3D Visualizations in Learning: An Evaluation of an *AR+Core* Application for Computer Hardware Education using the Hedonic Motivation System Adoption Model

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Abstract **– This study delineated the development of an augmented reality (AR+Core) mobile application to enhance computer hardware education. By offering 3D visualizations of computer internals, the application enables students to immerse in hardware-related learning without the need of actual devices. This virtual approach ensures accessibility from anywhere, making tangible components unnecessary. The Multimedia Development Life Cycle (MDLC) informed the design process, while the Hedonic Motivation System Adoption Model (HMSAM) offered insights into technology adoption. Feedback from 7th-grade participants was overwhelmingly positive, with them acknowledging the app's utility, engagement value, and user-friendliness. Notably, the app scored 85 of 100 for its perceived ease of use, underlining its efficacy for the target age group.**

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These results underscore the importance of intuitive and engaging AR educational tools in enhancing learning experiences.

Keywords **– Mobile application, AR, HMSAM computer hardware, MDLC.**

1. Introduction

In the past two decades, significant progress has been made in expanding access to schooling, especially in low and middle income countries. Various factors and initiatives have driven this progress, aiming to address educational inequalities and provide quality education opportunities for children and youth from disadvantaged backgrounds [1]. Education technology, commonly known as EdTech, integrates information and technology tools into teaching and learning processes. It has been widely recognized as a potentially transformative force that can significantly change the school system [2]. The introduction of EdTech has often been described as a disruptive innovation with the potential to revolutionize education [3]. Recent advances in gamification, immersive technologies [4], [5], [6], [7], [8], artificial intelligence (AI), machine learning, and online and blended learning have revolutionized the way we approach teaching and learning.

However, the impact of the latest COVID-19 pandemic has accelerated the need for technology in education. Understanding computer hardware is crucial for individuals seeking a comprehensive understanding of computer functionality [9].

The high cost of computer hardware often presents a significant barrier to accessing education, especially for individuals residing in distant or rural areas where costs may be prohibitive. The current study proposes using augmented reality (AR) technology as an interactive learning tool to address this challenge. This technology facilitates the presentation of virtual objects within a real-world environment [10]. By leveraging AR, students may engage with computer hardware concepts more effectively, transcending the boundaries of traditional classroom settings. This approach enhances students' understanding and retention of the subject matter and fosters a more profound curiosity and enthusiasm for learning. Integrating AR technology into computer hardware education aligns with the demands of a rapidly evolving digital landscape.

The main objective of this study is to develop an engaging and user-friendly educational AR application for 7th-grade middle school students. The study aimed to assess students' perceptions of the app's usefulness, enjoyment, ease of use, and ability to promote curiosity and exploration. Additionally, the study sought to evaluate the app's potential in creating an immersive learning experience, enhancing learning outcomes and retention, and serving as a valuable tool for learning and exploration in this age group.

By addressing these objectives, the study aims to contribute to developing practical educational AR applications that can enhance the learning experience for students.

2. Literature Review

The following sections comprehensively explore the key concepts and advancements in AR technology and their applications. This section aims to lay the groundwork for understanding the current landscape and research findings in the field, setting the stage for a detailed examination of AR's impact on education.

2.1. Augmented Reality

AR technology overlays computer-generated virtual objects onto the user's view of the natural world, typically via the camera lens of a smartphone or tablet [4]. AR systems use accelerometers, GPS, and gyroscopes to track the user's movements and adjust digital content in real-time [11]. It uses computer vision algorithms to recognize target objects, such as a printed image or a physical object [12].

