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Development of Interactive AR Computer Lab

Muhammad Fazrulhelmi Ahmad[1], Aidilynn Balqis[1], Balqees Humaira[1], Nur Aqilah Maisarah[1], Reyanhealme Rohanai[2]*

[1]C[2]Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Malaysia

Correspondence: E-mail: mfazrul@uthm.edu.my

ABSTRACT

Information technology is critical in processing, transmitting, and making information available in different formats and has a key role to play in modern decision-making, automation, communication, data management, and innovation. Within educational contexts, traditional approaches often do not provide interactive or practical learning experiences, especially when it comes to computer hardware education. This research is intended to improve the learning experience of students studying computer hardware by using TechAR (Augmented Reality) technology that creates an immersive and interactive learning environment. The methodological approach followed a systematic route based on the Waterfall Model, which ensured AR-related developments are systematically embedded into user-friendly web platforms. The platform enables students to manipulate 3D models of computer parts through virtual simulation. Extensive tests and quality assurance procedures ensured functionality, usability, and performance were guaranteed. The results indicate that the use of AR techniques, compared with conventional methods, greatly improves study outcomes as well as retention levels. The key findings of this research are that TechAR technology in computer hardware education enhances learning experiences, improves study outcomes, and increases retention levels through an immersive and interactive environment. This Interactive AR Computer Lab is a cutting-edge teaching tool that bridges the gap between theory and practice, allowing for a deepening of theoretical understanding.

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1. INTRODUCTION

Information technology (IT) plays a fundamental role in contemporary society by enabling the processing, transmission, and management of digital information across multiple domains, including education, industry, and innovation. Rapid advancements in areas such as cloud computing, the Internet of Things (IoT), artificial intelligence, and cybersecurity have significantly transformed how knowledge is delivered and accessed in higher education environments. However, despite these technological developments, teaching and learning approaches in computer hardware education often remain conventional, relying heavily on static materials, textual explanations, and limited physical demonstrations. Such approaches may restrict students' ability to visualise complex internal components and understand their functional relationships, ultimately affecting learning engagement and retention (Radianti et al., 2020; Garzón et al., 2021).

To address these challenges, immersive technologies particularly Augmented Reality (AR) has gained increasing attention as effective pedagogical tools in technical and vocational education. AR enables the overlay of digital content onto real-world environments, allowing learners to interact with Three-Dimensional (3D) representations of objects in an intuitive and meaningful manner. Recent studies have demonstrated that AR-supported learning environments can significantly enhance conceptual understanding, motivation, and long-term knowledge retention when compared to traditional instructional methods (Ibáñez & Delgado-Kloos, 2018; Akçayır & Akçayır, 2017). In computer hardware education, AR provides a safe and cost-effective alternative to physical laboratories by allowing students to explore internal and external components virtually, reducing dependency on physical equipment while maintaining experiential learning quality.

In line with these developments, this study proposes the development of an Interactive AR Computer Lab using AR technology to enhance students' learning experiences in computer hardware courses. TechAR offers additional advantages by enabling AR access directly through standard web browsers without requiring dedicated applications or specialised hardware, thus improving accessibility and scalability. The primary objective of this research is to design, develop, and evaluate a TechAR-based learning platform that allows students to manipulate and explore 3D models of computer components interactively. By bridging the gap between theoretical instruction and practical understanding, this study aims to contribute empirical evidence on the effectiveness of TechAR as an innovative teaching aid in information technology education, supporting more engaging, flexible, and student-centred learning environments (Pellas et al., 2018).

2. METHODS

The integration of Augmented Reality (AR) in education has gained significant attention over the past decade due to its potential to transform traditional learning environments into immersive and interactive experiences. AR is widely recognised for its ability to overlay digital information onto the real world, enabling learners to visualise abstract concepts and interact with virtual objects in meaningful contexts. In higher education, particularly in science, technology, engineering, and mathematics (STEM) disciplines, AR has been shown to enhance learners' conceptual understanding, motivation, and engagement by supporting experiential and constructivist learning approaches (Radianti et al., 2020; Garzón et al., 2021). These characteristics make AR especially suitable for subjects that require spatial understanding and practical exploration, such as computer hardware education.

