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User-Centered Design of Marker-Based Augmented Reality Learning Media to Improve Informatics Learning Effectiveness

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Abstract. Computer science education in schools still relies heavily on traditional teaching methods, resulting in low student motivation, particularly in topics related to computer hardware components. This study develops an interactive Augmented Reality (AR) learning medium with Marker-Based Tracking using a User-Centered Design (UCD) approach to improve Informatics Learning effectiveness among 73 junior high school students at SMP Negeri 28 OKU. The UCD method was implemented through four stages: establishing requirements, designing, prototyping, and evaluating. Learning effectiveness was measured using N-Gain, a paired sample t-test, and Cohen's d based on pre-test and post-test scores. User experience was evaluated using the User Experience Questionnaire (UEQ), covering six dimensions: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. The N-Gain score reached 0.937, classified as "High." The paired t-test yielded a statistically significant difference between pre-test and post-test scores ($p < 0.001$), and Cohen's d was 1.757, indicating a "Very Large" effect size. UEQ evaluation results across all six dimensions exceeded the benchmark threshold for the "Excellent" category. These findings indicate improved learning outcomes in the evaluated class and positive user experience with the developed AR medium.

Keywords: Augmented Reality, User-Centered Design, Marker-Based Tracking, Learning Media, Informatics

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1. INTRODUCTION

Augmented Reality (AR) is one of the most cutting-edge reality technologies for education in recent years [1],[2]. AR has been effectively applied in a number of industries, including education [3]. One of the newest innovations is augmented reality technology, which is becoming more and more popular. The effectiveness of its application in teaching has been the subject of numerous international research [4]. For example, because of its distinctive features that combine virtual and actual elements, Augmented Reality (AR) has been widely accepted in higher education [5]. For example, it has a good impact on academic achievement and learning motivation [6]. In addition to learning achieved through self-directed learning, collaborative learning, personalized learning, and experiential learning approaches, augmented reality (AR) offers meaningful learning experiences and improves cognitive, affective, and psychomotor learning [7]. It is intended that by employing pre-tests and post-tests, we would be able to gauge how much students gain from visual computer-based learning with augmented reality technology [8]. Since computer science is a discipline that deals with abstract and technical ideas, it needs visual aids that can provide students a concrete understanding of the subject. In actuality, though, the majority of the learning process is still carried out in a traditional manner, which makes pupils more likely to be unmotivated and inactive.

In recent years, augmented reality (AR) has drawn a lot of interest as a technology that overlays virtual items to improve the user's vision and interaction with the actual environment [9]. Our research provides insightful information about how educators and students can profit from the integration of AR technology with learning analytics, as well as how educational institutions and business organizations can capitalize on the adoption of this technology [10]. AR-enhanced teaching approaches have proven to be quite beneficial in recent years, especially in higher education [11]. The authors further explain interaction as multimodal sensory based on earlier research on human-technology interaction [12]. This study examines if integrating AR with marker-based tracking in computer science classes can enhance students' learning efficacy.

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In addition to identifying, tracking, and reacting to students' affective states and taking into account their emotions, personalities, traits, knowledge, and preferences to provide adaptive and personalized learning, as shown here, another study emphasizes their capacity to provide engaging and interactive learning experiences [13]. According to later study, augmented reality (AR) has the potential to revolutionize physical education by enhancing student engagement and excitement through interactive and engaging learning experiences. In order to improve the dynamics and results of learning in physical education, this study argues in favor of incorporating augmented reality technology into educational curriculum. It also emphasizes the need for more investigation into the long-term effects and scalability of augmented reality applications in a variety of academic settings and fields. In a different study, a physical model was created to forecast the transport velocity of crushed rock material traveling in a circular motion along a vibrating screen. These factors, such material layer thickness and capacity, are essential for comprehending and improving screening performance [14]. The integration of Augmented Reality (AR) into Music Education (MusEdAR) has been the subject of further research, which highlights the innovative potential and current state of AR [15].

The goal of subsequent research, which uses systematic mapping, is to give an overview of how augmented reality and mobile devices have been used over the past ten years, which academic fields have benefited from this creative academic approach, and the main advantages and difficulties of utilizing this technology in early childhood and elementary education [16]. In comparison to their classmates in the traditional group, students in an AR-based gamification group with self-directed settings demonstrated notable improvements in academic achievement, engagement, self-efficacy, and overall satisfaction, according to another study [17]. In order to examine participants' opinions regarding the use of augmented reality, other studies gather and assess data [18]. According to a different survey, the use of augmented reality (AR) in commercial applications has grown significantly in recent years and is expected to expand much more in the future. In particular, this study seeks to pinpoint the major augmented reality elements that effect e-commerce and investigates how these elements affect consumers' comprehension of products and their ability to create an engaging experience, thereby improving the entire consumer experience [19]. Another

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study used virtual reality and augmented reality texts to compare the retelling skills of two groups who engaged in reading activities [20]. Additionally, using augmented reality (AR) in physical education has the potential to improve the wellbeing of kids with special needs in Malaysian schools, eliminate barriers, and create a more inclusive learning environment [21].

Within the context of computer science education at the junior high school level, the subject matter involves abstract and technical concepts—such as computer hardware components and their functions—that are difficult to convey through conventional text-based instruction alone. Based on initial observations at SMP Negeri 28 OKU, teachers face significant limitations in using interactive learning media for hardware-related topics. Students struggle to recognize the physical form and understand the function of hardware components solely through textual explanations and static images, leading to reduced enthusiasm and engagement in learning.

Marker-Based Tracking is well-suited to the school context because it operates reliably on widely available Android smartphones without requiring high-end devices or dedicated infrastructure [22]. It enables students to point their device cameras at printed markers to trigger interactive 3D visualizations in the classroom or laboratory environment, making it both practical and accessible for regular instructional use.

