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Performance Analysis of Meta-UI on Membatik Mixed Reality Application Using Nielsen's Heuristic Method

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***Abstract*—Moving beyond immersive learning, the rapid advancement of Mixed Reality (MR) technology is diversifying its applications across various sectors, including education, healthcare, and corporate training. However, standalone MR devices pose challenges related to performance and visualization realism. In this study, we focused on enhancing immersive learning by optimizing the User Interface (UI) of an MR batik-making application using the Meta-UI principle. This research aimed to assess the impact of these UI approaches on user satisfaction, measured through Nielsen's usability methods. User feedback was collected and analyzed to refine the UI design. Nielsen's usability heuristics guided the evaluation of UI attributes such as clarity, efficiency, and user satisfaction. The utilization of Meta-UI demonstrated a notable increase in user satisfaction. Nielsen's usability guidelines indicated ratings ranging from 3.93 (good) to 4.30 (very good), signifying users' positive perceptions of learnability, efficiency, memorability, error handling, and overall satisfaction within the MR batik-making application. This research also addressed these issues by meticulously optimizing 3D assets within MR applications. The results indicated that the application's CPU utilization is around 22%, attributed to its startup processes, resource allocation, and any initial computations it performed. However, the application continued to run within 4 GB of installed memory with the network bandwidth usage at 0.27 Mbps. User comfortability was enhanced, which is evident in improved ratings for importance and satisfaction levels (4.26 and 4.16, respectively) in the MR application.**

***Keywords*— Education; immersive learning; user interface; mixed reality application; Nielsen's heuristics.**

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I. INTRODUCTION

Individuals seek profound connections with their environment or activity to achieve optimal immersive engagement. Achieving this state involves various strategies, including interactive displays, sensory stimuli, and cutting-edge technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). These immersive experiences have far-reaching applications in entertainment, education, and training [1]–[12]. Immersive learning enhances the educational process by allowing students to practice and apply their skills within a safe and controlled environment [13]. Immersive learning, a subset of immersive experiences, proves especially beneficial in education, enhancing student engagement through interactive and captivating learning environments [14]–[20]. Technologies like VR and AR actively immerse students, making the educational journey enjoyable and compelling. Beyond mere enjoyment, immersive learning improves retention and comprehension compared to traditional instructional methods [21], [22]. The success of immersive learning hinges on a carefully crafted user interface that fosters presence and sustains student engagement. An effective interface must be visually appealing, responsive, and adaptable to various learning preferences. The efficacy of immersive learning is profoundly influenced by the extent to which the user interface effectively facilitates the learning experience [23].

On the other hand, user experience is crucial, and the perfect user interface should be clear-cut, easy to use, and provide insightful feedback. To improve the user experience through interface elements, the authors of this study are now evaluating a mixed-reality application for batik simulation, which is in its second round of testing. Their goal is to examine how MR technology is used in user interface design, especially in art education. The study strongly emphasizes the effective use of user interfaces in smart environments to facilitate content delivery. Research on 3D interface and interaction technologies has lasted for years [24]–[26].

This research is geared towards providing substantial insights to enhance user interfaces in art education, specifically by delving into the opportunities for optimizing interfaces within MR technology. The project's overarching objective is to elevate the overall user experience within immersive educational applications, particularly prioritizing usability and ensuring effective content delivery. A crucial aspect of our approach involved using user-centric design principles in crafting the user experience. This meant placing the end-user, in this case, students in art education, at the forefront of the design process. The user-centric design approach entailed a deep understanding of the users' needs, preferences, and behaviors. By actively involving the target audience in the design and testing phases, we aimed to create interfaces that aligned seamlessly with users' expectations and enhanced their learning journey. This approach contributed to developing intuitive, user-friendly interfaces tailored to the student's specific requirements, fostering an environment conducive to effective learning.

By prioritizing user-centric design, the author strived to create intuitive user interfaces that are easy to navigate and capable of providing a rich and immersive educational experience. This holistic approach acknowledged that the success of academic applications, particularly in the dynamic realm of MR technology, hinged on how well the interface catered to the users' expectations and fostered an environment conducive to effective learning. Ultimately, the project aimed to contribute to advancing user interfaces in art education and the broader discourse on user-centric design principles in developing immersive educational technologies.