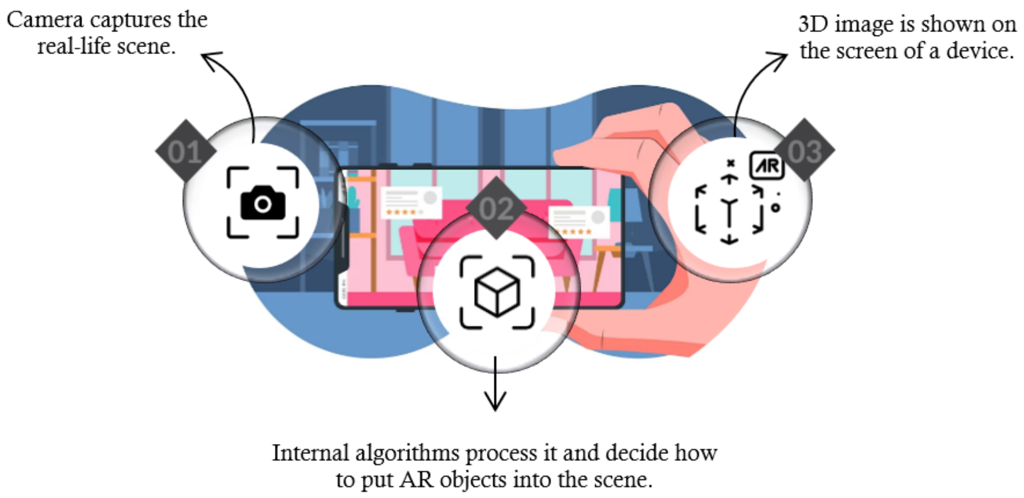


Figure 1. Illustration of how AR works

AR can be categorized into two main types: marker-based AR and marker-less AR. Marker-based AR utilizes visual markers, such as printed images or QR codes, to activate and display digital content [13]. The AR software uses the visible marker as a reference point to determine the position and orientation of digital content relative to the real world. On the other hand, markerless AR uses the device's camera and sensors to detect and track the user's environment, such as location, surface, and lighting conditions, and places digital content within that environment [14]. AR technology has many applications, from entertainment and gaming to education, healthcare, and manufacturing [15]. With the ability to create an immersive and interactive experience, AR technology is rapidly gaining popularity and becoming a key area of research and development.

AR technology can revolutionize learning and interaction with information [16]. By providing interactive and immersive experiences, AR may enhance learning and increase engagement, particularly in subjects that require visualization or hands-on expertise [17]. It can teach various topics, from science and math to art and history, and may help students develop critical thinking, problem-solving, and creativity skills.

Therefore, AR technology has the potential to transform the traditional classroom and support the improvement of education quality [18]. Numerous studies have demonstrated the efficacy of AR in supporting the learning process. For instance, Nagashree [19] developed a web-based AR application to showcase interior designs. In contrast, Kalpana [20] developed a marker-based AR application to support interactive, fun expedition services for zoo locations.

Additionally, Jumat M. and Su G. [21] developed an AR application to study the solar system, and "Picsar" was designed for learning physics, specifically the atomic model [22]. AR applications can also support language learning, animal anatomy, and human anatomy [23].

2.2. Mobile Application

Mobile applications, also known as "mobile apps," have emerged as powerful tools that run on mobile devices such as smartphones and tablets, transforming various aspects of our daily lives. Mobile applications have become an integral part of modern society with the increasing availability and adoption of mobile technologies. Mobile applications in education have opened up new learning and knowledge acquisition possibilities. They have enabled learners to access educational resources anytime and anywhere, engage in interactive activities, collaborate with peers, and receive personalized feedback [25]. Mobile applications have also facilitated the integration of multimedia content, gamification, and adaptive learning approaches, enhancing engagement and motivation among learners.

3. Methodology

The MDLC framework guided the application design process during the research study. The MDLC framework comprises various stages: concept development, design, material collection, assembly, testing, and distribution [26].

Following this structured and systematic framework, we successfully developed and implemented the *AR+Core* application.

The MDLC framework facilitated thorough testing and evaluation at each stage of the development process, ensuring that the final product met the desired requirements and objectives. This approach created a robust and effective educational tool that aligns with the research study's goals.

Figure 2. Multimedia Development Life Cycle (MDLC)

3.1. Concept

The concept stage of the MDLC is the initial phase of the framework, where the overall concept and vision for the multimedia project are defined. We establish the project goals, objectives, and requirements during this stage. The main focus is on understanding the target audience, identifying their needs and preferences, and determining how the multimedia application or product will effectively meet those requirements.