Previous studies on AR in education have primarily focused on subjects such as Science, Mathematics, Art, and Physical Education [23][24]. AR applications specifically designed for computer hardware topics at the junior high school level remain scarce. Furthermore, the limited research that does exist on AR for Informatics education has rarely integrated a User-Centered Design (UCD) approach with a rigorous learning-effectiveness evaluation. This gap motivates the present study.

This study aims to (1) apply the UCD method in the design and development of Marker-Based AR learning media for Informatics education, and (2) evaluate the effectiveness of the produced media in enhancing students' conceptual understanding of computer hardware components and their functions, as well as their user experience as measured by the UEQ.

2. METHODS

This study employs User-Centered Design (UCD) [25][28],, a multidisciplinary design approach based on active user engagement to enhance understanding of user needs and tasks, as well as design iteration and evaluation. It is also a methodology in the development of products, services, or systems that focuses on the needs, preferences, and experiences of end-user. This approach serves as a crucial foundation for designing human-computer interactions in the hardware subject to this study.

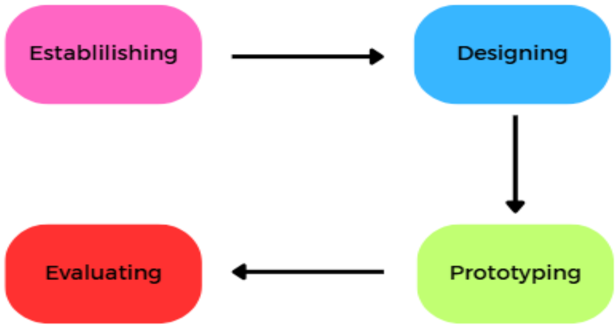

Figure 1. UCD Research Workflow

As shown in Figure 1, the first step is Establishing requirements, also known as user research, which involves collecting data on end users—including interviews, surveys, observations, and contextual analysis—to understand their needs and preferences. The second process is concept design (Design), where a basic framework or initial idea for the product or system is created based on insights from user research. The third stage is prototyping (Prototype), which involves building an early version of the product or system that users can test to obtain valuable feedback. The fourth stage is user evaluation (Evaluating). This stage involves users in testing the prototype or the actual product to identify issues and gather feedback that can be used for improvements. Modeling interactive interfaces using User-Centered Design (UCD) in recommendation systems is crucial for creating a user-friendly, engaging, and personalized experience. Researchers have identified a problem regarding the lack of interactive teaching materials, which results in students being less enthusiastic about learning. However, if such materials are used, it is expected that students will become more interested in understanding the lessons provided.

2.1 Research Stages

2.1.1 Estabillishing

During the problem analysis stage, the researcher identified the difficulties and challenges faced in the computer science learning process at school. The analysis was conducted to identify emerging issues, such as students' difficulty in understanding abstract concepts in computer systems, the limited availability of interactive learning materials, and low student motivation. The results of this analysis served as the basis for determining the needs to be addressed through the development of AR-based learning materials using the UCD method. The data collection phase was conducted to obtain accurate information regarding the actual conditions of the teaching and learning process as well as user needs for learning media. The technique used was interviews with teachers and students. Interviews with teachers aimed to identify difficulties in delivering material, the media typically used, and expectations regarding the new learning media. Meanwhile, interviews with students were conducted to understand their learning experiences, the difficulties they faced, and their preferences regarding interactive learning media. The data obtained at this stage served as the foundation for understanding the context of use for the media to be developed. After the data was collected, the researcher identified the context of use. This phase focused on understanding the situations and environments where the AR educational media would be used, such as classrooms, computer labs, or independent use via smartphones. In addition, the researchers also identified the primary users (teachers and students) and their characteristics, such as technological proficiency, learning interests, and prior experience with digital media. An analysis of the devices used was also conducted to ensure the compatibility of the AR application with available devices.

2.1.2 Designing

The design phase involves a user requirements analysis aimed at defining the functional and non-functional requirements of the system to be developed. Data from interviews with teachers and students was used to determine the key features needed in the learning media, such as the ability to display 3D objects, the addition of explanatory text, marker-based interaction, and user-friendly navigation. Non-functional requirements, such as an attractive interface, response speed, and ease of use, are also

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considered. The results of this requirements analysis serve as the primary reference during the AR media design phase. The design phase involves creating a solution based on the results of the requirements analysis. The researcher designs the AR media's user interface (UI/UX) to be easy to understand, intuitive, and visually appealing. The design process began with the creation of a flowchart to illustrate the system flow, from the marker detection process to the display of 3D objects and supporting information. Next, wireframes were created to visualize each screen display and the interactions the user would experience. This design served as a guide during the development of the AR prototype, which was based on UCD principles.

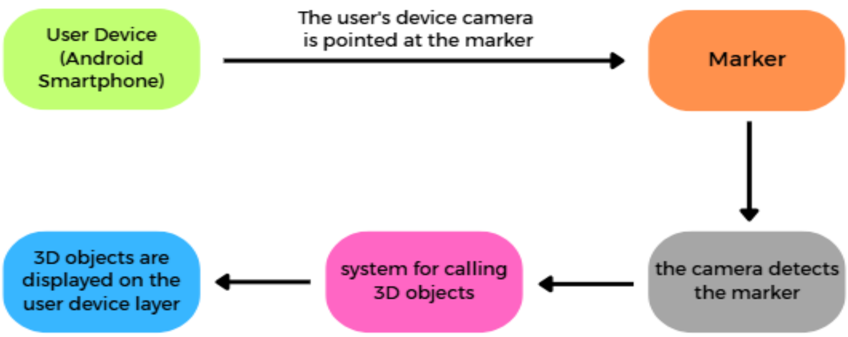

Figure 2. The Application Augmented Reality (AR) works

Figure 2 illustrates how the application works: the user points the camera at a marker, and the system reads the marker. Once the marker matches the one in the application, the application displays the object in the form of augmented reality.

