginning of each chapter. When the HoloLearn application scanned these codes, it spawned the 3D models associated with that QR code. These models allowed students to visualize and manipulate complex anatomical features in ways that are not possible with flat images or physical models. For example, students could explore the layers of the heart and get a deeper understanding of each part of the heart through their interaction with the virtual asset. We acquired 3D assets from Sketchfab and ensured that they were labeled and closely mimicked the labeled diagrams in the printed learning material.

Preliminary usability testing of the XR application was conducted with a couple of students to ensure the visibility of the 3D models in different environments. This test was crucial in ensuring that the app was intuitive, thus minimizing any potential frustration or confusion during the experiment's learning process.

5.4 Forms

For the comprehensive evaluation of the educational interventions, several forms were deployed through Qualtrics to gather data on various aspects of the participant experience, their baseline knowledge, and the outcomes of the learning sessions. These forms included the pre-study survey, learning assessment, post-study survey, and XR post-study survey specifically for the experimental group.

5.4.1 Pre-study Survey. The pre-study survey was designed to collect baseline data on the participants' demographic background, their prior knowledge of biology, and their familiarity with XR technologies. This survey included questions about:

(1) **Demographics:** Age, gender, major, and years of study at the university.
(2) **Academic Background:** Previous coursework or self-study on biology-related topics.
(3) **Technology Familiarity:** Experience with XR and other digital learning tools.

This preliminary data collection was crucial for understanding the starting point of each participant, allowing for a more nuanced analysis of learning outcomes. The survey was distributed among students through flyers and online posts.

5.4.2 Learning assessment. To measure knowledge acquisition, a series of content-specific questions were administered after the learning sessions. These assessments were tailored to the biological concepts covered in the study materials and included:

(1) **Multiple Choice Questions (MCQs):** Designed to assess recall and understanding of key factual information.
(2) **True/False Questions:** Used to evaluate the participant's ability to distinguish correct from incorrect statements.
(3) **Matching Questions:** Aimed at testing the comprehension of relationships and functions within biological systems.
(4) **Labeling Questions:** Tested how well students remembered the labeling of diagrams and models.

The learning assessments were identical for both groups to ensure the comparability of the data collected.

5.4.3 Post survey. : Following the learning session, a post-study survey was administered to all participants to gauge their engagement, motivation, satisfaction, and relevance as outlined by Keller (2010) [6]. This allowed us to evaluate the learning material in the following areas:

(1) **Engagement:** Questions designed to measure the level of attention and interest maintained throughout the learning session.
(2) **Motivation:** Items assessing the participants' drive to learn and interact with the material.
(3) **Satisfaction:** Queries regarding the participants' satisfaction with the learning process
(4) **Relevance:** Evaluate the perceived relevance of the content.

5.4.4 XR post survey. Exclusive to the experimental group, this survey collected detailed feedback on the usability and functionality of the XR application based on MARS [10]. It included questions about:

(1) **Engagement:** Evaluates the ease of use, identifies encountered problems, and assesses overall satisfaction with the XR features.
(2) **Functionality:** Measures the effectiveness of interactive elements, such as 3D models and AR overlays.
(3) **Aesthetics:** Evaluates the graphical and educational quality of the XR content.
(4) **Information:** Assesses the educational quality and clarity of the information provided within the XR content.

5.5 Methodology

The methodology of this study was designed to evaluate the effectiveness of traditional versus XR-enhanced learning methods within a controlled, comparative environment. This section details the procedural steps undertaken, from participant selection to data analysis, to assess educational impacts thoroughly.

5.5.1 Participant Selection. University students from NYUAD were chosen for this experiment, and our selection criteria aimed to ensure that differences in learning outcomes can be more directly attributed to the learning methods used.

(1) **Recruitment**: Participants were recruited through campus advertisements and online postings, and full study details were provided to ensure informed consent.
(2) **Eligibility Criteria**: Eligibility was restricted to students who had not previously taken advanced courses in the biology topics being studied, in order to minimize bias from their previous knowledge.
(3) **Random Assignment**: Participants were randomly assigned to the control or experimental groups to evenly distribute potential confounding variables such as age, academic major, and general academic aptitude.

