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# Development of a Marker-Based Augmented Reality Application for Computer Hardware Learning Using the Multimedia Development Life Cycle

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***Abstract*** – Understanding computer hardware is a fundamental competency for vocational students. However, limited access to physical hardware components often restricts practical learning activities in vocational schools. This study aims to develop and evaluate VirtuComp, a marker-based Augmented Reality (AR) application for computer hardware learning using the Multimedia Development Life Cycle (MDLC) methodology. The application visualizes seven essential computer hardware components as interactive three-dimensional (3D) objects to support students in recognizing and understanding hardware structures through an immersive learning experience. The development process followed the six phases of the MDLC framework. The application was evaluated through functional performance testing and usability assessment involving 68 tenth-grade students from SMK Muhammadiyah 02 Cileungsi using the User Experience Questionnaire (UEQ). The functional evaluation demonstrated that the marker-based tracking system operated reliably under adequate lighting conditions with an optimal detection distance of 4–12 cm. The usability evaluation produced positive results across all six UEQ dimensions. Efficiency achieved a score of 1.89, which was classified as Excellent. Attractiveness (1.74), Perspicuity (1.78), and Stimulation (1.38) were rated as Good, while Dependability (1.40) and Novelty (0.96) were categorized as Above Average. These findings indicate that the proposed application provides a reliable and user-friendly learning medium that supports computer hardware education, particularly in vocational schools with limited laboratory resources.

***Keywords – Augmented Reality, Multimedia Development Life Cycle, User Experience Questionnaire, Computer Hardware, Central Processing Unit.***

## I. INTRODUCTION

Mastery of computer hardware is a fundamental competency for students enrolled in the Computer and Network Engineering (TKJ) vocational program. Understanding the structure, functions, and interrelationships of hardware components is essential for developing the practical skills required in computer maintenance and system assembly. However, many vocational schools face challenges in providing sufficient and up-to-date laboratory equipment due to budget limitations. Consequently, students often have limited opportunities to interact directly with physical hardware, which may reduce the effectiveness of practical learning activities [1][2].

Recent advances in educational technology have introduced Augmented Reality (AR) as an effective medium for enhancing interactive learning experiences. Previous studies have reported that AR improves students' motivation, engagement, and conceptual understanding by integrating virtual three-dimensional objects into real-world environments. In parallel, the Multimedia Development Life Cycle (MDLC) has been widely adopted as a systematic framework for developing multimedia-based educational applications because it provides structured stages for design, implementation, and evaluation [3][4]. Furthermore, usability evaluation using standardized instruments such as the User Experience Questionnaire (UEQ) has become increasingly important for assessing the quality of educational applications from the users' perspective [13].

Despite these developments, existing studies have primarily emphasized the implementation of AR technology or the development of multimedia learning applications without comprehensively integrating a systematic development framework and standardized usability evaluation in the context of vocational computer hardware education. In addition, studies focusing specifically on the visualization of internal computer hardware components for vocational learning remain limited. This gap indicates the need for an educational application that not only provides realistic three-dimensional visualization but also demonstrates both technical reliability and positive user experience through empirical evaluation [6][7][14][15].

To address this gap, this study develops VirtuComp, a marker-based Augmented Reality application for learning computer hardware using the Multimedia Development Life Cycle (MDLC) methodology. The application visualizes seven essential computer hardware components in an interactive three-dimensional environment and is evaluated through technical performance testing and the User Experience Questionnaire (UEQ) [5]. The main contribution of this study is the integration of a structured multimedia development framework with comprehensive usability evaluation to provide an effective interactive learning medium for vocational computer hardware education. The findings are expected to support technology-enhanced learning by offering an accessible alternative for schools with limited laboratory resources while improving students' learning experience through immersive visualization.

## II. RESEARCH METHODOLOGY

### 2.1. Research Design and Object

This study employed a research and development (R&D) approach to design, develop, and evaluate a marker-based Augmented Reality application for computer hardware learning. The development process followed the Multimedia Development Life Cycle (MDLC) methodology, which provides a systematic framework for multimedia application development through six sequential phases: Concept, Design, Material Collecting, Assembly, Testing, and Distribution. The proposed application was subsequently evaluated to assess its technical performance and user experience.