Figure 3 shows the wireframe development for the initial design of an Augmented Reality (AR)-based educational tool, aimed at illustrating the layout structure, object placement, text, images, and navigation before the final design process begins. The wireframe is created as a black-and-white digital sketch to facilitate the evaluation of layout and information flow for each computer hardware component, such as the monitor, motherboard, printer, RAM, mouse, keyboard, hard drive, and processor. This stage helps developers ensure the design aligns with user needs before proceeding to the full interface implementation phase.

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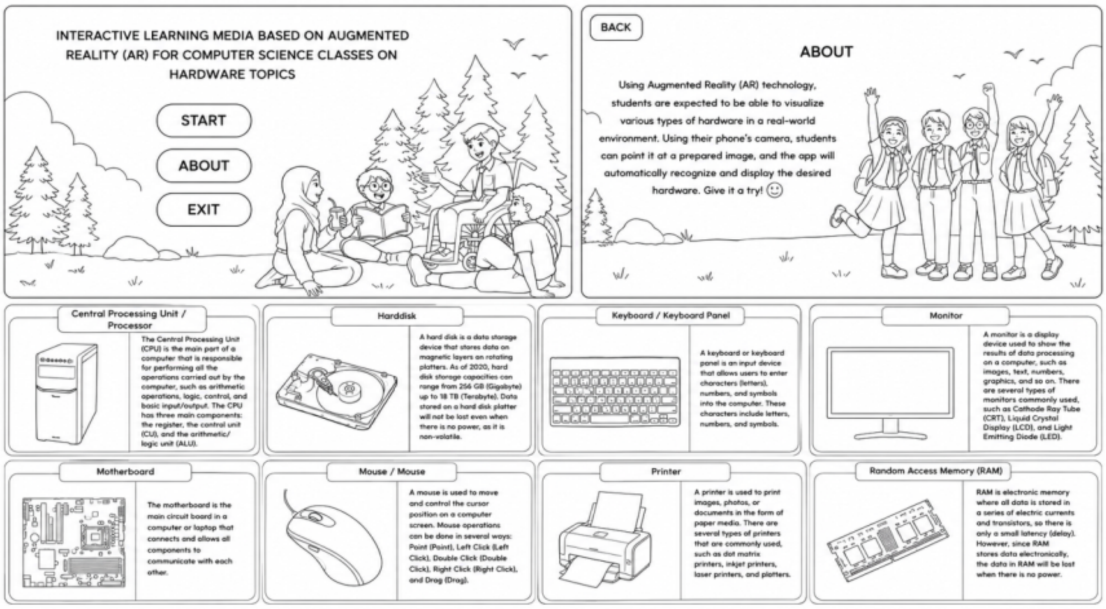

Figure 3. Augmented Reality (AR) Wireframe Design

2.1.3 Prototyping

The prototype stage is the actual implementation of the design results. The researchers developed 3D AR-based learning media by adding visual content in the form of three-dimensional images and explanatory text on computer science material. The prototype was then tested on a limited basis with teachers and students to obtain feedback on usability, appearance, and the benefits of the media in learning using UEQ.