Recent studies highlight the effectiveness of AR-based learning environments in improving academic performance and knowledge retention compared to conventional instructional methods. Ibáñez and Delgado-Kloos (2020) reported that AR-supported learning significantly improves students' comprehension of complex systems by enabling active exploration and immediate feedback. Similarly, Akçayır and Akçayır (2018) found that AR enhances learner engagement and promotes deeper cognitive processing, although they emphasised the importance of usability and instructional design in ensuring learning effectiveness. In the context of technical education, AR applications allow students to simulate hands-on experiences that would otherwise require costly or limited physical resources, thereby addressing logistical constraints commonly faced by educational institutions.

The emergence of Web-based Augmented Reality (TechAR) further extends the accessibility and scalability of AR in education. Unlike traditional AR applications that require installation of specialised software, TechAR operates directly through standard web browsers, allowing learners to access immersive content using commonly available devices such as smartphones and laptops. Studies by Pellas et al., (2018) demonstrated that TechAR increase learner participation and reduce technological barriers, making AR more inclusive and adaptable for large-scale educational implementation. In computer hardware education, TechAR enables learners to explore internal and external components through interactive 3D models without the risks associated with physical disassembly. Despite these advantages, existing literature indicates a need for more empirical studies focusing on TechAR applications in computer hardware learning, particularly within diploma-level and vocational education contexts. This research seeks to address this gap by developing and evaluating an Interactive AR Computer Lab that leverages TechAR technology to enhance learning effectiveness and user experience.

3. METHODS

For designing the TechAR, it adopted the Waterfall Model, a structured approach where each phase sequentially follows the previous one. The research was conducted through a systematic process involving literature review, needs assessment, prototyping, and evaluation. The choice of the Waterfall Model was based on its clear and systematic progression through defined phases, ensuring a methodical development process aligned with project requirements and objectives.

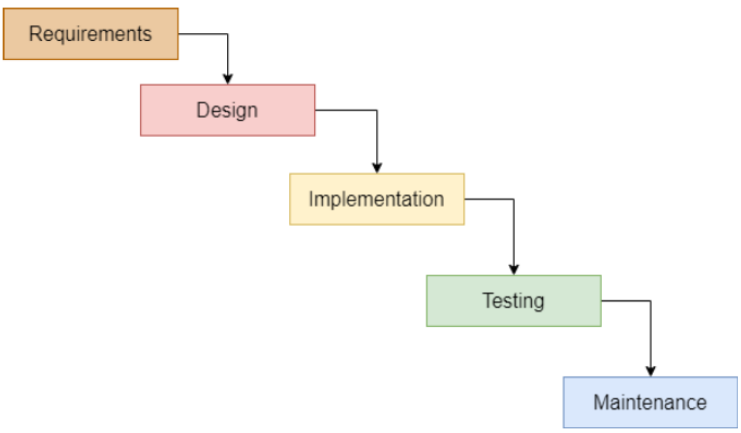

Figure 1. Waterfall methodology.

3.1. Requirement analysis

Coming from the plan that was created based on the primary findings of the analysis, further research and stakeholders' interviews were aimed at gaining better understanding of the necessary functions to be implemented in the framework of the TechAR. This entailed determining the components of AR that allow for user engagement, the nature of the application determining AR's domain, and other features required for an intuitive interface. Holding a detailed understanding of the requirements of the product helped in guaranteeing that the end product can sufficiently satisfy the stakeholders.

3.2. Design and development

Finally armed with clear understanding of all the projects specifications it was time to Design and Develop solutions. To achieve this, it prioritized the site's appearance and layout so that all users would be able to easily interact with it. At the same time, we implemented advanced AR features, which enable the user to move through the futuristic digital world and effectively learn the basics of computer components and their functions. Also, it created custom information texts, instructional videos, and games, which included simple but useful text descriptions of moves and controls.