The research was conducted at SMK Muhammadiyah 02 Cileungsi, with tenth-grade students from the Computer and Network Engineering (TKJ) program serving as the research participants. These participants were selected because the developed application was specifically designed to support the learning of computer hardware components within the vocational school curriculum.

Figure 1 illustrates the overall research methodology adopted in this study. The research process began with problem identification and requirement analysis through field observation and literature review, followed by application development using the Multimedia Development Life Cycle (MDLC) method [3]. The final stage involved technical performance evaluation through marker detection testing under different environmental conditions, as well as usability evaluation using the User Experience Questionnaire (UEQ) to assess users' perceptions of the proposed application. This systematic research framework ensured that both the technical functionality and the educational usability of the developed application were comprehensively evaluated.

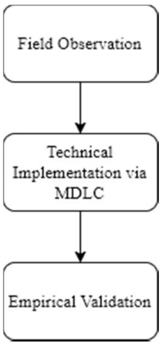


Figure. 1 Research Methodology.

### 2.2. Development Framework (MDLC)

The proposed application was developed using the Multimedia Development Life Cycle (MDLC) methodology, which provides a structured framework for developing multimedia-based applications. The MDLC approach consists of six sequential phases that ensure the systematic design, implementation, and evaluation of the proposed Augmented Reality application [3].

1. **Concept**: This phase identified the instructional objectives, target users, and functional requirements of the application, as well as the computer hardware components to be visualized in the learning environment.
2. **Design**: The system architecture, user interface, application workflow, and marker-based interaction mechanism were designed to support intuitive navigation and effective visualization of three-dimensional objects.
3. **Material Collecting**: Learning materials, three-dimensional models, textures, hardware specifications, and multimedia assets were collected and prepared for integration into the application.
4. **Assembly**: All multimedia assets were integrated into the development environment using the Unity game engine and the Vuforia Software Development Kit (SDK). Interactive features, including marker recognition, object visualization, and user interaction, were implemented during this phase.
5. **Testing**: The application underwent functional and technical evaluations to verify marker detection accuracy, object visualization stability, and application performance under different operating conditions. Usability was subsequently assessed using the User Experience Questionnaire (UEQ).
6. **Distribution**: The completed application was packaged as an Android application package (APK) and deployed for evaluation by the target users in the learning environment.

Figure 2 illustrates the six phases of the Multimedia Development Life Cycle (MDLC) implemented in this study. The framework provides a systematic development process, beginning with concept formulation and application design, followed by multimedia asset integration, system implementation, testing, and final deployment. The adoption of the MDLC methodology ensured that the proposed Augmented Reality application was developed in a structured manner while meeting both functional requirements and educational objectives.

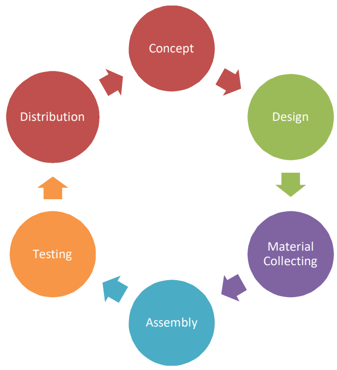


Figure. 2 Stages of the Multimedia Development Life Cycle (MDLC) Method.

### 2.3. Usability Evaluation

The usability of the proposed Augmented Reality application was evaluated using the User Experience

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Questionnaire (UEQ), a standardized instrument widely employed to assess users' perceptions of interactive systems. The UEQ measures six dimensions of user experience: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty, providing a comprehensive evaluation of both pragmatic and hedonic aspects of system usability.

The evaluation was conducted after participants completed the learning activities using the developed application. A total of 68 tenth-grade students from the Computer and Network Engineering (TKJ) program at SMK Muhammadiyah 02 Cileungsi participated in the evaluation. The sample size was determined using the Slovin formula to ensure that the selected respondents adequately represented the target population.