5.5.2 Learning Environment. Both groups attended structured learning sessions in similar classroom settings to control for environmental variables that might influence study outcomes.

(1) **Control Group**: Engaged solely with traditional textbook materials, mimicking a conventional study setting with passive learning techniques.
(2) **Experimental Group**: Used identical textbook materials augmented with the HoloLearn XR application to provide an immersive and interactive learning experience.

5.5.3 Instructional Materials. The educational content for both groups was identical in terms of learning objectives and curriculum relevance, differing only in the method of delivery.

5.5.4 Data Collection. Data were collected through both pre-study and post-intervention assessments, which included:

(1) **Knowledge Tests**: Administered before and after the sessions to gauge changes in participants' understanding of biological concepts.
(2) **Surveys**: Used to evaluate participants' engagement, motivation, and satisfaction with their learning methods, with additional questions for the experimental group regarding their experiences with XR technology.

5.5.5 Data Analysis. : Quantitative data from the tests and surveys were analyzed using statistical software, specifically Python along with data analytics libraries such as Pandas and Matplotlib. This analysis approach facilitated the following:

(1) **Descriptive Statistics**: Employed to summarize and describe the data features.
(2) **Inferential Statistics**: Utilized to test hypotheses regarding differences in learning outcomes between groups. Python's statistical tools, including the SciPy library, were employed for conducting t-tests for independent samples. This framework ensured accurate hypothesis testing and data analysis, supporting the validity of the research findings.

5.5.6 Ethical Considerations. : Conducted in accordance with ethical guidelines to safeguard participant privacy and well-being, all procedures were approved by the NYUAD Institutional Review Board.

(1) **Ethical Approval**: Both the study design and all related materials received prior approval.
(2) **Data Privacy**: Strict measures ensured confidential and secure handling of participant data, complying with university guidelines and data protection laws.

This methodological framework provided a basis for a balanced and controlled comparison between traditional and

XR-enhanced learning, aiming to yield reliable and generalizable insights to guide future educational practices and technology integration in learning environments.

5.6 Research Analysis

(1) **Pre-Study Survey Analysis**
The survey results indicate that a significant majority of the participants, 93.6%, reported having rarely used VR technology, with only minimal exposure to it (having used it only a couple of times). This limited prior exposure to virtual reality highlights the novelty of the experience for most participants and underscores the potential impact of introducing such technology into educational settings. The remaining participants reported using VR technology occasionally (once or twice a month) or frequently (once or twice a week).

(1) **Learning Assessment Analysis**
The control group, using traditional 2D textbook visuals, achieved an average score of 20.65 ± 5.01. In contrast, the experimental group, which interacted with identical content presented through immersive 3D holography via QR codes, scored significantly higher, with an average of 24.37 ± 5.07. The difference in mean scores was statistically significant, with a t-test yielding a p-value of 0.027, indicating a notable improvement in performance attributed to the XR intervention. Figure 7 illustrates the distribution of scores between the groups, highlighting the shift towards higher achievement within the experimental group.

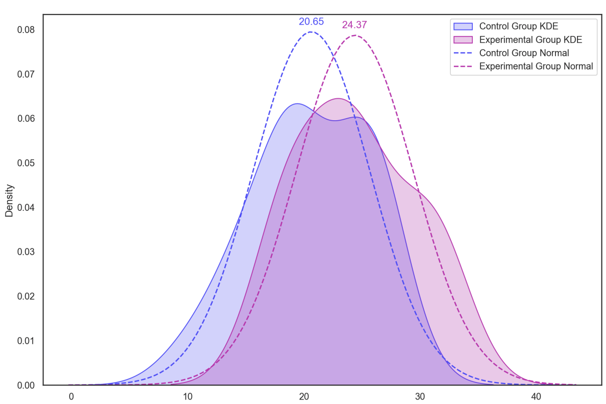

Figure 7: Kernel Density and Normal Distribution of Assessment Scores

(1) **Post Survey Analysis**
To see how participants viewed the learning material we provided, we gave them a survey after their learning assessment. We applied Keller's instructional materials motivation survey framework [6] to ensure internal consistency in this survey, evidenced by Cronbach's alpha values greater than 0.7 for all measured dimensions. The survey responses were scored using a 5-point Likert scale, ranging from "Definitely False" to "Definitely True". Our analysis proceeded by dividing participants into experimental and control groups, based on their participant IDs, to investigate any differences in how they viewed the educational material. The t-test results for each dimension are as follows:

Table 1: T-Test Results for Post Survey Dimensions

Dimension	T-Statistic	P-Value
Confidence	-0.072	0.943
Attention	-1.235	0.226
Satisfaction	-0.766	0.452
Relevance	0.361	0.721

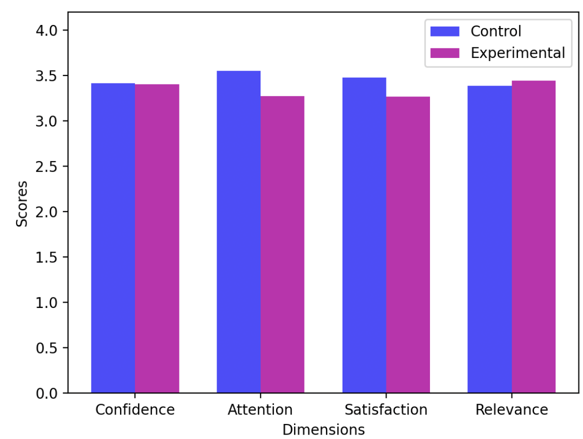

Figure 8: Mean Score Comparison of Post Survey Responses Between Control and Experimental Groups

These results do not indicate statistically significant differences in the way the educational material was perceived by the control and experimental groups, since all dimensions have p-values greater than 0.05. This suggests that both groups perceived the material in a similar way, as illustrated in Figure 8.

(1) **XR Post-Study Survey Analysis**
The XR Post-Study Survey utilized the Mobile Application Rating Scale (MARS) to assess the HoloLearn application in four different dimensions: Engagement, Functionality, Aesthetics, and Information Quality, which also has Cronbach's alpha values greater than 0.7.
The application performed exceptionally well in the survey, scoring a perfect 5 out of 5 in three dimensions (Functionality, Aesthetics, Information Quality) and

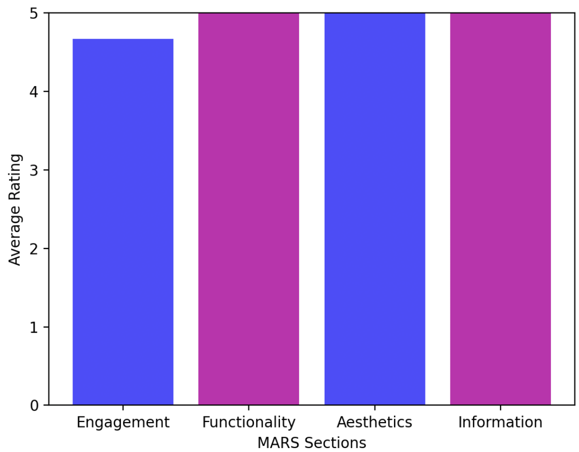

Figure 9: Average Ratings Across MARS Sections

4.67 out of 5 in Engagement, as seen in Figure 9. These scores indicate a high level of satisfaction and usability perceived by the participants, reflecting the effectiveness of the application's design and implementation.

In addition to the MARS, the post-study survey included qualitative feedback too. This was visualized through a word cloud to see the concepts that were most frequently mentioned by the participants [Figure 10]. Key terms such as "learning," "visual," "engaging," and "labels" indicate a positive reception towards the interactive and visual aspects of the HoloLearn application.

Figure 10: Word Cloud from XR Post-Study Survey Feedback

Furthermore, participants were asked about their likelihood of recommending the HoloLearn application to others.

The responses, as shown in Figure 11, suggest a high level of endorsement, with 35% of the participants stating that they would definitely recommend the app to everyone and another 35% indicating that they might recommend it to several people.