II. Materials and Method

Immersive worlds like AR and VR rely on effective interface design to provide users with a seamless and immersive experience. To enhance user engagement, designing AR, VR, and MR interfaces should prioritize clarity, usability, and responsiveness. A well-constructed interface avoids ambiguity and ensures intuitive navigation and informative feedback. By considering these factors, developers can create interfaces that fully empower users to immerse themselves in immersive environments.

According to Fagerholt and Lorentzon [27] terminology, various technological user interfaces can be classified. These types provide different ways for users to interact within immersive environments. Explore each type, including diegetic, spatial, meta, and non-diegetic interfaces. By understanding the various sorts of immersive client interfacing, creators can viably create locks-in and instinctive interfacing that improve client interaction and contribute to an immersive encounter, as shown in Fig. 1.

Firstly, *Diegetic UI* seamlessly integrates UI elements into the game world, with in-game characters acknowledging their existence. These elements, like the wristwatch displaying gas mask filters in "Metro 2033," heighten immersion and contribute to the narrative. On the other hand, Non-Diegetic UI *provides* players with vital gameplay information, such as health bars and mini-maps, without disrupting the game's narrative flow. It's a common and widely used form of UI in games.

Is it part of the story?

Is it in the game space?	Yes	No
Yes	Diegetic	Spatial
No	Meta	Non - Diegtic

Fig. 1 UI Components in Immersive Technology

Guertin-Lahoud et al. [28] explored how social and interactive dimensions in Virtual Environments (VEs) affect User Experience (UX) in VR. Twenty-eight participants engaged in VR individually or in pairs with varying interactivity levels. Using psychometric surveys, user interviews, and psychophysiological measures, the researchers assessed immersive and affective experiences. Results showed that shared VR experiences increased positive affect in the social dimension, while presence, immersion, flow, and state anxiety were unaffected by real-world presence.

A. The Current Immersive Research on Evaluating User Interface

A study by Firmanda et al. [29] examined the effectiveness and usability of *meta-interfaces* in mobile AR applications. They emphasized the importance of *a* clear and intuitive meta-interface, including visual design, interaction techniques, and information presentation. By understanding the strengths and weaknesses of different meta-interface designs, developers can create more immersive and user-friendly experiences in mobile AR. Fig. 2 shows *an* example of their examination.

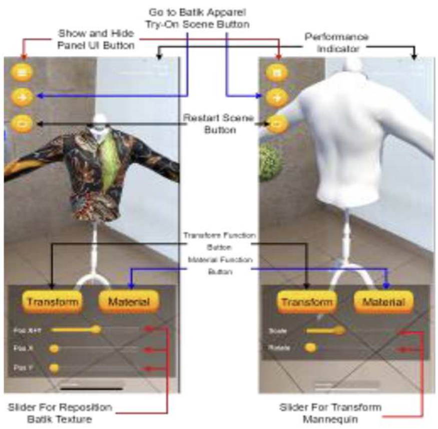

Fig. 2 Meta-UI on Desain Batik Scene

Miranto et al. [30] explored the UX design in cultural heritage VR displays, focusing on the diegetic method. They developed a conceptual framework and conducted user research to assess the effectiveness of the diegetic approach on user engagement and comprehension. Fajrianti et al. [31] studied the effectiveness of meta-UI (meta-user interface) in educational AR and VR apps for medicine. Through user trials, they found that incorporating meta-UI features significantly improves user engagement, task performance, and learning efficacy. Participants reported higher satisfaction and perceived the apps with meta-UI as more user-friendly and intuitive. Jansen et al. [32] explored the challenges in evaluating Automotive User Interfaces (AUI) due to novel interaction modalities, driving automation, diverse data, and changing environmental contexts. They recognized the absence of a tool for immersive analytics in the automotive domain. To address this gap, they developed AutoVis, a system that combines a non-immersive desktop with a virtual reality view for mixed-immersive analysis of AUIs.