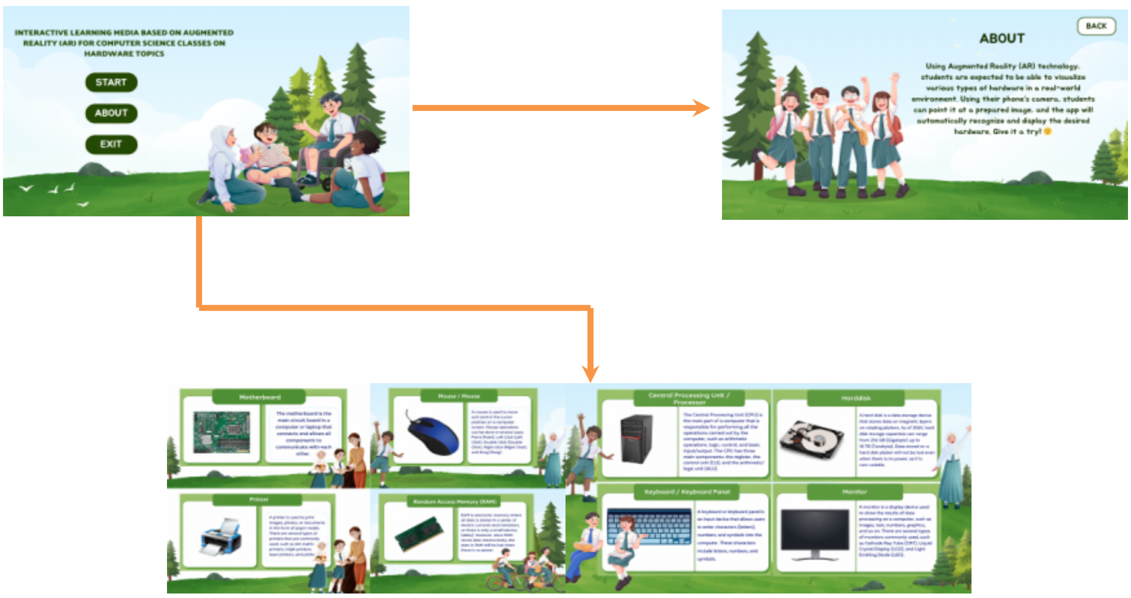

Figure 4. Augmented Reality Learning Medium

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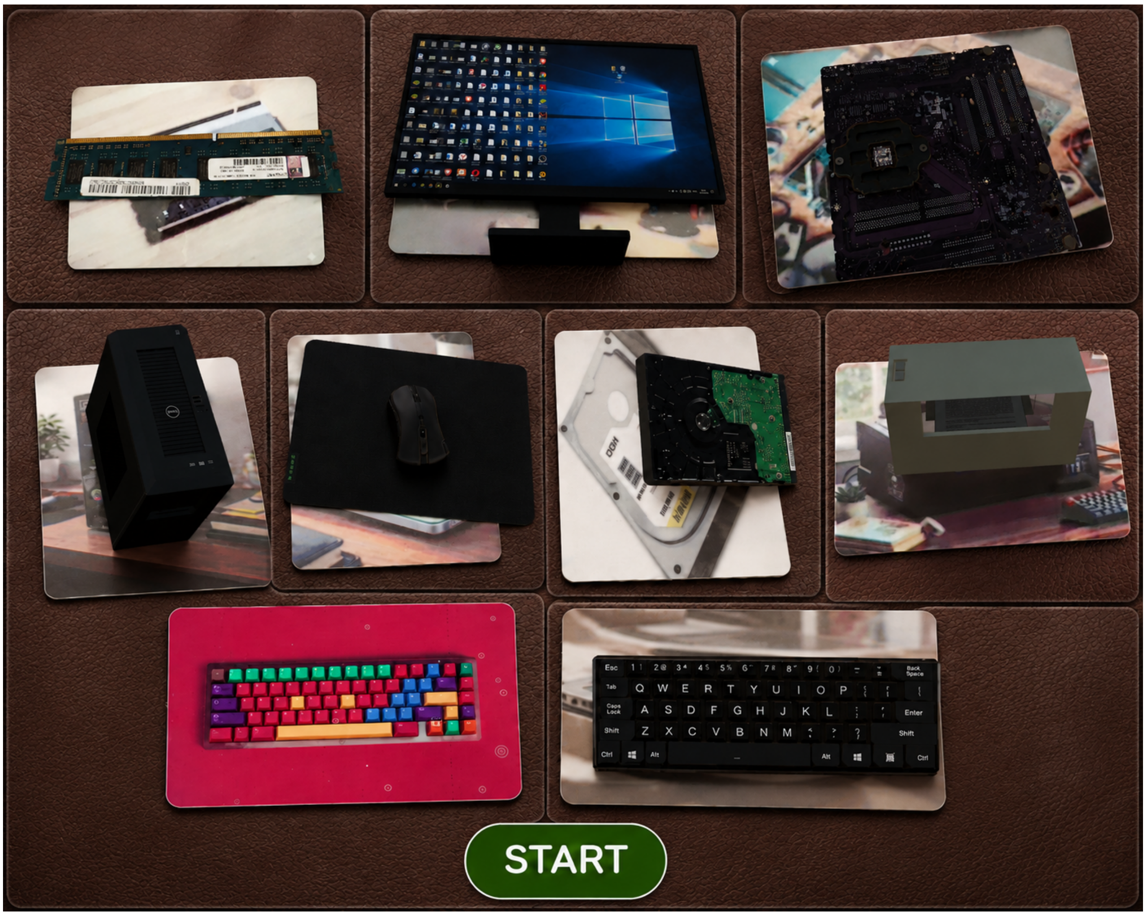

Figure 5. Augmented Reality Marker_Based Tracking

2.1.4 The evaluation was conducted using:

1) The UEQ (User Experience Questionnaire)

Which is one of the questionnaires whose results can be used in usability testing to quickly measure a product's user experience. The UEQ can be downloaded at www.ueq-online.org. The User Experience Questionnaire (UEQ) is an evaluation method used to measure user experience through six main aspects, including attractiveness, perspicuity, and efficiency. Ease of use is one of the primary concern in the development of Augmented Reality applications. Student perception questionnaire: assessing the learning experience after using the AR media, measured using the UEQ [25].

The selection of the User Experience Questionnaire (UEQ) as the evaluation instrument in this study was based on the need to comprehensively measure user experience with the developed Augmented Reality (AR) learning media. The UEQ is an internationally standard instrument specifically designed to assess the quality of user interaction with

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technology-based systems, covering the following aspects: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty.

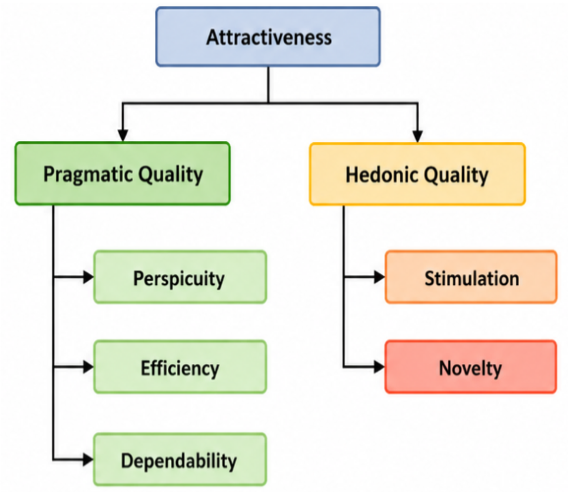

Figure 6. UEQ Measurement Scale

These six dimensions are relevant to the reaobjectives of this study, which seeks not only to assess the functional performance of the AR medium as a learning tool, but also to evaluate the extent to which the medium is capable of delivering a learning experience that is engaging, easy to use, motivating, and aligned with students' needs.

Furthermore, the use of the UEQ is consistent with the User-Centered Design (UCD) approach, which places users at the center of the entire system development process. Through the UEQ, users' perceptions of the resulting product can be obtained directly and in a structured manner, ensuring that the evaluation outcomes genuinely reflect students' actual experiences when using the AR medium. The UEQ was also selected for its practicality, conciseness, and accessibility to school-level respondents, making it well-suited for application in educational research contexts. UEQ data were analyzed using descriptive qualitative methods to interpret the meaning of user experiences, and the findings were further supported by observational and interview data. As such, the UEQ functions not merely as a usability measurement tool, but also as a means of gaining deeper insight into the quality of students' learning experiences and evaluating the success of User-Centered Design (UCD) implementation in AR-based learning media development.

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2) Data Analysis

Normality Test: Before applying the paired t-test, the normality of the pre-test–post-test score differences was assessed using the Shapiro-Wilk test (n < 100). Results indicated that the score differences were approximately normally distributed ($W = 0.971$, $p = 0.082$), justifying the use of the parametric paired t-test.