The collected UEQ responses were analyzed by calculating the mean score for each evaluation dimension and comparing the results with the established UEQ benchmark categories. This benchmarking process enabled the usability and user experience of the proposed application to be interpreted according to internationally recognized evaluation standards, thereby providing empirical evidence of the application's effectiveness and user acceptance.

## III. RESULTS AND DISCUSSION

### 3.1. Application Implementation and 3D Visualization

The implementation phase resulted in the development of VirtuComp, an Android-based Augmented Reality (AR) application designed to facilitate the learning of computer hardware components through interactive three-dimensional visualization [8]. The application was developed following the Multimedia Development Life Cycle (MDLC) framework and integrates marker-based AR technology to present virtual hardware models in a real-world environment. This implementation enables users to explore computer hardware interactively, providing a more engaging and immersive learning experience than conventional two-dimensional instructional media.


Figure. 3 Application UI.

Figure 3 presents the implemented Android application user interface. The interface consists of the Instruction and Main Menu screens, which serve as the primary interaction points for users. The Instruction screen provides guidance on operating the application, while the Main Menu offers access to the application's core functions, including AR visualization, learning materials, and additional features. The interface was designed with an intuitive navigation structure to enhance usability and facilitate efficient interaction.

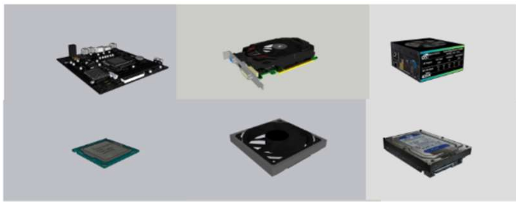

Figure. 4 3D Visualization.

Figure 4 illustrates the three-dimensional visualization of computer hardware components implemented within the application. The developed models, including the motherboard and other CPU components, were designed with realistic geometric structures and textures to closely resemble actual hardware. The integration of interactive 3D visualization allows users to observe each component from multiple perspectives, thereby improving conceptual understanding of hardware structures and supporting a more immersive learning process [9][11].


Figure. 5 AR Markers.

Figure 5 presents a representative AR marker used in the proposed marker-based Augmented Reality application. The marker functions as the primary recognition target, enabling the system to detect and track physical images before rendering the corresponding three-dimensional computer hardware model together with its instructional information. This marker-based recognition mechanism ensures stable object visualization, accurate tracking, and seamless interaction, thereby enhancing both the reliability of the application and the overall learning experience [12].

### 3.2. Experimental Results of Performance Evaluation

The performance evaluation was conducted to assess the effectiveness of the marker-based tracking mechanism under different environmental conditions, including variations in detection distance and lighting intensity. The evaluation aimed to determine the operating conditions that provide stable object recognition and visualization, thereby ensuring the reliability of the proposed Augmented Reality application during instructional activities.

Table 1 summarizes the experimental results obtained from the marker detection tests. The results indicate that the

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application achieved its most stable performance when the marker was positioned at a distance ranging from 4 cm to 12 cm from the device camera. Within this range, the system consistently recognized the marker and rendered the corresponding three-dimensional object with accurate alignment and minimal tracking instability. At shorter distances, the marker occupied a larger portion of the camera frame, while distances within the optimal range provided sufficient image detail for reliable feature extraction and tracking.

Table 1. Testing Parameters

| Testing | | Good | Fair | Poor |
|---|---|---|---|---|
| Distance (cm) | 4 | ✓ | | |
| | 8 | ✓ | | |
| | 12 | ✓ | | |
| | 27 | | ✓ | |
| | 50 | | ✓ | |
| Tilt Angle | 0° | ✓ | | |
| | 45° | ✓ | | |
| | 70° | ✓ | | |
| Lighting Condition | Bright | ✓ | | |
| | Dark | | ✓ | |

As the detection distance increased beyond approximately 27 cm, the tracking performance gradually deteriorated. This reduction in accuracy can be attributed to the decreasing image resolution of the marker captured by the camera, which limits the number of distinguishable feature points available for the computer vision algorithm. Consequently, the system experienced delayed recognition or failed to render the virtual object consistently.