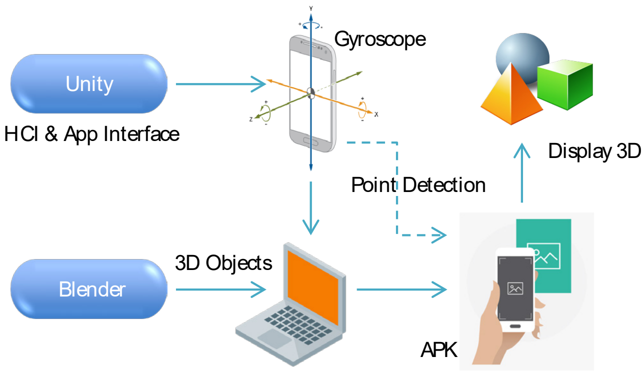


Figure 3. Concept: "markerless-based" tracking

The research studies on AR have consistently demonstrated its positive impact on learning, emphasizing the ability to enhance learning effectiveness and efficiency. Previous studies in computer recognition have focused on developing AR applications using marker-based methods, which involve using cards or flashcards to display virtual objects (using marker-based methods) [25], [26].

In contrast, this current study introduces markerless AR applications, which enable the visualization of 3D objects directly through the smartphone camera lens on a flat surface (Figure 3). This advancement allows for a more seamless and user-friendly experience, eliminating the need for physical markers and expanding the potential applications of AR in education.

3.2. Design

During the design of *AR+Core*, we placed a strong emphasis on UI/UX design, incorporating e-modules, learning videos, and an AR lens to enable 3D visualization of computer hardware components. We used Blender software to create objects displayed on a flat surface, providing audio explanations. Users could zoom in and rotate objects, creating an immersive learning experience.

3.3. Material Collection

We recorded separate audio explanations for each object and combined them with the 3D objects during the assembly stage. This attention to detail ensured that the *AR+Core* application provided an effective tool for learning about computer hardware.

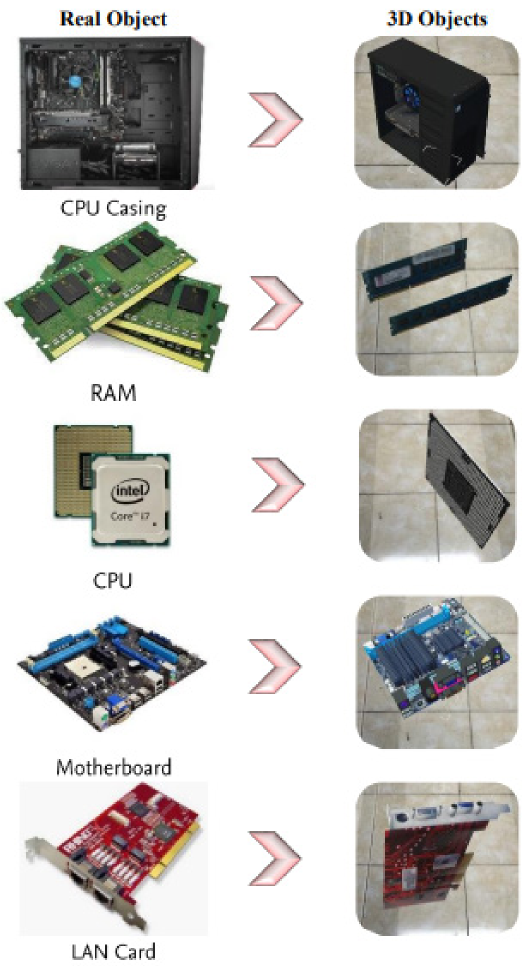


Figure 4. 3D objects of computer hardware components

3.4. Assembly

Once we had collected all the necessary materials, we began combining the assets using Unity Pro 2020 2.7f1 for the Android platform as a build target. This software allowed us to seamlessly integrate the 3D objects and audio explanations, resulting in a fully functional *AR+Core* application. However, it should be noted that this application is limited to Android smartphones only and cannot be used on other platforms. Despite this limitation, the *AR+Core* application provides an innovative and engaging way for users to learn about computer hardware components through augmented reality technology.

