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FROM STATIC DISPLAYS TO INTERACTIVE AR: EVALUATING THE EFFECTIVENESS OF AN AR APP FOR GEN Z AND ALPHA IN MUSEUM PUSAKA

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ABSTRACT

Museums play a crucial role in preserving and disseminating cultural heritage; however, they often struggle to engage modern audiences who seek immersive and interactive experiences. Traditional static displays fail to engage visitors or transfer cultural values to the new generations, specifically the Gens Z and Alpha. This research explores the implementation of Augmented Reality (AR) in museum settings to enhance visitor engagement and learning effectiveness, with a particular focus on the Museum Pusaka at Taman Mini Indonesia Indah in Jakarta. An applied empirical research design was utilized, two different studies involving a total of 40 and 86 students who were divided into a control or an experimental group. The experimental group used an AR mobile application that contains 3D models and interactive content, while the control group used traditional printed materials. To measure the learning outcomes and engagement, pre-and post-tests were conducted, and the data were analysed and compared using paired sample t-tests and ANCOVA. The results showed significant improvements in both learning and engagement among participants using the AR mobile application. These findings indicate that AR has the potential to transform the museum exhibit more engaging, interactive, and impactful.

Keywords: *Augmented Reality, Museum Studies, Educational Technology, User Experience, Learning Outcomes*

1. INTRODUCTION

Augmented Reality (AR) is a game-changing technology in various fields, including studies in education and museums [1]. Since AR superimposes digital information on real-world objects, it takes user interactivity into a new realm and provides interactive learning experiences that traditional ways cannot provide [2]. AR helps visitors and students to perceive and gain more knowledge in a fun way. Thus, AR helps them to learn faster and more comprehensively. AR is gaining traction as a core tool in the arsenal of museums, which have long worked to create stationary exhibits that entertain visiting patrons while also providing insights into historical artefacts.

Museums face many challenges in the display of artefacts. Traditional museums actively adopt static exhibition layouts to showcase information regarding their artefacts, but visitors are not allowed to touch them. Additionally, the information on the artefacts is explained in their country's national language and displayed in the form of small pieces of text, making it a problem for international audiences **(Research Problem)** [3]. The satisfaction of Gen Z and Gen Alpha is an emerging problem faced by museums, as they are digital natives and prefer to explore the artefacts' information in digital forms. The museums should highlight user engagement along with experience challenges to make sure digital exhibits are interesting and informative at the same time to every generation and multicultural audience **(Research Problem)** [4].

AR can help museums to handle these challenges by presenting the artefact's information in an interactive and engaging way, thus providing meaningful experiences. Such experience is more effective compared to traditional approaches like static images or text. AR provides information about the artefacts in the form of audio, videos, and links, as well as in the form of 3D models, which make the artefacts live and more personalised to visitors [4]. This engaging experience enhances the learning outcomes by allowing information to be more related to the visitor's choices and accessible [5]. Studies show that AR can help in improving comprehension and retention of information, which makes it a valuable tool in educational settings [6].

This study aims to address these challenges by implementing the interactive AR mobile application in museum exhibits to bridge the gap between the expectations of visitors, especially Gen Z and Alpha and the museum's classical artefacts display. **(Main Objective)** This research takes the Indonesian government-owned Museum Pusaka as a case study because this museum preserves numerous relics of artefacts and traditional weapons. The artefacts include an extensive display of ethnographic collections such as Keris and heirloom spears to swords that indicate a rich tapestry cultural heritage across seventeen thousand islands of the Southeast Asian nation. It is in Taman Mini Indonesia Indah (TMII) Jakarta. It is a centre to educate anyone interested in exploring and developing an appreciation of Indonesia's cultural heritage via exhibitions, research as well as conservation work. Digitalising these artefacts and converting them into 3D models, we use AR technology to present them engaging and immersive. The AR mobile app built for the study uses audio and video information, interactive text, and 360-degree views of the models to achieve the mission of cultural dissemination to the new generations.