Lighting conditions also had a significant influence on tracking performance. Stable visualization was achieved under adequate illumination, whereas darker environments reduced image contrast and degraded the visibility of marker features. Since marker-based Augmented Reality relies on feature detection and image matching, insufficient lighting negatively affected the system's ability to distinguish the marker from the surrounding background, resulting in unstable tracking and reduced visualization accuracy.

Overall, the experimental findings demonstrate that the proposed application provides reliable marker recognition and stable three-dimensional visualization when operated within the recommended distance and lighting conditions. These results confirm the technical feasibility of employing marker-based Augmented Reality as an effective instructional medium for computer hardware learning.

### 3.3. Usability Evaluation and Empirical Findings

The usability of the proposed application was evaluated using the User Experience Questionnaire (UEQ), which measures user perceptions across six dimensions: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. The evaluation aimed to assess both the usability and overall user experience of the marker-based Augmented Reality application after users completed the learning activities [10].

The UEQ Benchmark graph and the corresponding mean scores are presented in Figures 6 and 7, providing a comprehensive comparison between the obtained results and the established UEQ benchmark categories. These findings offer quantitative evidence of the application's usability and interaction quality, allowing its performance to be evaluated against a large collection of benchmarked interactive systems.

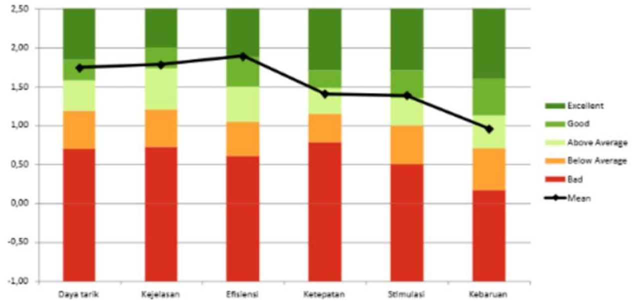


Figure. 6 UEQ Benchmark Graph.

The benchmark analysis indicates that the application achieved a mean score of 1.89 for the Efficiency dimension, placing it in the Excellent category. This result demonstrates that users were able to complete learning tasks efficiently, navigate the interface with minimal effort, and interact with the application's features without unnecessary complexity. The high efficiency score reflects the effectiveness of the interface design and interaction flow in supporting computer hardware learning.

The remaining dimensions also produced favorable results. Attractiveness (1.74), Perspicuity (1.78), and Stimulation (1.38) were classified as Good, indicating that users perceived the application as visually appealing, easy to understand, and engaging throughout the learning process. These findings suggest that the combination of intuitive navigation, clear instructional content, and interactive three-dimensional visualization contributed positively to the overall learning experience.

Meanwhile, Dependability (1.40) and Novelty (0.96) were categorized as Above Average, demonstrating that users considered the application reliable while also recognizing its innovative characteristics. Although the Novelty score was lower than the other dimensions, it still exceeded the average benchmark, indicating that the application offers a satisfactory level of innovation while leaving opportunities for future enhancements, such as richer interactive features, adaptive learning scenarios, or more immersive Augmented Reality interactions.

| Scale | Mean | Comparisson to benchmark | Interpretation |
|---|---|---|---|
| Daya tarik | 1,74 | Good | 10% of results better, 75% of results worse |
| Kejelasan | 1,78 | Good | 10% of results better, 75% of results worse |
| Efisiensi | 1,89 | Excellent | In the range of the 10% best results |
| Ketepatan | 1,40 | Above Average | 25% of results better, 50% of results worse |
| Stimulasi | 1,38 | Good | 10% of results better, 75% of results worse |
| Kebaruan | 0,96 | Above Average | 25% of results better, 50% of results worse |

Figure. 7 UEQ Mean Scores.

Overall, the empirical findings demonstrate that the proposed application delivers a positive user experience across all six UEQ dimensions. The consistently favorable benchmark ratings indicate that the application not only functions reliably from a technical perspective but also provides an effective, engaging, and user-friendly learning environment. These results support the feasibility of employing marker-based Augmented Reality as an instructional medium for computer hardware education and confirm that the developed application satisfies key usability requirements for educational technology.