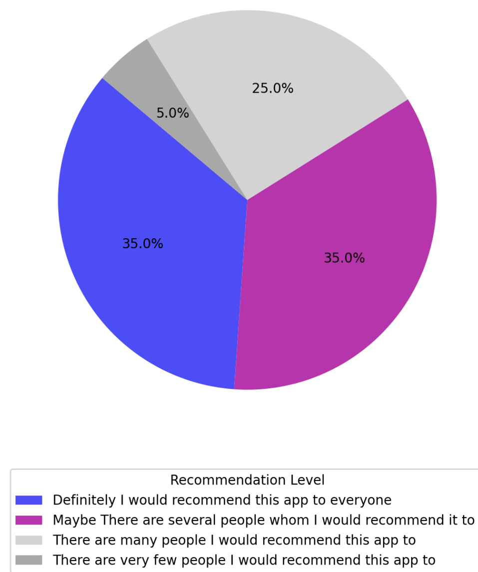

Figure 11: Participant Recommendation Levels for the HoloLearn App

5.7 Discussion

The data presented in the previous sections reveal several key insights into the effectiveness of the HoloLearn application and its impact on learning outcomes. Despite the majority of participants (93.6%) reporting only minimal prior exposure to virtual reality, the experimental group using the XR-enhanced learning method showed a statistically significant improvement in test scores compared to the control group using traditional methods. Specifically, the experimental group scored on average 3.72 points higher, which is a significant 9.3% increase from the control group's average score of 20.65.

This finding is particularly important as it demonstrates that XR technologies can be effectively integrated into educational settings to enhance learning outcomes. This is supported by the lack of significant differences in the post-study survey results across the measured dimensions (Confidence, Attention, Satisfaction, and Relevance), indicating that the increase in scores was due to the enhanced learning experience provided by the HoloLearn application rather than differences in how the material was perceived by the participants. This uniform perception across control and experimental groups suggests that the educational content remained consistent across different delivery mediums.

Furthermore, the high ratings in the Mobile Application Rating Scale (MARS) across all dimensions reflect the application's strong design and usability, which likely contributed to the improved learning outcomes. The qualitative feedback captured in the word cloud, with terms like "engaging," "visual," and "informative," further reinforces the notion that XR technology provides a more interactive and engaging learning environment. Overall, the results from this study suggest that XR technology does not merely serve as a novel tool but is capable of significantly enhancing traditional learning methods, thereby offering substantial benefits in educational settings. This is exemplified by the willingness of participants to recommend the application, indicating both satisfaction with and endorsement of the XR learning experience.

6 LIMITATIONS

(1) **Tests short-term memory**: The study primarily evaluates the short-term memory retention of the students. For a more comprehensive analysis, future research could include longitudinal follow-up tests to assess long-term retention of the learned material.

(2) **Sample size and statistical power**: The sample size in this study, while sufficient for initial observations, is relatively small, which could limit the statistical power and the generalizability of the results. Larger studies are necessary to confirm these findings and provide more definitive conclusions.

(3) **Limited demographic**: The participant pool primarily consisted of university students from NYUAD, which may not fully represent other educational demographics or age groups. Future studies should consider a broader and more diverse participant base to enhance the external validity of the findings.

(4) **VR technology novelty effect**: The novelty of VR technology may have contributed to heightened engagement and interaction with the 3D assets, potentially diverting attention from the learning objectives to exploring the technology. This could mean that the learning outcomes might have been even more pronounced if participants were more accustomed to using such technology, minimizing the distraction factor. Future studies should consider the impact of novelty and explore ways to mitigate its effects to focus more strictly on learning outcomes.

7 FUTURE STUDY

Building on the insights and addressing the limitations of this study, future research should consider a range of strategic improvements. A longitudinal study design is essential to evaluate long-term memory retention and the enduring effects of XR technology on learning outcomes. By re-testing participants weeks or months after their initial exposure, researchers can assess the sustained impact of immersive educational experiences compared to traditional methods. Additionally, increasing the sample size would enhance the statistical power of the findings and allow for a more detailed analysis of different demographic subgroups. This approach would help in understanding how diverse populations, including various age groups and educational backgrounds, adapt to and benefit from XR technologies.