This study has three objectives. The authors' first target is to build an AR framework to improve museum artefact presentation. **(RQ1)** The second research objective is to assess the efficacy of the developed AR framework in enhancing visitors' understanding and engagement with the museum exhibits. **(RQ2)** Finally, we measure the framework's effectiveness by comparing AR-enhanced learning with traditional paper-based learning. **(RQ3)** The authors conducted an experimental study involving two groups of school students to assess their understanding of the artefacts using pre-post tests to achieve this study's goals.

This study addresses these objectives as a contribution to the knowledge in the field of AR in museum and educational contexts. It offers validation through research on the advantages of AR in improving learning outcomes and provides practical insights for museum professionals pursuing the application of AR to their exhibits.

1.1 Related Research on AR Museums

Museums have been conservators of culture, history, and art for generations and currently have become pivotal portals for spreading culture and history [7]. They have become tourist destinations for domestic and international visitors as they play a part in government initiatives to promote cultural tourism. To attract a broader audience and improve visitors' engagement, museums gradually adopt various digital technologies [8]. However, the most crucial challenge lies in attracting visitors and equipping them with a memorable and immersive user experience. Several research studies have shown the advantages of AR in engaging users and transforming static information into interactive and personalised information [1]. Therefore, AR is an emerging technology in cultural heritages and in learning settings. Museums can engage multi-cultural and multi-generation users with the help of AR.

Research has shown that AR can enhance museum exhibits by providing several layers of interactive and context-aware information. For instance, [9] reported that AR applications can provide immersive and interactive experiences which enhance visitor engagement and satisfaction. The 'Archeoguide' system developed by [10] is an innovative effort because the study proved the potential of AR superimposing the reconstructions of ancient structures over existing ruins in the historical sites, providing a glimpse into the past. Similarly, the Augmented Reality project for Cultural Heritage also showed that AR could provide animated and interactive storytelling to enhance visitors' understanding and engagement [11].

[12] designed and developed a system to provide contextual and interactive elements to visitors in museum exhibits. They found that integrating AR applications can substantially enhance the educational value of exhibits. However, they strongly recommend a user-centric design in

AR applications to ensure accessibility and usability for broader audiences. [13] also reported a similar observation that the user-friendliness of AR applications boosts their educational potential. It shows that a user-centric design plays a vital role in engaging users. On top of that, they also mentioned that AR is a tool which can provide inclusive education that can reach users with varying levels of digital literacy. [14] also support this concept and claim that a well-designed AR application could cater to all generations of visitors by offering an intuitive and engaging interface.

In addition, [15] have found that AR can present complex and abstract concepts, which can reconnect the new generation with museum exhibits. Museums can easily achieve their objective of cultural dissemination by conceptualising historical events, scientific phenomena, or cultural practices via AR. AR has the potential to enhance the educational value of exhibits and make them memorable and enjoyable. They claimed that AR can change the passive visitor experience into an active learning experience.

In summary, research has proved that AR can transform museums' traditional exhibits by offering interactive and immersive learning environments. However, to achieve these objectives, the technical challenges must be carefully considered. Along with the technical challenges the design and contents should also follow the learning theories such as constructivist learning, situated learning, and multimedia learning.

1.2 Related Articles on Education Impact Of AR

The educational impact of AR has been reported by many researchers because this technology has the ability to present augmented information in a way closer to visitors expectations. AR helps active learning by offering interactive content in an engaging approach that helps maintain the interest and motivation of students, enhancing the learning outcomes [15]. Numerous research studies depict the revolutionary impact of AR on learning in various contexts. For instance, [16] depict AR-based learning environments remarkably enhanced students' understanding of complex scientific concepts. Research by [17] documented that AR improved students' spatial abilities and engagement in environmental science education. A recent study by [18] included a meta-analysis of AR in education, showcasing the significant enhancement in learning performance and motivation.