B. Proposed System

Building a UI for an application aims to provide an organized and efficient system for delivering information and controls to the user. The UI design should prioritize clarity, simplicity, and ease of use, considering the user's needs and preferences. It should align with the user's meta-understanding and interaction capabilities, taking advantage of the unique affordances of MR technology.

In Fig. 3, the user interface design approach for the blended reality or MR application focuses on providing users with an organized framework that enhances their experience in the immersive environment. Understanding user demographics and preferences is crucial, and a user-centered design approach is employed to create a user-friendly and engaging interface. The necessary capabilities, such as 3D asset display with control through Meta-UI, are prioritized based on user recommendations and scenarios. The application mentioned in this context is the Membatik Application, which implements this approach.

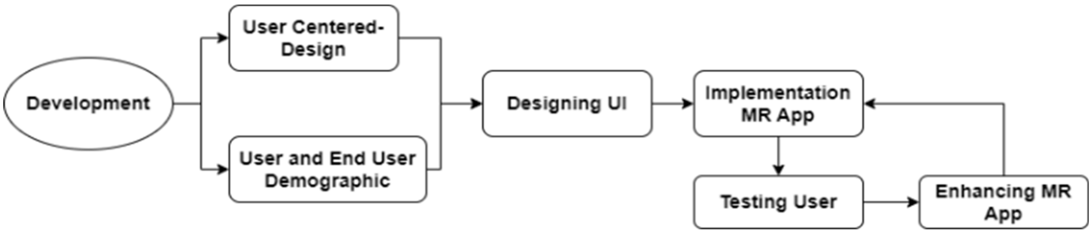

Fig. 3 Approach to User Interface Design for MR Applications

To understand and adapt to the needs of users in the art education industry utilizing mixed reality (MR) apps, it is critical to categorize users based on demographics. Demographics provide a complete profile of each user, including generation, gender, marital status, education, and income. This study's user demographics include medical students of various marital statuses, educational backgrounds, genders, and salaries. A User-Centered Design (UCD) method is also used to improve the user experience. The Norman and Draper [33] UCD method provides nine phases for building a UI.

The authors prioritize critical tasks in MR applications by implementing user suggestions and scenarios, notably showing 3D assets with control via Meta-UI. These characteristics are essential for delivering an immersive and engaging learning experience in MR apps for art education, which adapts to the different demands of medical students as target users.

C. The Usability Testing User using Nielsen's Heuristic Evaluation Method

Nielsen's Heuristics are usability guidelines used to assess user interface design. They cover learnability, efficiency, memorability, errors, and satisfaction [34]. Nielsen's Heuristics, a set of fundamental principles in usability testing and user interface design, provide a comprehensive framework for assessing the quality of an interface's design. These heuristics encompass critical usability aspects, including learnability, efficiency, memorability, error prevention and recovery, and user satisfaction. Employing Nielsen's Heuristic Evaluation Method involves subjecting a system or application to a rigorous evaluation process to identify potential issues and areas for enhancement. By adhering to these heuristics, usability testers can gauge an interface's intuitive and user-friendly, ensuring that it aligns with users' preferences and requirements. This evaluation approach enhances the overall user experience. It empowers designers and developers to make informed design choices that prioritize user needs and preferences, resulting in a more polished and effective user interface.

D. The User Interface in MR Membatik Application

Membatik is an MR application for Hololens 2 that explores Indonesian batik heritage [35]. Through interactive elements, it educates users about batik's history, techniques, and significance. The app features 3D models and virtual fabric simulations, enabling users to explore intricate details. Users can also use virtual tools and materials to engage in a virtual batik-making process. Hololens 2 seamlessly integrates virtual elements into the real world, providing an immersive and creative learning experience. Membatik Application was built with a design system, as shown in Fig. 4.