3) Effectiveness

The effectiveness of the intervention was assessed by analyzing pre-test and post-test results using the following measures: the N-Gain test, the significance test (paired t-test), and the effect size (Cohen's d), which were analyzed using Microsoft Excel.

a) Improvement Test (N-Gain)

The first step was to conduct the Improvement Test (N-Gain) [26], with the following criteria as shown in Table 1.

Table 1. Scale Interpretation N-Gain

N-Gain	Category
≥ 0,7	High
0,3 - <0,7	Moderate
< 0.3	Low

b) Significance Test (Paired Sample T-Test)

Following the N-Gain test, the next step was to conduct the Paired Sample T-Test [29], with the following criteria as shown in Table 2:

Table 2: paired sample t-test testing criteria (*alpha 5%*)

Paired Sample T-Test Testing Criteria (*ALPHA 5%*)	
P-VALUE < 0,05	Significant difference exists
P-VALUE > 0,05	No significant difference

c) Effect Size (Cohen's d)

Effect size was calculated to determine the magnitude of the effect resulting from the implementation of the AR marker-based tracking learning medium on students' ability

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in the Informatics subject. The following presents the Effect Size interpretation scale as shown in Table 3 [27]:

Table 3. Scale Interpretation *Effect Size*

Effect Size	**Interpretation**
0 < d < 0,2	Small
0,2 < d ≤ 0,5	Moderate
0,5 < d ≤ 0,8	Large
d > 0,8	Very Large

2.2 Participants

The study involved participants across two phases. In the UCD development phase, two Informatics teachers and 3 students from SMP Negeri 28 OKU participated in needs analysis interviews and prototype evaluation. In the learning-effectiveness evaluation phase, 73 eighth-grade students from the same school participated in a one-group pre-test–post-test design. Participants were selected using purposive sampling based on the availability of the target class and the relevance of the computer hardware topic in the current curriculum. The duration of the learning session, which also served as the learning-effectiveness evaluation stage, was 2 lesson hours (40 minutes/1 lesson hour).

Table 4. Participant Flow Across UCD Stages

UCD Stage	Teachers Involved	Students Involved
Establishing Requirements	2	3
Designing	2	3
Prototyping	2	3
Evaluating (UEQ)	2	73
Pre-test & Post-test	—	73

2.3 AR Development Environment

The AR application was developed using Unity 3D (version 2021.3 LTS) with the Vuforia Engine SDK for marker detection and tracking. Hardware components visualized in 3D included the monitor, motherboard, processor (CPU), RAM, hard drive, keyboard, mouse, and printer. Markers were designed as printed cards with high-contrast visual patterns

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to ensure stable detection under typical classroom lighting conditions. The application was built for Android (minimum SDK version 24, Android 7.0) and tested on mid-range smartphones (3 GB RAM, 13 MP rear camera) representative of devices commonly available to students.

2.4 UCD Iteration Process

Stage 1 – Establishing Requirements: Data were collected through semi-structured interviews with two Informatics teachers and ten students. Teachers identified difficulties in delivering hardware material and expressed expectations for visual, interactive media. Students reported difficulty recognizing hardware components from images alone and expressed preference for media that could be used independently via smartphone.

Stage 2 – Designing: Based on interview findings, the research team defined functional requirements (3D object display, explanatory text per component, marker-based interaction, simple navigation) and non-functional requirements (attractive interface, fast response, ease of use). A system flowchart and wireframes were developed for each hardware component screen.

Stage 3 – Prototyping: A functional AR prototype was developed and evaluated in a limited session with teachers and students. Feedback from this stage led to revisions including: simplifying the navigation menu based on student suggestions, increasing font size of explanatory text based on teacher feedback, and improving marker contrast to reduce detection failures.

Stage 4 – Evaluating: The revised prototype was deployed to 73 students for the learning-effectiveness evaluation (pre-test–post-test) and UEQ assessment.

2.5 Pre-test and Post-test Instruments

The pre-test and post-test instruments consisted of 10 multiple-choice items covering two learning indicators: (1) recognition of computer hardware components by name and physical appearance, and (2) understanding of each component's function within the computer system. Score range was 0–10 (each correct answer scored 1). Both instruments were validated by two subject-matter experts (Informatics teachers with more than five years of teaching experience) prior to deployment, ensuring alignment

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with the curriculum indicators and appropriate difficulty level. The questions used in the pre-test and post-test were identical or equivalent.

3. RESULTS AND DISCUSSION

3.1. Analysis of User Experience Questionnaire (UEQ)

The collected data were analyzed using the UEQ data analysis tool to evaluate the user experience with the developed AR Learning Medium. The UEQ provides analysis through 26 items across 6 scales, encompassing attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. Figure 6 presents the response distribution for each UEQ item on a 7-point Likert scale.

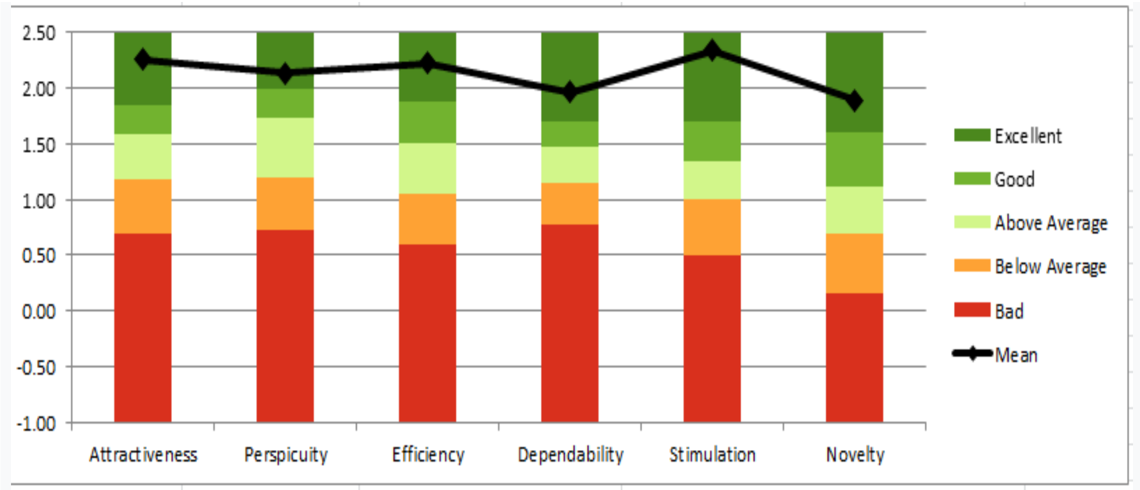

Figure 8. UEQ Benchmark Results [28]