3.5. Testing

During the testing phase of the *AR+Core* app, we primarily focused on evaluating the functionality of the AR lens and audio features. Our main objective was to verify that we could accurately display the 3D objects representing computer hardware components without markers and that users could interact with them while listening to audio explanations. Through rigorous testing, we addressed and resolved all of the identified issues and glitches, ensuring the optimal performance and functionality of the app. This meticulous testing process aimed to create a seamless and immersive learning experience for users of the *AR+Core* app.

3.6. Distribution

In the final stage, we distributed the *AR+Core* application to 7th-grade students and conducted a questionnaire using the HMSAM. We used HMSAM to identify the applications or systems' usage and adoption level. This model adopts and consists of seven main components: control, joy, curiosity, perceived usefulness, perceived ease of use, immersion, and behavioral intention to use (Table 1).

Table 1. Seven main components of HMSAM

No	*Category*
1	Control
2	Joy
3	Curiosity
4	Perceived usefulness
5	Perceived ease of use
6	Immersion
7	Behavioral intention to use

We designed the questionnaire to measure the level of these components according to the focus on HMSAM and utilized a 5-point Likert scale for responses (Table 2).

Table 2. 5-Point Likert scale

Score	***Description***	***Interval***
1	Strongly Disagree	< 34
2	Disagree	35 – 64
3	Neutral	65 – 74
4	Agree	75 – 84
5	Strongly Agree	85 – 100

By including a well-designed and comprehensive questionnaire in this study, they have yielded valuable insights into the efficacy of the *AR+Core* application as an engaging and motivational tool for learning about computer hardware. The feedback gathered from the participants served as a critical source of information, enabling researchers to refine and optimize the application to better cater to the specific needs and preferences of the target audience.

By leveraging the power of augmented reality technology, the application provided an interactive and immersive learning experience, fostering active participation and knowledge retention among students. The meticulous analysis of the questionnaire responses allowed researchers to gain a deeper understanding of the application's strengths and areas for improvement, facilitating the development of targeted strategies to enhance educational impact. Ultimately, incorporating the questionnaire into the research methodology proved instrumental in guiding the iterative design process and maximizing the effectiveness of the *AR+Core* application in promoting interactive learning through augmented reality technology.

4. Results and Discussion

In this section, we have provided a detailed account of the results obtained from the development of the AR+Core application. We discussed the process of application development and shed light on the evaluation conducted, which included the outcomes derived from the utilization of HMSAM. Following the presentation of our findings, we delved into a thorough discussion, aiming to interpret the results and extract their implications.

4.1. AR+Core Application

We developed the *AR+Core* application using Unity Pro 2020 2.7f1, specifically designed for the Android platform. It focused on using 3D virtual objects to deliver learning material about computer hardware.

The application's user interface started with a menu selection page consisting of e-modules, learning videos, quizzes, and an AR lens (Figure 5).

The unique feature of the application was the AR lens, which provided users with a wide selection of computer hardware components, including RAM, monitors, CPUs, HDDs, and more (Figure 4). Users could choose which elements to display in virtual 3D objects. Once selected, the camera lens became active, and users pointed their camera at a flat surface to track the feature and present it as a 3D object (Figure 6).

In addition, users could rotate the 360-degree perspective of the object, enlarge it, and listen to the accompanying learning audio to enhance their comprehension. The application's significant advantage was its ability to display objects without unique markers, allowing for a more convenient and user-friendly experience. By combining all these features, the *AR+Core* application provided a potent learning tool for anyone seeking to enhance their understanding of computer hardware.