### 3.4. Scientific Discussion

The findings of this study demonstrate that the integration of marker-based Augmented Reality with the Multimedia Development Life Cycle (MDLC) methodology provides an effective approach for developing interactive learning media for computer hardware education. The technical evaluation confirmed that the proposed application achieved stable marker recognition under appropriate operating conditions, while the usability evaluation indicated positive user perceptions across all six User Experience Questionnaire (UEQ) dimensions. These results suggest that the application successfully fulfills both its functional requirements and usability objectives.

Compared with previous studies, such as Ramadhan (2021), which primarily emphasized the overall quality of Augmented Reality systems, the present study specifically focuses on the visualization of computer hardware components within a vocational education context [9]. This domain-specific implementation enables students to interact directly with three-dimensional representations of hardware components, thereby supporting a more engaging and intuitive learning process. The adoption of the MDLC framework also provides a structured development process that facilitates systematic multimedia application design and evaluation.

The Efficiency score of 1.89, categorized as Excellent according to the UEQ benchmark, indicates that users were able to operate the application with minimal effort and navigate its features effectively. In addition, the positive scores obtained for Attractiveness, Perspicuity, Dependability, Stimulation, and Novelty demonstrate that the application offers a balanced user experience by combining functional usability with engaging visual interaction. These findings indicate that the developed application is suitable for supporting practical learning activities in vocational education.

From an educational perspective, the proposed application offers a practical alternative for introducing computer hardware concepts in situations where access to physical laboratory equipment is limited. Rather than replacing conventional laboratory practice, the application complements existing instructional methods by providing interactive three-dimensional visualization that enhances students' conceptual understanding and learning engagement. Consequently, the proposed Augmented Reality application has the potential to support technology-enhanced learning environments while reducing the dependence on extensive physical hardware resources.

## IV. Conclusion

This study developed VirtuComp, a marker-based Augmented Reality (AR) application for computer hardware learning using the Multimedia Development Life Cycle (MDLC) method. The application enables students to explore three-dimensional models of computer hardware components interactively, providing a more engaging learning experience than conventional instructional media. The experimental evaluation demonstrated that the marker-based tracking mechanism operated reliably under adequate lighting conditions and at an optimal detection distance of 4–12 cm, ensuring stable visualization of virtual objects. Furthermore, the User Experience Questionnaire (UEQ) results indicated positive user perceptions across all six evaluation dimensions, with the Efficiency scale achieving an Excellent benchmark rating, reflecting the application's ease of use and effective interaction design. These findings suggest that the proposed application is a practical and effective learning medium for supporting computer hardware education while reducing the need for extensive physical laboratory equipment. Future research may focus on integrating virtual hardware assembly simulations, incorporating interactive assessment features, and improving marker tracking performance under challenging environmental conditions to further enhance learning effectiveness and user experience.

## References

[1] Anakotta, R., Sugiarso, B. A., & Tulenan, V. (2023). Augmented Reality Identifikasi Perangkat Keras Komputer Untuk Anak Kelas 7. *Jurnal Teknik Elektro Dan Komputer*, *12*(1), 25–34. Retrieved from https://ejournal.unsrat.ac.id/v3/index.php/elekdankom/article/view/43850/42456

[2] Andreas, N., & Suryantara, I. G. N. (2023). Pengenalan Komponen Komputer Berbasis Augmented Reality Pada Android Dengan Metode Single Marker. *Jurnal Algoritma, Logika Dan Komputasi*, *6*(1). https://doi.org/10.30813/j-alu.v6i1.3610

[3] Atmanto, E. A., Pudjoatmodjo, B., & Sularasa, A. (2021). Implementasi Augmented Reality Pada Aplikasi Mutiara Furniture Berbasis Android Menggunakan Metode MDLC. *E-Proceeding of Applied Science*, *7*(6), 3412–3419.