As museums play a role in educating the nation's culture, AR has depicted its contribution by offering more interactive and engaging exhibits to visitors. According to [19], AR could enhance visitor's cognitive and affective experiences by exhibiting the artefacts with holistic and contextually rich information. [5] also depict the potential of AR applications that led museums equipped with higher retention rates of exhibited information compared to traditional approaches. Recent research by [20] indicated that AR can significantly improve informal learning environments, like museums, by offering engaging and contextually relevant content. AR can change inactive learning into an active and interactive process by providing interactive experiences, making the learning experiences enjoyable, and improving information retention.

Additionally, some studies have proven that AR enhances student inspiration and involvement. It is supported by [21] whose finding depicted that AR-based learning environments enhanced the excitement of students and their dedication to the subject matter versus the traditional teaching approaches. The interactivity of AR applications enables learning to be more stimulating and enjoyable, which enhances student engagement and participation.

1.3 Types of Theoretical Frameworks Endorse the Use of AR In Education

Several theoretical frameworks highlighted the importance of interactive and immersive learning experiences that supported the utilisation of AR in education. Constructivist learning theory, proposed by [22], posits that learners construct knowledge actively by interacting with their environment. The theory principles align with recent research; for instance, [23] depicts that AR facilitates active engagement by enabling learners to explore and control digital content to enhance insight and retention. This supports the constructivist idea that students engaged in the process are the most impactful in absorbing the knowledge.

As for situated learning theory [24], this theory proposes that learning will be more effective when it occurs and authentic, where learners participate in the process actively. As AR overlays digital information onto physical objects, offering

immersive and real-world learning experiences for learners, it is suitable for creating contextualised learning environments. Recent studies, such as [25], depicted AR applications designed with situated learning principles enhance student engagement, comprehension, and retention by embedding learning within a meaningful context.

The cognitive theory proposes that learners understand information more effectively when presented through words, images, and other multimedia elements. This is similar to the nature of AR, where AR integrates these multimedia elements seamlessly, enhancing both cognitive processing and learning outcomes [26]. [27] supports this theory that AR is a powerful educational tool which can superimpose text, audio, and visual information to reduce cognitive load and improve learning efficiency.

The experimental learning theory proposed by [28] also supports the role of AR in learning because AR provides interactive content to users. This interactivity provides an experimental learning environment. This experimental interactivity enables learners to handle and interact with digital objects in a real-world context, which enhances knowledge retention and further understanding. [29], have demonstrated that AR applications create immersive and interactive environments suitable for experiential learning.

Overall, it is clear that many researchers agree that AR is a tool to boost learning, especially in museum contexts. AR can transform the static, passive and boring environments in museums into interactive and immersive learning environments. Aside from that, most of the learning theories, such as constructivist learning, situated learning, multimedia learning, and experiential learning, offer a strong foundation for AR to enhance the learning of cultural knowledge and experience in museum contexts. According to [30], Keris is known as a dagger with wavy and jagged patterns and has a prominent place in Indonesian culture. Based on the statistic report from Badan Pusat Statistik Provinsi DKI Jakarta [31], it show a decrease in the number of visitors visited TMII in 2024 (1,890,792) compared to 2023 (2,770,013). In TMII, there are a total of 15 museums. The digital technologies adopted by the TMII to allow visitors to access are audio visual contents, the official website Of TMII, applications as well as self-service terminals, however, the self-service terminals provide limited information and the applications (Jelajah TMII, Reborn Keong Mas and Museum adventure) adopted still continue to be develop [32]. The Jelejah TMII was recently updated where the app display general information of all the museums in TMII, while Reborn Keong Mas is app for Keong Mas Theater and Museum adventure is for Science and Technology Demonstration Center Museum. The general information of all the museums in TMII can be access using Jelajah TMII which the artefacts information of an individual museum is limited. The display in the Museum Pusaka still adopt the traditional display method, static display along with short explanation. Reviewing the past articles related to TMII, there are articles that suggesting TMII to develop applications. Bramantya [33] suggest the TMII to develop application that can provide explanations regarding various types of information along with the collections displayed in various languages that can also be used to provide personal tour guides with teaching insight. In addition, Syalis Ibnih Melati Istini, and Revan Pasha Kautharnadhif [34] suggested future researchers to develope application with AR features for TMII. There have yet to have AR application specifically for Museum Pusaka and the research conduct by Khairi, Munandar, and Setiawati [35] indicated the need of AR application for Museum Pusaka where it enables visitors to learn about the types of Keris exhibited and not exhibited in the physical museum. The listed research in the literature review indicates the implementation of AR can solve museums' challenges along with the exhibition method in the Museum Pusaka, leads the researchers to conduct a research on developing an AR application for the Museum Pusaka and test whether the AR app enhance the understanding and engagement of Gen Z and Gen Alpha regarding the Keris collection as well as the effectiveness of the AR App.