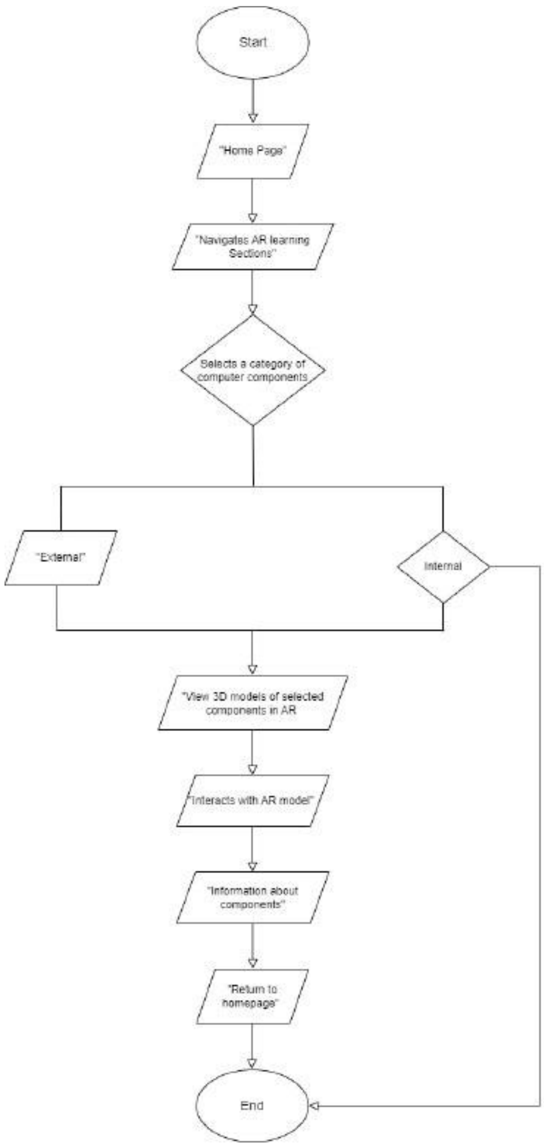

Figure 2. Process of our development for TechAR.

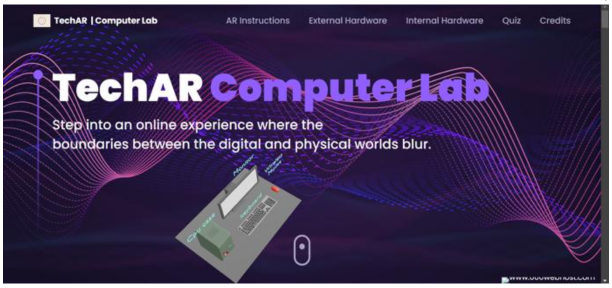

Figure.3 Product homepage.

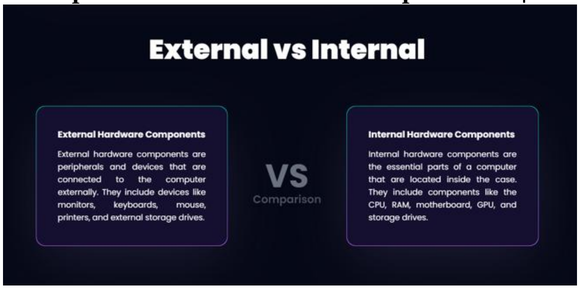

Figure.4 Product external/internal comparison.

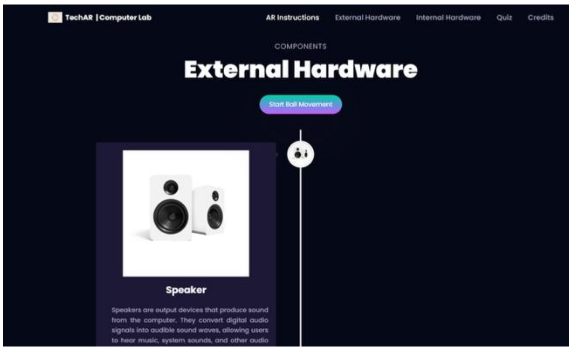

Figure.5 Product External Hardware Interface.

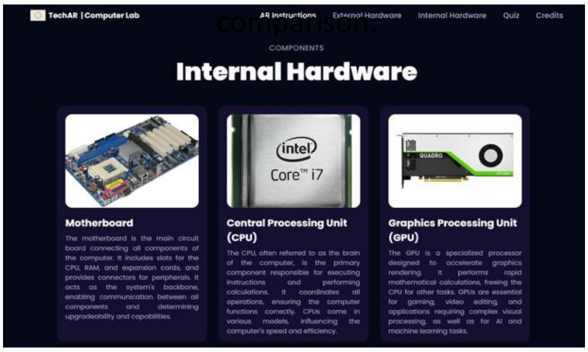

Figure.6 Product Internal Hardware Interface.