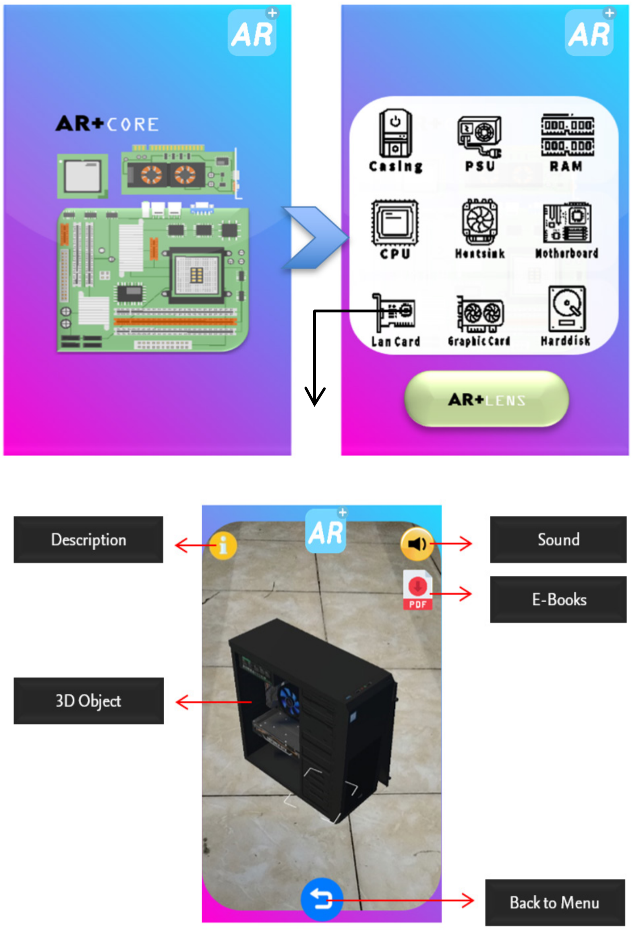


Figure 5. AR+Core application

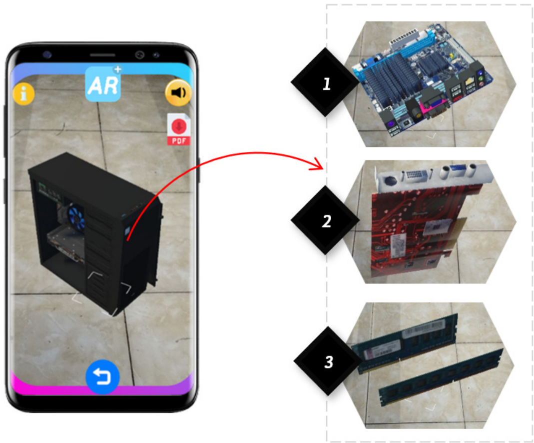
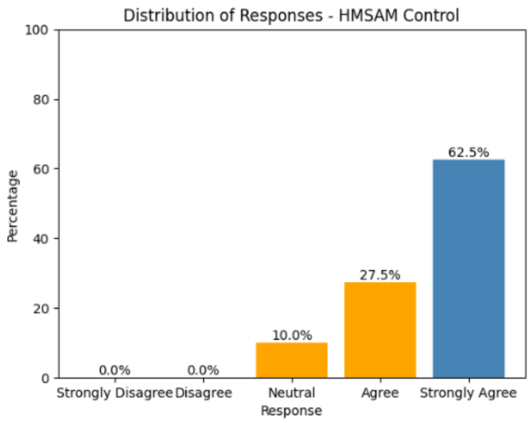


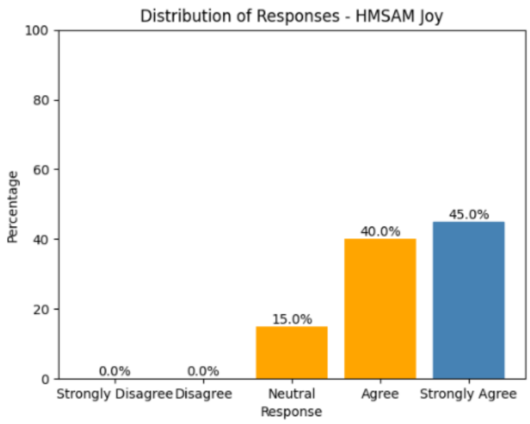
Figure 6. Application view with 3D objects