Furthermore, to mitigate the potential distraction caused by the novelty of XR, future studies could include participants with prior VR experience or provide a preliminary training session on VR usage. This would help establish the true improvement in knowledge acquisition through XR. Comparative studies across various disciplines and educational settings would also be valuable. Such research could explore the effectiveness of different technological tools and pedagogical approaches, identifying optimal strategies for integrating XR into education.

8 CONCLUSION

The HoloLearn application has shown promise in enhancing educational methods through immersive holographic experiences. This application transforms textbooks into three-dimensional educational tools, enabling more effective visualization of complex subjects and thereby boosting student engagement and comprehension. This improvement is substantiated by thorough user testing and research included in this study. Nonetheless, challenges such as the high costs of holographic content development and the current technological limitations of hardware may hinder widespread adoption. Despite these hurdles, using the Unity framework aids the development of the application, highlighting the potential of such tools in educational environments.

HoloLearn aims to positively impact educational approaches, particularly for a generation accustomed to digital interaction. Embracing such technologies could provide a more engaging and personalized educational experience, preparing students for a future that increasingly values digital literacy. The potential for immersive learning technologies like HoloLearn to enhance educational practices is notable, highlighting the possibilities for future advancements in this area.

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APPENDIX

A DETAILED USER TESTING RESULTS

We conducted a pilot study to have a user testing phase with 7 participants from diverse backgrounds and majors. The primary objective was to evaluate the usability and user experience of both our application and web platform. Participants were asked to engage with HoloLearn and provide their feedback through a comprehensive survey.

A.1 Survey Methodology

The HoloLearn Mixed Reality Usability Survey was designed to gather detailed feedback from the users. Key areas of focus included ease of use, engagement level, ergonomic design, technical performance, and overall satisfaction. The survey consisted of the following sections:

1. **User Information**: Gathering demographic data such as age group and occupation.
2. **Initial Impressions**: Understanding users' first reactions to the application.
3. **Features and Functionality**: Evaluating specific aspects like QR scanning, AI-powered chatbot, voice-to-text interaction, and multimedia integration.
4. **Learning Experience**: Assessing the impact of HoloLearn on users' learning and the subjects where it was most beneficial.
5. **Technical Aspects**: Identifying any technical issues encountered and evaluating overall app performance.
6. **Overall Satisfaction and Feedback**: Gauging the general user satisfaction and collecting suggestions for improvement.

A.2 Incorporation of User Feedback

Participants' responses were meticulously analyzed to identify areas for improvement. The feedback was crucial in understanding both the strengths and weaknesses of HoloLearn. Suggestions for enhancements and reported issues were prioritized in the subsequent development phases.

A.3 Evaluation of Application Performance and Usability

The evaluation process focused on the application's performance in terms of speed, responsiveness, and reliability. Usability aspects, such as the intuitiveness of the interface and the ease of interaction with holographic content, were also assessed. The survey results played a pivotal role in measuring these metrics, providing us with valuable insights into the user experience. The user testing and evaluation phase was instrumental in refining HoloLearn, ensuring it meets the educational needs of our diverse user base while providing an engaging and intuitive mixed reality experience.

B USER TESTING RESULTS

B.1 Demographics

Our initial pilot study involved 7 participants representing various age groups and differing levels of expertise with XR/AR technologies.

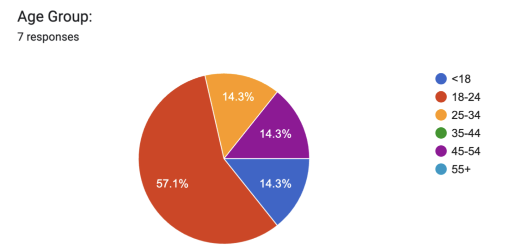

Figure 12: Age distribution of the participants.

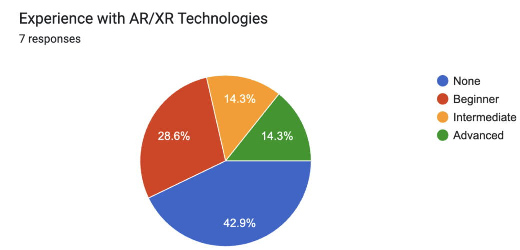

Figure 13: Experience levels among the participants.