Photos that are hosted by TechAR serve as markers for users to aim their camera at to create 3D graphics for them on TechAR if they in order to learn on. People can basically capture these images with their gadgets that have a camera function and with the help and support of our unique AR software. When searching or browsing, the application immediately creates an animated 3D figure based on the scanned image for a user's exploration, enabling them to study different parts of computer hardware in depth and from multiple angles.

3.3 Implementation Phase

The implementation phase translates the web AR platform design into an educational functional product for supporting students in working with computer hardware. It is important to configure the development tools, 3D models, and AR functionality at this stage. In addition, it will be followed by learning aids like tutorials and quizzes. Afterwards, testing and stakeholder collaboration are done rigorously for functionality assurance and user satisfaction, supported by comprehensive documentation for sustainability and knowledge sharing purposes.

3.4 Testing and Quality Assurance

It was very important to go through the tests and provide high quality platform to the users with fine features and necessary stability and performance. Some of the tests conducted were functionality testing whereby we affirmed primary operations, usability testing whereby we examined user experiences and task interactions, and performance testing to measure server reaction and systems capacity. This made it possible to check for any flaws that may have been present in the products before delivering the unit to the end-consumer market, as we worked to provide the best quality product.

3.5 Deployment and Maintenance

After giving the lab the test, it was ready for usage and release to the public as the Interactive TechAR. The adapted goal as a result of the shift is to sustain and further enhance the platform through post-deployment maintenance. This entailed constant observation of the users, especially in relation to their feedback, alongside reporting and fixing complications that emerged from bug checks from time to time, as well as making ongoing optimization to include added or advanced features to support the functionality and ease of use over time.

4. RESULTS AND DISCUSSION

The goal of the evaluation is to assess how often and in what way the users of TechAR engages with the services provided by the website. Collecting this feedback is important for measuring the usefulness of the current platform and its overall comprehensibility for the target audience. Through the proposed TechAR, the authors plan to improve the learning of concepts regarding computer hardware by applying AR technology as a means of making the educational experiences diverse and exciting for students and professors. Upon the end of development stage, the TechAR had been assessed by three experts chosen among the Information Technology lecturers of the Universiti Tun Hussein Onn Malaysia (UTHM). Also, there is a feedback form to capture the perceptions of UTHM students.

There were 26 participants in the survey, and their responses on the performance of the website cross-sectional with a variety of opinions. This was developed by creating a feedback collection survey using Google Forms. Thus, to address these research questions, the authors developed a comprehensive self-completed web-based questionnaire to capture a range of aspects of the website, such as usability, quality and quantity of content, operation of AR, and general levels of satisfaction. The link to the questionnaire was then shared on WhatsApp with the experts and users to allow easy access to its content through their mobile devices. The feedback that was received from the survey showed the key highlights and the areas of improvement on TechAR.

Table 1. Mean for user survey on our TechAR.

No.	Item	Response					Mean
		Highly Dissatisfied	Dissatisfied	Neutral	Satisfied	Highly Satisfied	
1.	How satisfied are you with the overall user experience of the Interactive TechAR?	0%	0%	14.3%	39.3%	42.9%	0.14
2.	How well did the app meet your expectations in terms of functionality?	0%	7.1%	0%	32.1%	53.6%	0.07
3.	How would you rate the TechAR performance in terms of stability?	0%	0%	32.1%	39.3%	25%	0.30
4.	How effectively were you able to interact with the 3D models within the TechAR?	0%	0%	25%	28.6%	46.4%	0.30

5.	How satisfied are you with the loading times of the TechAR?	0%	0%	28.6%	35.7%	32.1%	0.29
6.	How appealing did you find the visual design of the TechAR?	0%	0%	21.4%	14.3%	64.3%	0.14
7.	How satisfied are you with the clarity and quality of the TechAR visuals and models?	0%	0%	14.3%	21.4%	64.3%	0.14
8.	How easy was it to learn how to use the app?	0%	0%	14.3%	39.3%	46.4%	0.14
9.	How satisfied are you with the app's user interface?	0%	0%	14.3%	21.4%	64.3%	0.14
10.	How well did the app perform on your device?	0%	7.1%	14.3%	39.3%	39.3%	0.07
11.	How satisfied are you with the educational content provided by Interactive TechAR?	0%	0%	10.7%	25%	64.3%	0.11
12.	How likely are you to recommend Interactive TechAR to others?	0%	0%	17.9%	32.1%	50%	0.18
						Total	**1.93**