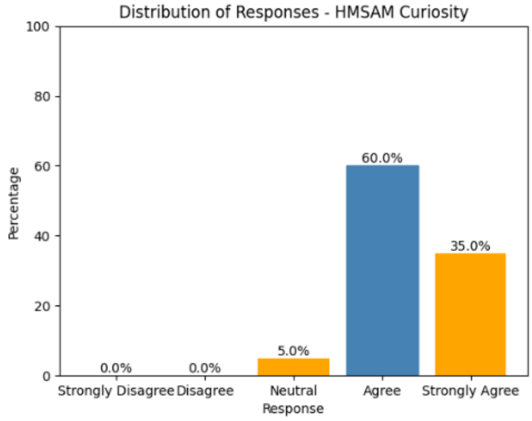
4.2. HMSAM Results

We conducted the app evaluation by distributing the download link of the app and the questionnaire link to 7th-grade middle school students. The questionnaire was designed based on the components assessed in the HMSAM. A total of 40 students participated in the evaluation.

The findings from the survey indicate that the *AR+Core* application has received a strong positive reception among the participants. Across various aspects, such as control, joy, curiosity, usefulness, ease of use, immersion, and behavioral intention to use, most respondents showed high levels of agreement and positive perception (Figures 7-9).







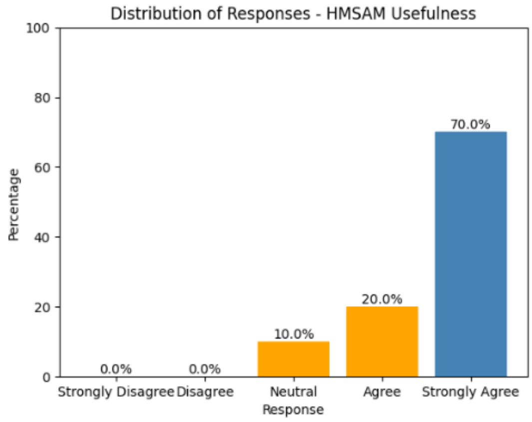


Figure 7. HMSAM results

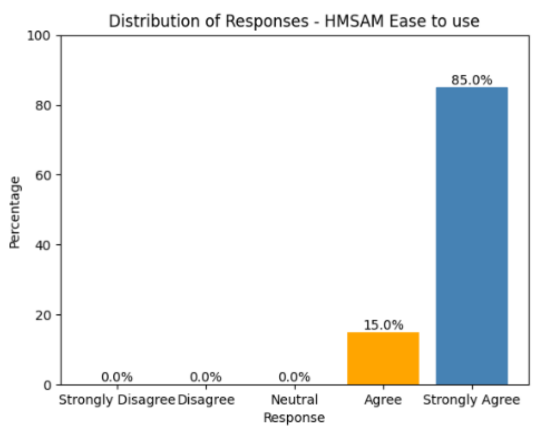
Control – The majority (62.5%) strongly agree; this shows a strong positive sentiment towards the control aspect. Moreover, 27.5% agreed, supporting user satisfaction with control features. Positive experiences and satisfaction with the control aspects of the app indicate that users find them intuitive, easy to navigate, and responsive to their input. Good control features are essential for a smooth and enjoyable user experience, as they empower users to interact with applications effectively and efficiently. This aligns with the Nielsen Heuristic, one of the key principles of user-centric design, giving users a sense of control and freedom [28].

Joy – Among the participants, 45% strongly agreed that the application brought them joy, while 40% agreed. These findings indicate a positive emotional response among the users, suggesting that they found the application enjoyable and capable of eliciting positive emotions. When an application can bring joy to users, it often implies that the user experience is engaging, entertaining, and fulfilling. The feedback concerning the joy derived from the application correlates with the affective computing theory and the positive technology framework. Affective computing, as proposed by Rosalind Picard, focuses on creating systems and devices that can recognize, interpret, and simulate human emotions.

The users' joyful responses align with this theory, indicating that the application meets functional needs and caters to emotional and experiential aspects, fostering a holistic and fulfilling user experience [29].