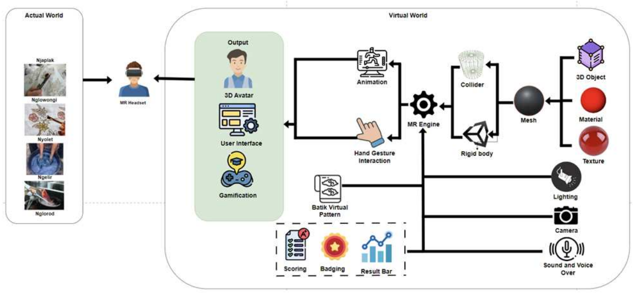

Fig. 4 Design System of the Application

Membatik MR application utilizes a meta interface in Fig. 5 as a start screen, presenting a visually engaging UI with a prominent "begin" button. This meta interface seamlessly integrates with the user's perceived reality, providing a smooth, immersive experience. The strategically placed "begin" button simplifies the user's interaction process, allowing them to navigate and initiate their virtual batik-making experience easily.

Fig. 5 The Initial View of the App

In the Membatik MR application, Meta-UI is incorporated to present an instruction panel for selecting batik patterns, which introduces an exciting blend of the digital and physical worlds. As users wear their Meta AR headset or glasses, they are immersed in an environment where virtual information seamlessly integrates with their real-world surroundings. The Meta-UI, visible within their field of view, plays a pivotal role in guiding users through choosing batik patterns. This instructional panel, featuring clear step-by-step guidance, visuals, and text, appears before users as they explore various design options. Moreover, the interactivity of this Meta-UI allows users to employ hand gestures, voice commands, or the Meta controller to navigate through patterns, personalize their selections, and even preview the placement on the physical fabric. This integration not only enhances usability but also elevates user satisfaction, making selecting and creating batik patterns an intuitive and engaging experience in the world of mixed reality. Fig. 6 is the “Membatik Application” that integrates in mixed reality using Meta-UI for user interfaces.

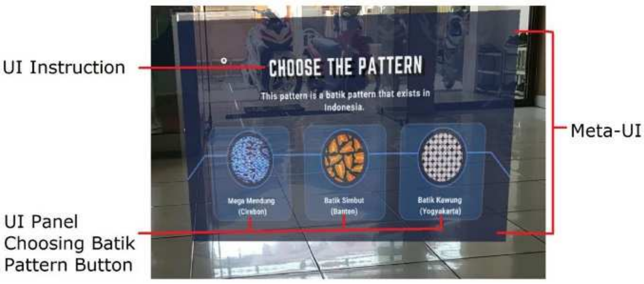

Fig. 6 User Interface for Introduction of Membatik Application

As can be seen in Fig. 6, the "Membatik Application" is a groundbreaking application that seamlessly fuses the ancient art of batik with cutting-edge mixed reality technology, all elegantly wrapped within the intuitive Meta-UI. This innovative app invites users to embark on a journey into the world of batik, where they can effortlessly craft intricate patterns using augmented and virtual reality elements. With a user-friendly Meta-UI, the app provides clear and engaging instructions, ensuring that beginners and seasoned artists can easily dive into the batik-making process.

The "Membatik Application" introduces an immersive and dynamic dimension to the world of batik art through its "Start Simulation" button and Meta-UI integration. When users activate the "Start Simulation" button, they are transported into a captivating virtual environment within mixed reality. The simulation scene for the user can be seen in Fig. 7.

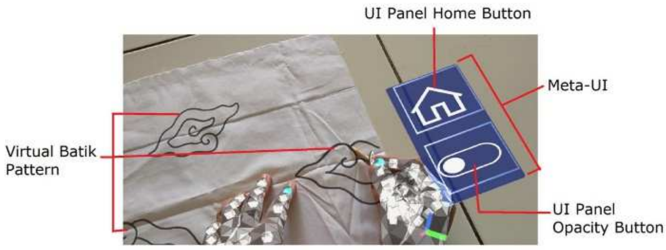

Fig. 7 Simulation Scene

In the Membatik MR application simulation scene, users are transported into an enchanting world of digital batik creation, allowing them to unleash their artistic talents. After this immersive experience, the app seamlessly transitions into a quiz scene that can be seen at Fig. 8, creating a holistic and engaging learning journey. Within this quiz environment, users are presented with an interactive learning experience that tests their newfound knowledge and enhances their understanding of the art of batik. To simplify the quiz process and encourage active engagement, the Meta-UI offers intuitive buttons enabling users to select true or false answers swiftly. This user-friendly approach ensures that users can focus on the content of the quiz rather than struggling with complex interfaces. Furthermore, the visually appealing presentation of the quiz questions interface adds an extra layer of immersion to the learning experience, reinforcing the app's commitment to making the world of batik both accessible and captivating.