This study examined the effectiveness of the TechAR by analysing user feedback related to usability, functionality, learning experience, and overall satisfaction. A total of 26 respondents, consisting of students and academic staff with backgrounds in information technology, participated in the evaluation. The findings provide empirical evidence on how Web-based AR can support computer hardware learning in a practical educational context. Overall, the findings indicate a positive user response and strong acceptance of the TechAR platform. More than half of the respondents (56.4%) reported being satisfied with the overall user experience, while no respondents indicated dissatisfaction. This suggests that the system interface, navigation flow, and interaction design were generally effective and did not create unnecessary cognitive burden. Prior studies have highlighted that learner satisfaction is closely linked to system usability and perceived ease of interaction in immersive learning environments (Umar et al., 2024). The absence of negative feedback reflects that TechAR achieved an appropriate balance between technical complexity and user friendliness.

In terms of system functionality, 85.7% of respondents indicated that the platform met or exceeded their expectations. Core features such as AR visualisation, 3D object manipulation, and browser-based access functioned as intended for most users. Although some respondents expressed neutral views regarding system stability, no critical failures were reported. This finding aligns with recent research showing that TechAR, when properly optimised, can deliver stable performance comparable to native AR applications, particularly in educational settings (Saidin et al., 2022). The interaction with 3D computer hardware models was one of the most positively rated aspects of TechAR, with 74.6% of respondents reporting effective interaction. This demonstrates that the platform successfully supported spatial visualisation and hands-on exploration of computer components. Such interaction is particularly valuable in hardware-related subjects, where understanding internal structures is often limited by physical access to equipment. Similar findings have been reported by Jin and Zhong (2025), who emphasised that interactive 3D visualisation enhances learners' mental models and conceptual understanding in technical domains.

Findings related to learning ease and educational value further reinforce the effectiveness of TechAR. A large majority of respondents (85.7%) stated that the platform was easy to learn, while 89.3% expressed satisfaction with the educational content provided. These results suggest that TechAR supports self-directed learning and reduces the learning curve commonly associated with advanced educational technologies. According to Alqahtani and Rajkhan (2020), AR-based instructional systems that combine clear visual cues with intuitive controls significantly improve learner confidence and knowledge retention. Regarding visual design and interface quality, 64.3% of respondents expressed satisfaction with the clarity and attractiveness of the AR models and user interface. While loading time received some neutral feedback, it did not appear to significantly hinder the learning experience. Importantly, 82.1% of respondents indicated that they would recommend TechAR to others, demonstrating strong perceived usefulness and adoption potential. Recommendation intention is widely recognised as a reliable indicator of educational technology effectiveness and long-term sustainability (Bond et al., 2021).

In summary, the findings confirm that the TechAR provides a meaningful and engaging learning environment for computer hardware education. The platform demonstrates strong usability, effective AR interaction, and high educational value, making it a viable alternative to traditional teaching approaches. While minor technical improvements can further enhance performance, the results support the role of TechAR as a practical and impactful instructional tool, particularly for diploma level and vocational education contexts.

5. CONCLUSION

From the case of the Interactive TechAR, it has been substantiated that augmented reality can help students to increase their interest in the field of computer hardware studies due to the app's engaging TechAR environment. It turns students into end users of ideas using tangible 3D models of computer parts that actual students can play around with alongside the use of the technologies in the classroom. Most of the stakes holders had a favorable impression of the app by exhibiting enhancements in learning outcomes and retention of the learners Though, areas such as stability and the rate at which the app loads were seen to be areas of strength that needed to be developed more. Evaluation regarding the effectiveness of the educational application will also be ongoing, with frequent updates to advance the app and keep the learning aspect intact. Interactive AR Computer Lab is one such model that demonstrates how essential tools in education assist learners in embracing the best technology to upgrade old learning strategies in computer hardware classes.

5. AUTHOR CONTRIBUTION

The authors confirm contribution to the paper as follows: **study conception and design:** Muhammad Fazrulhelmi Ahmad, Balqees Humaira, Aidilynn Balqis; **data collection:** Nur Aqilah Maisarah; **analysis and interpretation of results:** Muhammad Fazrulhelmi Ahmad, Balqees Humaira, Aidilynn Balqis, Nur Aqilah Maisarah; **draft manuscript preparation:**

Balqees Humaira, Nur Aqilah Maisarah. All authors reviewed the results and approved the final version of the manuscript.

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