Based on the results of this study, it was found that the evaluation scores for all aspects were positive, with all UX dimensions obtaining scores above 0.8. This is consistent with Rauschenberger, who states that mean impression values between −0.8 and 0.8 represent a normal evaluation range, values above 0.8 indicate a positive evaluation, and values below −0.8 indicate a negative evaluation. The mean measurement scores for each variable, including the novelty dimension of the UEQ, can be seen in Figure 8.

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Table 5. User Experience Questionnaire Results

Scale	Mean	Comparison to benchmark	Interpretation
Attractiveness	2.26	**Excellent**	In the range of the 10% best results
Perspicuity	2.14	**Excellent**	In the range of the 10% best results
Efficiency	2.23	**Excellent**	In the range of the 10% best results
Dependability	1.96	**Excellent**	In the range of the 10% best results
Stimulation	2.34	**Excellent**	In the range of the 10% best results
Novelty	1.89	**Excellent**	In the range of the 10% best results

Based on the comparison with the Table 5, the dimensions of attractiveness, perspicuity, efficiency, dependability, novelty, and stimulation all yielded excellent results. These findings demonstrate that the Augmented Reality-based Learning Medium has achieved an outstanding level of quality.

3.2. Effectiveness Evaluation

Effectiveness Evaluation was conducted by examining the pretest and posttest results, with the obtained data analyzed using:

3.2.1. Pre-test and Post-test Descriptive Statistics

To provide an initial overview of the participants' performance before and after the intervention, descriptive statistics were calculated for the pre-test and post-test scores of 73 participants. The analysis includes the mean, standard deviation, minimum, and maximum scores for each assessment. These descriptive measures provide a preliminary indication of changes in participants' scores following the intervention and serve as a basis for subsequent inferential statistical analysis. Table 6 presents the descriptive statistics of the pre-test and post-test scores.

Table 6. Descriptive Statistics of Pre-test and Post-test Scores

Statistic	Pre-test	Post-test
N	73	73
Mean	4.931	9.736
Standard Deviation	2.697	0.628

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Statistic	Pre-test	Post-test
Minimum	1.0	8.0
Maximum	9.0	10.0

3.2.2. Improvement Test (N-Gain),

The first step was the N-Gain test based on the pretest and posttest results obtained. The N-Gain test was employed to measure the effectiveness of learning outcome improvement in the Informatics subject using the Augmented Reality learning medium with Marker-Based Tracking. The results of the N-Gain test for the pretest and posttest are presented in Table 7. Based on Table 7 it can be determined that the mean N-Gain score was 0.937 and the mean N-Gain percentage was 93.69%. Based on the N-Gain score of 0.937, this result falls within the High category.

Table 7. Result N-gain pretest and posttest

Statistic	Pre-test Mean	Post-test Mean	Mean Gain	N-Gain Score	N-Gain (%)	Category
Group (n=73)	4.931	9.736	4.795	0.937	93.68%	High

3.2.3. Significance Test (Paired Sample T-Test)

To determine whether the increase in students' scores from the pre-test to the post-test was statistically significant, a paired-samples t-test was conducted. This test was appropriate because the pre-test and post-test scores were obtained from the same 73 participants, allowing the analysis to assess changes in performance following the implementation of the Augmented Reality (AR) learning medium. The paired-samples t-test was performed using Microsoft Excel with a significance level of $\alpha = 0.05$. The results are presented in Table 8..

Table 8. Result Paired Sample T-Test pretest and posttest

t-Test: Paired Two Sample for Means	4	8
Mean	4.931	9.736
Variance	7.277	0.394

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Observations	73	73
Pearson Correlation	0.039	
Hypothesized Mean Difference	0	
df	72	
t Stat	-14.851	
P(T<=t) one-tail	0.000	
t Critical one-tail	1.667	
P(T<=t) two-tail	0.001	
t Critical two-tail	1.994	

The paired-samples t-test revealed a statistically significant difference between the pre-test and post-test scores. The mean score increased from 4.931 in the pre-test to 9.736 in the post-test, representing an increase of 4.805 points. The analysis yielded a t-statistic of −14.851 with a two-tailed significance value of $p < 0.001$, which is substantially lower than the predetermined significance level of $\alpha = 0.05$. Therefore, the null hypothesis (H_0), which states that there is no significant difference between the pre-test and post-test scores, was rejected. These findings indicate that students demonstrated significantly higher learning outcomes after participating in the learning activities using the AR-based medium. The substantial increase in the mean score provides empirical evidence that the intervention was associated with improved student performance.

3.2.4. Effect Size (Cohen's d).

The subsequent step was the Cohen's d test based on the pretest and posttest results obtained. The results of the Cohen's d test for the pretest and posttest are presented in Table 9. A Cohen's d value of 1.757 indicates a very large effect size, confirming that the use of the AR medium was associated with a practically significant improvement in student learning outcomes within this study.

Table 9. Result Cohen's d

Mean Difference	4.794520548
SD Difference	2.728241722
Number of Samples (N)	73

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Cohen's d	1.757366479
Interpretation	Very Large

3.3. Discussion

This study is novel in that it applies a User-Centered Design (UCD) approach to Marker-Based Augmented Reality learning materials in computer science education, with a focus on simultaneously improving user experience and learning effectiveness. Previous research has focused solely on developing AR without considering a User-Centered Design (UCD) approach. This study applied a User-Centered Design approach to the development of Marker-Based Augmented Reality learning media for computer hardware topics in junior high school Informatics education. The results provide preliminary evidence of improved learning outcomes and positive user experience in the evaluated class.