Curiosity **–** A significant percentage of respondents, 35%, strongly agreed that the application sparked their curiosity, while approximately 60% agreed. These findings indicate that the application successfully captured users' interest and encouraged a sense of curiosity. When an application can stimulate curiosity, it implies that it offers unique and intriguing experiences or content that pique users' interest and encourage them to explore further. This can lead to increased motivation and engagement with the application. The feedback regarding the application's ability to stimulate curiosity strongly correlates with the Self-Determination Theory (SDT), particularly intrinsic motivation. SDT, proposed by Deci and Ryan, posits that individuals have innate psychological needs: competence, autonomy, and relatedness. Individuals are more likely to be intrinsically motivated when these needs are satisfied, meaning they engage in an activity for its inherent satisfaction rather than an external reward [24].

Perceived usefulness **–** Based on the provided data, it is clear that respondents perceived the application to be highly useful. A significant majority of 70% strongly agreed, and an additional 20% agreed that the application is practical. These findings indicate that users highly regard the application as valuable and beneficial in supporting their learning needs. Perceived usefulness is a crucial factor in determining user satisfaction and adoption of an application. When users find an application helpful, it effectively fulfills their needs, solves problems, or provides valuable tools or information.



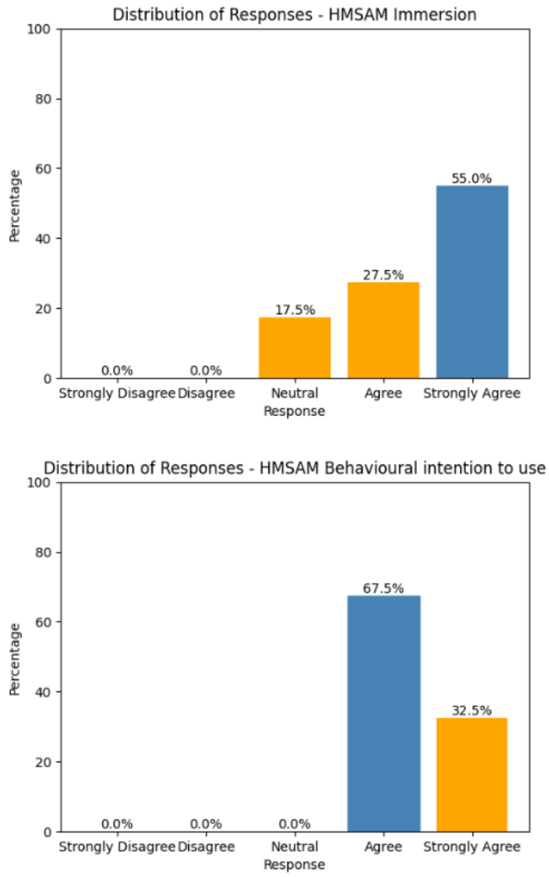


Figure 8. HMSAM results (cont.)

Perceived ease to use **–** A significant majority of 85% strongly agreed, and an additional 15% agreed that the application is easy to use. The provided data regarding the application's perceived usefulness and ease of use is consistent with the principles outlined in the technology acceptance model, emphasizing its potential for wide acceptance and continued usage among its user base [27]. This high percentage of agreement suggests that the application is perceived as user-friendly and intuitive, facilitating user adoption and engagement. Perceived ease of use is critical in determining user satisfaction and acceptance of an application. When users find an application easy to use, it is straightforward, intuitive, and requires minimal effort to navigate and interact with.

Perceived Immersion **–** A majority of 55% strongly agreed, and an additional 27.5% agreed that the application offers a satisfactory level of immersion. These findings indicate that users generally perceive the application as immersive, although there is room for improvement to enhance its immersive qualities further. Immersion refers to how an application can engage users and create a sense of being fully absorbed or involved in a virtual or augmented environment.

A high level of immersion can enhance the user experience and make it more captivating and enjoyable. The fact that most respondents strongly agreed with the application's immersion suggests that the application successfully created a sense of presence and engagement. The agreement from the additional 27.5% indicates that users generally found the immersion level satisfactory.