[4] Dalimunthe, H. F., & Simanjuntak, P. (2023). APLIKASI PENGENALAN PERANGKAT KERAS KOMPUTER BERBASIS ANDROID MENGGUNAKAN AUGMENTED REALITY. *Computer and Science Industrial Engineering (COMASIE)*, *9*(2). https://doi.org/10.33884/comasiejournal.v9i2.7624

[5] Fadillah, M. A., Yunus, A., & Budianto, A. E. (2022). ANALISIS USER EXPERIENCE PADA AUGMENTED REALITY ORGANOLOGY

MENGGUNAKAN USER EXPERIENCE QUESTIONNAIRE (UEQ). *JATI (Jurnal Mahasiswa Teknik Informatika)*, *6*(2), 512–518. https://doi.org/10.36040/jati.v6i2.4888

[6] Khoiron, M., Huda, W. S., & Sholiha, H. (2023). Media Pengenalan Hardware Komputer Berbasis Game Menggunakan AR Markerless. *Larisa Teknik Informatika*, *1*(01), 24–33.

[7] Putra, J. A., & MZ, Y. (2023). Implementasi Serta Edukasi Aplikasi Augmented Reality Pengenalan Perangkat Keras Jaringan Menggunakan Metode Marker-Based Tracing Pada SMKN 3 Yogyakarta. *Jurnal ADARMA*, 49–55. Retrieved from https://e-journal.janabadra.ac.id/index.php/adarma/article/view/2485/1657

[8] Putri, A. E., & Hendriyani, Y. (2023). Pengembangan E-Modul Berbasis Augmented Reality Untuk Mata Pelajaran Komputer dan Jaringan Dasar Siswa Kelas X TKJ di SMK Negeri 3 Seluma. *JAVIT: Jurnal Vokasi Informatika*, *3*(1), 56–63. https://doi.org/10.24036/javit.v3i1.70

[9] Ramadhan, A. F., Putra, A. D., & Surahman, A. (2021). Aplikasi Pengenalan Perangkat Keras Komputer Berbasis Android Menggunakan Augmented Reality (AR). *Jurnal Teknologi Dan Sistem Informasi (JTSI)*, *2*(2), 1–8. Retrieved from http://jim.teknokrat.ac.id/index.php/JTSI

[10] Rasio, H. S., & Perdana, S. R. (2020). Evaluasi User Experience Sistem Informasi Akademik Mahasiswa pada Perguruan Tinggi Menggunakan User Experience Questionnaire. *Jurnal Komputer Terapan*, *6*(1), 69–78. Retrieved from https://jurnal.pcr.ac.id/index.php/jkt/

[11] Rinov, M. (2023). Pelatihan Pembelajaran Berbasis Augmented Reality (AR) di Era Teknologi 5.0 pada Materi Instalasi Komputer. *JPM: Jurnal Pengabdian Masyarakat*, *2*(2), 209. https://doi.org/10.52434/jpm.v2i2.2744

[12] Saifuddeen, M., Fahim, M., Sahil, M., Sahil, M., & Afeel, A. (2023). Markerless Augmented Reality Implementation Using Computer Vision. *Journal of Advance Research in Mobile Computing*, *5*(1).

[13] Schankin, A., Budde, M., Riedel, T., & Beigl, M. (2022). Psychometric Properties of the User Experience Questionnaire (UEQ). *CHI Conference on Human Factors in Computing Systems*, 1–11. New York, NY, USA: ACM. https://doi.org/10.1145/3491102.3502098

[14] Tasrif, E., Mubai, A., Huda, A., & Rukun, K. (2020). Pemanfaatan media pembelajaran berbasis augmented reality menggunakan aplikasi Ar_Jarkom pada mata kuliah instalasi jaringan komputer. *Jurnal Konseling Dan Pendidikan*, *8*(3), 217. https://doi.org/10.29210/153400

[15] Taufik, A., Alamsyah, N., & Saputra, A. (2023). Development of Augmented Reality-Based Mobile App Learning Media for Computer Network Hardware Material. *EduLine: Journal of Education and Learning Innovation*, *3*(3), 320–327. https://doi.org/10.35877/454RI.eduline2004