B.2 Result Analysis

Participants were provided with User Guidelines to familiarize themselves with HoloLearn's features, which also facilitated the testing process. Following this, we conducted a survey to gather feedback, summarized as follows:

- **User Experience**: The intuitive hand-tracking controls of HoloLearn were well-received by pilot testers, indicating that the user interface design met our usability goals.
- **Virtual Keyboard**: The virtual keyboard, particularly the voice-to-text feature, was identified as problematic. User feedback suggested variability in performance, which may have been influenced by ambient noise levels or speech clarity.
- **Asset Manipulation**: The controls for scanning and manipulating 3D models proved to be highly effective. Testers were able to comfortably manipulate and

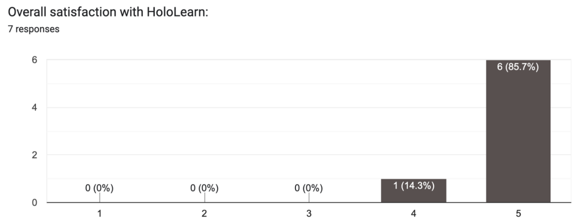

Figure 14: Overall User Experience Feedback

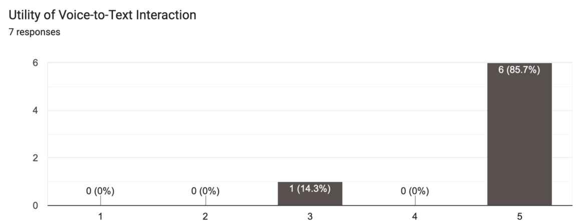

Figure 15: Feedback on Voice-to-Text Functionality

spawn 3D objects in the virtual environment, demonstrating the application's user-friendly design.

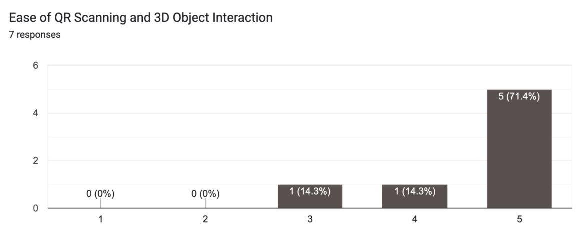

Figure 16: 3D Model Scanning and Manipulation

- **Application in Different Fields**: We explored potential applications of HoloLearn across various fields. Feedback indicated strong interest in using the technology in Science and History, with unexpected interest also shown in Art and Finance. These insights open new avenues for application development.

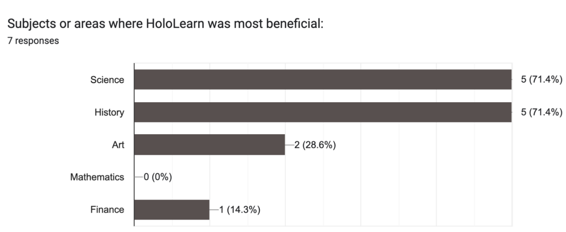

Figure 17: Potential Application Fields for HoloLearn

B.3 Application Insights and Challenges

Throughout the development and testing of HoloLearn, we encountered numerous challenges and garnered valuable insights:

- **Technical Challenges**: Integrating the MRTK framework with Unity posed significant challenges, particularly with customizing interaction models to work with the HoloLens hand tracker. Adapting standard controls to this new interface required extensive customization and learning.
- **User Experience Insights**: Direct feedback from user testing was crucial in iterative platform enhancements. Environmental factors played a significant role; for instance, one suggestion was to adjust the application's brightness in darker settings, and voice-to-text features were less effective in noisy environments.
- **Research Insights**: Our findings indicated that the learning curve associated with new XR technologies might be lower than anticipated. Simplified user interactions allowed even those with minimal XR experience to quickly learn how to use HoloLearn effectively. The enthusiasm and general interest from testers across various educational fields also highlighted the broad potential impact of our application.