Fig. 8 The Quiz Scene

During the usability testing phase of the "Membatik MR" application, Nielsen's heuristic evaluation method was employed to rigorously assess the effectiveness of the application, with a specific focus on the quiz scene. In this crucial phase, expert evaluators with a deep understanding of user interface design and user experience principles meticulously examined various aspects of the quiz scene. This evaluation aimed to identify any potential usability issues, inconsistencies, or areas for improvement in the quiz scene. The expert evaluators provided invaluable feedback based on established usability heuristics. This allowed the development team to fine-tune the user interface, optimize interactions, and ensure the overall user experience met the highest usability standards.

E. Device Limitation

The "Membatik Application" is designed to be compatible with the Microsoft HoloLens 2, Unity, and Sever to run the application. The hardware and software specifications are described in Table 1 and Table II.

TABLE I
HOLOLENS 2 SPESIFICATION

Component	Spesification
Display	2K Resolution per eye
Sensors	Depth, IMU, Eye-Tracking
Processors	Snapdragon 850
Memory	4GB RAM, 64GB Storage
Input Methods	Gesture, Voice, Hand
Operating System	Windows Mixed Reality
Battery Life	Up to 4 hours
Connectivity	Wi-Fi, Bluetooth
Ergonomics	Lightweight and Adjustable

TABLE II
UNITY SPESIFICATION

Component	Spesification
Version	UNITY 2020.3.421f1
Supported Platform	Windows, macOS, Linux, Android, iOS, tvOS, WebGL, UWP, PlayStation 4, PlayStation 5, Xbox One, Xbox Series X/S, Nintendo Switch
Windows OS	7 SP1 or later, 64-bit processor
iOS	10.13 or later, 64-bit processor
Linux	Ubuntu 16.04 LTS or later, 64-bit processor
WebGL	Chrome 51 or later, Firefox 52 or later, Edge 16 or later

III. RESULT AND DISCUSSION

A. Usability Testing Using Nielsen's Heuristic Evaluation Method

The application was tested with a sample size of 50 participants, including students of different age groups and genders. Data analysis employed a relative percentage evaluation technique using Equation 1 to establish a meaningful interpretation of the results.

$$Intervals = \frac{highest\ weight - lowest\ weight}{total\ wight} \quad (1)$$

The interval distance is obtained from the percentage score range using the equation above, as shown in Table III.

TABLE III
INTERVAL SCORE RANGE

Range	Rating
1.00 – 1.79	Very Not Good
1.80 - 2.59	Not Good
2.60 - 3.39	Average
3.40 - 4.19	Good
4.20 - 5.00	Very Good

The research involved a questionnaire consisting of 21 questions categorized into five usability indicators. The indicators and their corresponding question counts were as follows: "Easy to Learn" (3 questions), "Efficiency to Use" (4 questions), "Easy to Remember" (5 questions), "Fewer Errors" (3 questions), and "Pleasant to Use" (6 questions). The questionnaire data was analyzed using the percentage formula to calculate the percentage and average of respondents' answers for each variable. Equation 2 was used for the calculations.

$$P = \frac{f}{N} x\ 100 \quad (2)$$

P = Percentage number
f = frequency
N = number of frequencies
100 = constant number

After that, find the average of each score obtained for comparison concerning the interval score in Table 1 with the calculation of the average formula, which is like the following Equation 3:

$$M = \frac{x}{n} \quad (3)$$

The calculation results of each Usability Testing indicator with the Nielsen model are as follows in Table IV.