Behavioral intention to use **–** Based on the provided data, it is evident that the survey results indicate a positive behavioral intention to use the *AR+Core* application. Approximately 32.5% of respondents strongly agreed, and around 67.5% agreed they highly intend to use the application. This positive behavioral intention suggests a strong willingness among users to continue using the application and indicates a promising outlook for user adoption and usage. Behavioral intention to use is a crucial factor in predicting user behavior and the likelihood of continued usage of an application.

When users express a high intention to use an application, it indicates their strong desire and motivation to engage with it in the future.

5. Conclusion

In conclusion, the study findings suggest that 7th-grade students received the *AR+Core* application for learning computer hardware well. The HMSAM evaluation indicated positive outcomes in all aspects: control, curiosity, perceived usefulness, joy, immersion, perceived ease of use, and behavioral intention to use (Figure 9). The application was perceived as valuable and beneficial, supporting the learning needs of the students. It elicited positive emotions and was enjoyable to use. The user-friendly and intuitive design of the application facilitated user adoption and engagement. The application also successfully stimulated curiosity and encouraged exploration, promoting active learning. The positive behavioral intention to use indicates a strong willingness among students to continue using the learning application.

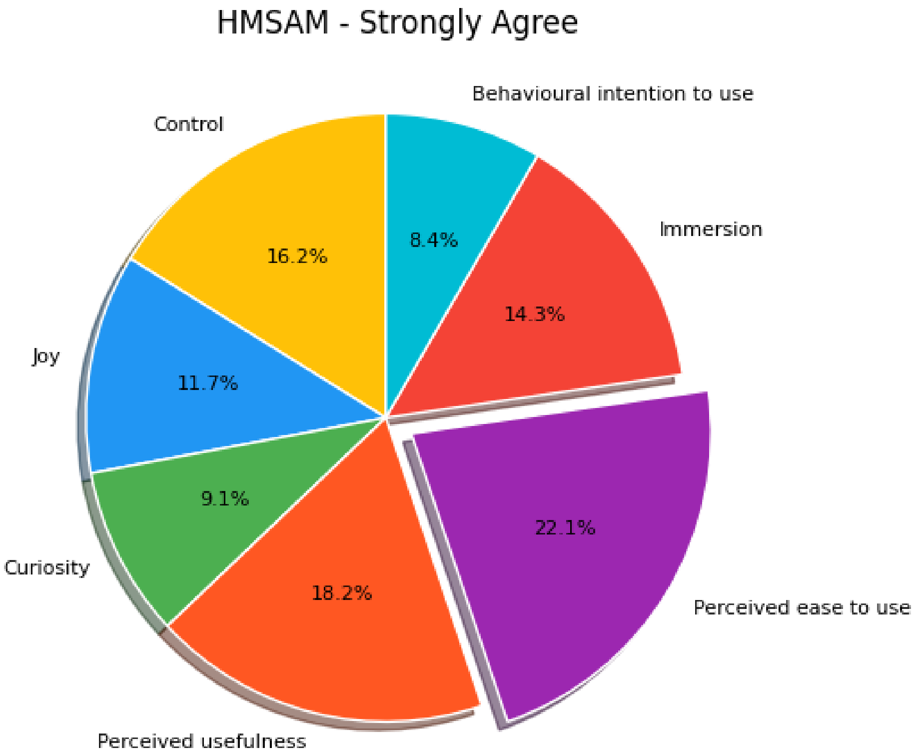


Figure 9. Distribution of 'Strongly Agree' by seven main components (HMSAM)

The survey results provide valuable insights for developers and designers to enhance further the application's features, usability, and immersive qualities, ensuring a more engaging and satisfying learning experience. The study acknowledges limitations regarding sample size and session duration, suggesting that more extensive evaluations are needed to validate the findings and explore long-term effects. Lastly, the study concludes that the *AR+Core* application is a promising and practical tool for learning and exploring computer hardware recognition. Its immersive features, positive user experience, and potential for enhancing engagement make it a valuable asset in educational settings.

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