The three-dimensional visualization of hardware components enabled students to observe the physical form of each component—monitor, motherboard, processor, RAM, hard drive, keyboard, mouse, and printer—in a way that static images cannot provide. Marker-based interaction required students to actively engage with the physical marker and the digital content simultaneously, which may have supported deeper encoding of component names and functions. The simple navigation design, based on iterative feedback from students during the UCD prototyping stage, minimized cognitive load associated with operating the application, allowing students to focus attention on the learning content.

The N-Gain score of 0.937 and Cohen's d of 1.757 observed in this study are consistent with findings from previous AR-based learning studies. For example, Ji et al. [15] reported improved student motivation and achievement in visual communication design education using AR, and Cheng et al. [10] found positive effects of AR on learning motivation and achievement in museum-based science learning. The present study extends these findings by demonstrating that systematically integrating UCD principles into the AR development process—particularly through iterative feedback from both teachers and students—can produce a medium that is both functionally effective and experientially engaging.

The high UEQ scores across all six dimensions, including Stimulation (2.339) and Novelty (1.890), may partly reflect a novelty effect—the heightened enthusiasm students experience when encountering an unfamiliar technology for the first time. Whether these positive perceptions would be sustained over multiple exposures or across a full semester of use remains an open question that future longitudinal studies should address.

It is important to note that this study used a one-group pre-test–post-test design without a control group. Accordingly, the observed improvement in scores cannot be attributed solely to the AR medium; other factors such as the learning experience itself, test familiarity, or teacher instruction may have contributed. The findings should therefore be interpreted as preliminary evidence of improved learning outcomes rather than definitive proof of AR's causal effectiveness.

The 3D visualization in this augmented reality learning media allows students to observe the shape, structure, and physical details of computer hardware components more realistically compared to two-dimensional images. The displayed three-dimensional objects can be viewed from various angles, allowing students to recognize the physical characteristics of each component more accurately. This helps overcome the limitations of understanding that were previously obtained only through textual descriptions or static illustrations.

Marker-based interaction provides a more active and contextual learning experience. When students point their device camera at the provided marker, the system automatically displays the 3D model along with information related to the component. This process creates a direct connection between the physical object (marker) and its digital representation, so that students not only observe but also actively engage in the exploration process. This type of interaction encourages curiosity and increases students' focus on the material being studied, as they play an active role in triggering the visualization rather than merely being passive recipients of information.

This study has several limitations that should be acknowledged. First, the research was conducted in a single school (SMP Negeri 28 OKU) with one class group, limiting the

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generalizability of the findings to other schools, student populations, or Informatics topics. Second, the one-group pre-test–post-test design without a control group makes it impossible to isolate the effect of the AR medium from other instructional factors. Third, the evaluation covered only one learning session; the sustainability of learning gains and user experience over extended use periods has not been assessed.

4. CONCLUSION

This study developed and evaluated Marker-Based Augmented Reality learning media using a User-Centered Design approach for teaching computer hardware topics in junior high school Informatics education at SMP Negeri 28 OKU, and the results provide preliminary evidence of improved learning outcomes, with an N-Gain score of 0.937 ("High" category), a statistically significant difference between pre-test and post-test scores ($t = -14.851$, $p < 0.001$), and a very large effect size (Cohen's $d = 1.757$), while the UEQ evaluation showed "Excellent" scores across all six dimensions—Attractiveness (2.256), Perspicuity (2.137), Efficiency (2.226), Dependability (1.962), Stimulation (2.339), and Novelty (1.890))—reflecting positive student perceptions; however, since this study did not include a control group, the observed improvements cannot be attributed solely to the AR medium, and broader validation across multiple schools and class groups is required, with future research needed to conduct experimental comparisons with a conventional-learning control group, explore markerless AR approaches, apply the medium to different Informatics topics, extend evaluation to longer use periods, and involve multiple schools to strengthen the generalizability of the findings.

REFERENCES

[1] N. A. M. Mokmin and R. P. Rassy, "Review of the trends in the use of augmented reality technology for students with disabilities when learning physical education," *Educ. Inf. Technol.*, vol. 29, no. 2, pp. 1251–1277, 2024, doi: 10.1007/s10639-022-11550-2.

[2] J. Forlizzi, "Moving Beyond User-Centered Design," Interactions, vol. 25, no. 5, pp. 22–23, Sep.–Oct. 2018, doi: 10.1145/3239558.

ISI Journal of Information Systems and Informatics
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[3] S. Singh, A. Kaur, and Y. Gulzar, "The impact of augmented reality on education: A bibliometric exploration," Front. Educ., vol. 9, Art. no. 1458695, 2024, doi: 10.3389/feduc.2024.1458695.

[4] Y. Koumpouros, "Revealing the true potential and prospects of augmented reality in education," Smart Learn. Environ., vol. 11, no. 1, Art. no. 2, 2024, doi: 10.1186/s40561-023-00288-0.

[5] G. Li, H. Luo, D. Chen, P. Wang, X. Yin, and J. Zhang, "Augmented reality in higher education: A systematic review and meta-analysis of the literature from 2000 to 2023," *Educ. Sci.*, vol. 15, no. 6, p. 678, 2025, doi: 10.3390/educsci15060678.

[6] A. Cheng, W. Zhang, A. Feng, Y. Wu, and W. Li, "Exploring psychological dimensions of augmented reality in education: a study on learning motivation and achievement in museums," *Front. Psychol.*, vol. 16, p. 1514117, 2025, doi: 10.3389/fpsyg.2025.1514117.

[7] G. Lampropoulos, "Augmented reality, virtual reality, and intelligent tutoring systems in education and training: A systematic literature review," *Appl. Sci.*, vol. 15, no. 6, p. 3223, 2025, doi: 10.3390/app15063223.