TABLE IV
RESULT OF QUESTIONNAIRE

Aspects of Assessment	Answer	Number of Answers	Weight	Result	Percentage
Easy to Learn	Very Agree	40	5	200	33.89
	Agree	90	4	360	61.01
	Less agree	10	3	30	5.08
	Disagree	10	2	20	3..38
	Very Disagree	0	1	0	0
	Amount	150		590	100.00
	Mean				**3.93**
Efficiency To Use	Very Agree	70	5	350	42.16
	Agree	100	4	400	48.19
	Less agree	20	3	60	7.22
	Disagree	10	2	20	2.40
	Very Disagree	0	1	0	0
	Amount	200		830	100.00
	Mean				**4.15**
Easy To Remember	Very Agree	70	5	350	34.82
	Agree	135	4	540	53.73
	Less agree	30	3	90	8.95
	Disagree	10	2	20	1.99
	Very Disagree	5	1	5	0.49
	Amount	250		1005	100.00
	Mean				**4.02**
Easy To Remember	Very Agree	60	5	300	46.51
	Agree	80	4	320	49.61
	Less agree	5	3	15	2.32
	Disagree	5	2	10	1.55
	Very Disagree	0	1	0	0.00
	Amount	150		645	100.00
	Mean				**4.30**
Easy To Remember	Very Agree	80	5	400	32.78
	Agree	170	4	680	55.73
	Less agree	40	3	120	9.83
	Disagree	10	2	20	1.63
	Very Disagree	0	1	0	0.00
	Amount	150		1220	100.00
	Mean				**4.06**

The respondents in this research consist of 50 individuals. Each usability indicator has a specific number of questions. The total number of responses for each usability indicator is calculated by multiplying the number of respondents (50) by the number of questions for that indicator. The indication "Easy to Learn" has the lowest mean score of 3.93 (Good). This suggests that users considered the MR application relatively simple to understand. However, there is undoubtedly space for development in this area.

Regarding "Easy to Learn," users found the application relatively easy to understand and navigate, resulting in a satisfactory mean score of 3.93 (Good). The "Efficiency to Use" indicator scored a mean of 4.15 (Good), indicating that users were satisfied with the application's efficiency and effectiveness in performing tasks. The "Easy to Remember" indicator achieved a mean score of 4.02 (Good), showcasing the application's ability to facilitate the retention of information and user-friendly interactions.

The highest satisfaction was evident in the "Fewer Errors" indicator, with a mean score of 4.30 (Very Good). Users appreciated the application's reliability and accuracy in minimizing errors during usage. Lastly, the "Pleasant to Use" indicator achieved a mean score of 4.06 (Good), signifying that users were content with the overall enjoyable and satisfying user experience.

This study's findings open the path for future advances in immersive educational applications for art instruction. By knowing the strengths and areas for development, developers may work on improving the user interface, optimizing content delivery, and creating an even more immersive and engaging learning experience.

B. User Experimental

The user experiment involved evaluating the environment application in MR devices. Participants were given MR headsets to immerse themselves in a virtual environment while interacting with the application. This experiment assessed how users perceived and experienced the MR environment, specifically focusing on the application's usability, engagement, and overall user experience.

The main interface displayed within the MR environment showcases essential elements to guide users through the learning process. A prominently placed "Start" button stands out, inviting users to begin the batik-making simulation. The "Start" button serves as the primary call-to-action, indicating that the user's journey is about to start, as shown in Fig.9.

Fig. 9 Initial View on User Testing.

By clicking or interacting with the "Start" button, users trigger the commencement of the simulation. This action activates the MR application, allowing users to delve into the virtual world of batik-making, where they can explore, learn [36], and create without physical space or material constraints.

In Fig. 10, the MR application showcases the cut scene section, where users experience a brief animated sequence. This cut scene immerses users further into the learning experience by setting the context and storyline for the batik-making activity. By incorporating the cut scene section with the animated avatar, the MR application enhances the storytelling aspect of the educational experience, making the learning process more meaningful and enjoyable for users.

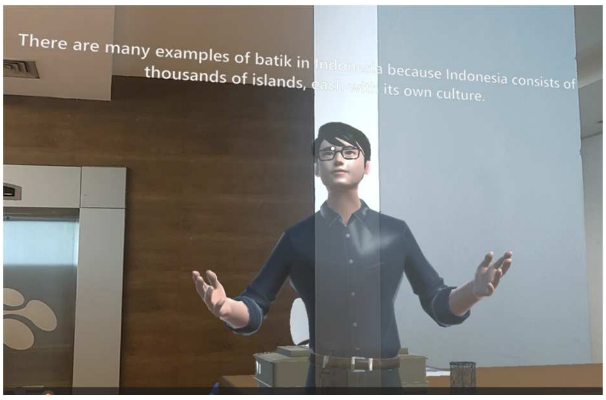

Fig. 10 User Testing in Cut Scene

In Fig. 11, users are shown engaging with the MR application by adjusting the batik pattern's position, rotation, and scale. This interaction enables them to align the pattern with the surface they intend to use for drawing or designing the batik. Through the Meta-UI, users can manipulate the batik pattern in the virtual environment using hand gestures, controllers, or voice commands. By adjusting the position, they can precisely place the pattern on the desired area of the virtual fabric. The rotation feature allows them to tilt or angle the pattern to align it with the fabric's orientation, ensuring a seamless and accurate design.

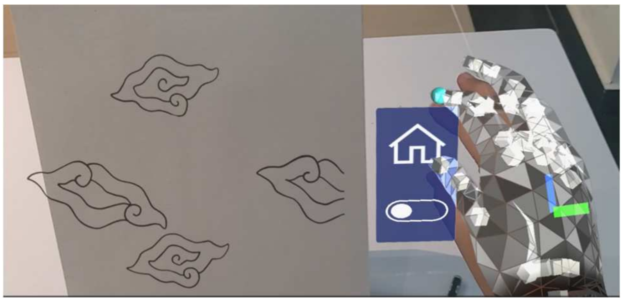

Fig. 11 Adjusting Pattern of Batik

In Fig. 12, the MR application showcases the drawing process where users follow the pattern displayed by the application. Users begin the actual batik-making process after adjusting the location, rotation, and size of the batik design to their desired requirements (as shown in Fig. 9); they engage in the actual batik-making process. In the real world, the user uses physical tools, such as a pencil, to draw on a physical surface, such as a piece of paper or fabric. However, through the MR application, the user sees a virtual representation of the batik pattern overlaid on the physical surface they are drawing on. The MR application's Meta-UI capabilities ensure seamless integration between the virtual and real-world elements, providing users with a unique and immersive drawing experience. By blending the digital batik pattern with the physical act of drawing, users can practice their batik-making skills with the guidance and convenience of virtual tools, all while engaging in a tangible, real-world creative process. to manipulate the batik pattern in the virtual environment. By adjusting the position, they can precisely place the pattern on the desired area of the virtual fabric. The rotation feature allows them to tilt or angle the pattern to align it with the fabric's orientation, ensuring a seamless and accurate design.

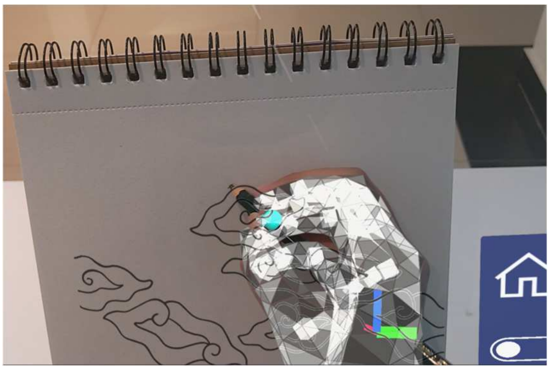

Fig. 12 Drawing Process in MR Application.

In Fig. 13, the MR application presents the quiz section, which users can interact with and answer true or false questions. The quiz is an interactive assessment tool to test the user's understanding and knowledge of the batik-making process or related art education concepts. The MR environment displays the quiz questions in a visually engaging format, allowing users to interact with the application using gestures or controllers to select their answers. The actual or false format simplifies the quiz, making it user-friendly and easy to comprehend.