[8] H. Ateş, "Integrating augmented reality into intelligent tutoring systems to enhance science education outcomes," Educ. Inf. Technol., vol. 30, no. 4, pp. 4435–4470, 2025, doi: 10.1007/s10639-024-12970-y.

[9] X. Sheng, S. Mao, Y. Yan, and X. Yang, "Review on SLAM algorithms for Augmented Reality," *Displays*, vol. 84, Art. no. 102806, 2024, doi: 10.1016/j.displa.2024.102806.

[10] A. Sakr and T. Abdullah, "Virtual reality, augmented reality, and learning analytics: Impact on learners and educators—A systematic review," *Educ. Inf. Technol.*, vol. 29, no. 15, pp. 19913–19962, 2024, doi: 10.1007/s10639-024-12602-5.

[11] S. Ji, N. A. M. Mokmin, and J. Wang, "Evaluating the impact of augmented reality on visual communication design education: Enhancing student motivation, achievement, interest, and engagement," *Educ. Inf. Technol.*, vol. 30, no. 5, pp. 6617–6639, 2025, doi: 10.1007/s10639-024-13050-x.

[12] C. Chen, K. Z. K. Zhang, Z. Chu, and M. Lee, "Augmented reality in the metaverse market: the role of multimodal sensory interaction," *Internet Res.*, vol. 34, no. 1, pp. 9–38, 2024, doi: 10.1108/INTR-08-2022-0670.

[13] G. Lampropoulos, P. Fernández-Arias, Á. Antón-Sancho, and D. Vergara, "Affective computing in augmented reality, virtual reality, and immersive learning environments," *Electronics*, vol. 13, no. 15, p. 2917, 2024, doi: 10.3390/electronics13152917.

[14] N. Omarov, B. Omarov, Z. Azhibekova, and B. Omarov, "Applying an augmented reality game-based learning environment in physical education classes to enhance sports motivation," *Retos*, vol. 60, pp. 269–278, Nov. 2024, doi: 10.47197/retos.v60.109170.

[15] L. Nijs and B. Behzadaval, "Laying the foundation for augmented reality in music education," *IEEE Access*, vol. 12, pp. 100628–100645, 2024, doi: 10.1109/ACCESS.2024.3427698.

[16] H. Salmi, A. Kaasinen, and V. Kallunki, "Towards an Open Learning Environment via Augmented Reality (AR): Visualising the Invisible in Science Centres and Schools for Teacher Education," *Procedia Soc. Behav. Sci.*, vol. 45, pp. 284–295, 2012, doi: 10.1016/j.sbspro.2012.06.565.

[17] H. Ateş and M. Polat, "Leveraging augmented reality and gamification for enhanced self-regulation in science education," Educ. Inf. Technol., vol. 30, no. 12, pp. 17079–17110, 2025, doi: 10.1007/s10639-025-13481-0.

[18] X. Tian and C. S. Ironsi, "Examining the impact of augmented reality on students' learning outcomes," *Sci. Rep.*, vol. 15, no. 1, p. 36957, 2025, doi: 10.1038/s41598-025-20833-w.

[19] X.-Y. Xu, Q.-D. Jia, and S. M. U. Tayyab, "Exploring the stimulating role of augmented reality features in E-commerce: A three-staged hybrid approach," *J. Retail. Consum. Serv.*, vol. 77, Art. no. 103682, Mar. 2024, doi: 10.1016/j.jretconser.2023.103682.

[20] B. Şimşek and B. Koparan, "The effects of virtual reality and augmented reality technologies on students' story retelling performance," PLoS ONE, vol. 20, no. 5, Art. no. e0323445, 2025, doi: 10.1371/journal.pone.0323445.

[21] N. A. M. Mokmin, R. P. Rassy, and D. L. Yie, "Evaluating augmented reality in physical education for dyslexic students from the perspectives of teachers and students," *Sci. Rep.*, vol. 15, no. 1, p. 7682, 2025, doi: 10.1038/s41598-025-92533-4.

[22] R. T. Azuma, "A survey of augmented reality," Presence: Teleoperators Virtual Environ., vol. 6, no. 4, pp. 355–385, 1997, doi: 10.1162/pres.1997.6.4.355.

ISI Journal of Information Systems and Informatics
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[23] Q. Wang and Y. Li, "How virtual reality, augmented reality and mixed reality facilitate teacher education: A systematic review," *J. Comput. Assist. Learn.*, vol. 40, no. 3, pp. 1276–1294, 2024, doi: 10.1111/jcal.12949.

[24] S. A. Nikou, M. Perifanou, and A. A. Economides, "Exploring teachers' competences to integrate augmented reality in education: Results from an international study," *TechTrends*, vol. 68, no. 6, pp. 1208–1221, 2024, doi: 10.1007/s11528-024-01014-4.

[25] B. Laugwitz, T. Held, and M. Schrepp, "Construction and evaluation of a user experience questionnaire," in *HCI and Usability for Education and Work* (Proc. 4th Symp. Austrian HCI Usability Eng. Group, USAB 2008), A. Holzinger, Ed., Lecture Notes in Computer Science, vol. 5298. Berlin, Heidelberg: Springer, 2008, pp. 63–76, doi: 10.1007/978-3-540-89350-9_6.

[26] R. R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.*, vol. 66, no. 1, pp. 64–74, 1998, doi:10.1119/1.18809.

[27] D. Lakens, "Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs," *Front. Psychol.*, vol. 4, Art. no. 863, 2013, doi: 10.3389/fpsyg.2013.00863.

[28] M. Schrepp, A. Hinderks, and J. Thomaschewski, "Construction of a benchmark for the user experience questionnaire (UEQ)," *Int. J. Interact. Multimed. Artif. Intell.*, vol. 4, no. 4, pp. 40–44, 2017, doi:10.9781/ijimai.2017.445.

[29] Student, "The probable error of a mean," *Biometrika*, vol. 6, no. 1, pp. 1–25, Mar. 1908, doi: 10.1093/biomet/6.1.1.