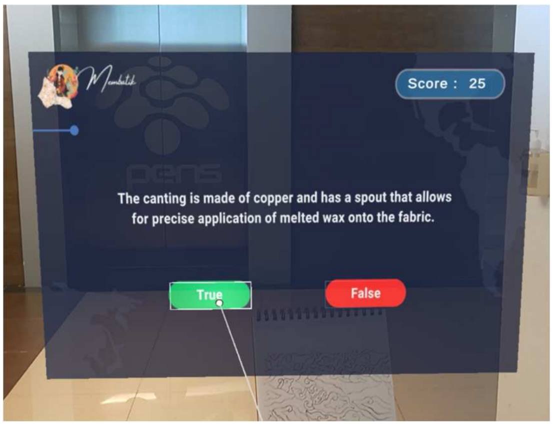

Fig. 13 User Testing in Quiz Section

C. Performance of Membatik Application

The evaluation was conducted to assess the performance of the official statistic monitoring application, a crucial tool in our system. The primary focus of this assessment was to gauge the application's effectiveness by measuring its average memory, I/O, network, and CPU utilization levels when deployed on a device. This data is pivotal in ensuring the application can efficiently handle its tasks without causing undue strain on the hardware. We established a well-defined testing environment to accomplish this evaluation, including specifying the hardware and software configurations relevant to the deployment scenario. The testing encompassed a range of use cases and scenarios the application is expected to handle, including tasks that stress the system to determine its robustness. The performance test when using the application can be seen in Fig. 14.

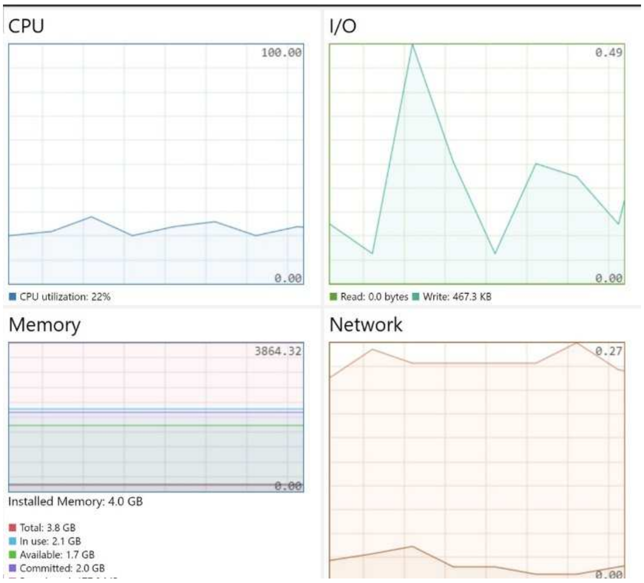

Fig. 14 CPU Usage

As seen in Fig. 13, the evaluation was undertaken to scrutinize the performance of our official statistic monitoring application, an indispensable tool within our system. We observed that when the application was initially opened in this section, the CPU utilization was around 22% CPU usage. This amount could be attributed to the application's startup processes, resource allocation, and any initial computations it performed. However, as the application continued to run within 4 GB of installed memory, the network bandwidth usage in the application was 0.27 Mbps. Such behavior indicates efficient resource management and suggests that the application adapts well to the operational environment.

IV. CONCLUSION

Based on the findings of this study, the incorporation of Meta-UI into an MR application for art instruction yielded positive results. User feedback and evaluations of usability indicators, such as "Easy to Learn," "Efficiency to Use," "Easy to Remember," "Fewer Errors," and "Pleasant to Use," demonstrated enhanced user happiness and engagement. The functionality and effectiveness of Meta-UI in the MR application were established through user suggestions and a well-considered design framework. Employing a user-centric approach, valuable feedback was collected and integrated into the interface design, ensuring alignment with users' needs and preferences. The research showcases that the user interface designed using Meta-UI in MR technology led to higher levels of satisfaction, engagement, and efficiency in the learning journey for users in the art education field.

These findings open avenues for future developments in MR-based educational platforms, offering promising opportunities to revolutionize and enhance learning experiences across various disciplines. The application's CPU utilization indicated a moderate load on system resources. While specific figures are omitted, it's noted that the application operated within reasonable parameters, with considerations for startup processes, resource allocation, and initial computations. The study provides valuable insights into the potential of Meta-UI in MR applications, setting the stage for continued advancements in educational technology.

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