2. METHODOLOGY

Museum Pusaka in Taman Mini Indonesia Indah (TMII), Jakarta, has a vast collection of traditional Indonesian artefacts, including various types of Keris and spears. The museum is a part of TMII, a cultural park exhibiting Indonesia's rich heritage, and is essential in preserving and educating visitors regarding the country's ancestral traditions. Its unique setting, along with numerous collections, equipped an ideal environment for evaluating the transformative impact of AR in improving the learning experiences of visitors.

Thus, the authors conducted the study in this museum.

2.1 Research Design: Applied Empirical Research Design

An applied empirical research method is used in this study to assess the effectiveness of a mobile application implementing augmented reality (AR) in improving students' learning outcomes compared to traditional paper-based content. This research design is suitable for educational research, especially in situations where random group assignments are not possible due to constraints such as the settings of classroom or school policies [36]. We conducted two separate studies; one study contained forty (40) students from XYZ School, while the other study contained 86 from XYZ School in Bintaro, Indonesia. The students were divided into two groups of twenty (20) and two groups of forty there (43) students in each control and experimental group. To make the comparison fair, the students were carefully selected based on their demographic and educational backgrounds. The reason of conducting the two separately is the setting of the classroom was not able to fit all 126 students at once to conduct the study.

The authors conducted unequal pre-post-tests in two separate studies, as depicted in Figure 1. The forty (40) and eighty-six (86) students were divided into experimental and control groups. Both study were conducted to test their knowledge about the artefact Keris Bali, a pre-test quiz was given to both groups. After that, the experimental group was allowed to use the mobile AR application and learn about Keris Bali. The mobile AR application contains interactive and engaging information about Keris Bali, while the control group was assigned to study it using traditional printed materials. After 30 minutes, both groups were tested using a post-test quiz. This method is highly suited to compare the mobile AR application with the traditional way of learning.

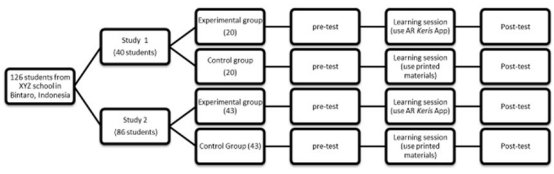

Figure 1: The applied empirical research design of this study

Furthermore, to find out whether a mobile AR application is more effective for absorbing information related to the Keris Bali than a traditional paper-based application, we analysed the pre-post-test data of both studies via paired sample t-tests and ANCOVA (analysis of covariance). To determine a significant difference within the group, we conducted the paired sample t-test, while ANCOVA was applied to analyse the significant difference between the two groups [37]. These two analyses were conducted using Excel's Data Analysis Toolpak.

3. RESULTS AND FINDINGS

3.1 Descriptive Data Analysis

This section analyses the data collected from both groups. A total of 126 students, in two separate studies, one study containing 86 and the other containing 40, participated in this research, 65.07% of whom were female and 34.9% male. Table 1 shows the demographic data of the participants of studies 1 and 2 of this research.

Table 1: Demographic Data of the Research Participants

	Group	Learning Approach	Female	Male	Total
Study 1	Controlled Group	Printed Materials	13	7	20
	Experimental Group	AR Keris App	14	6	20
	Total		**27**	**13**	**40**
Study 2	Controlled Group	Printed Materials	21	16	37
	Experimental Group	AR Keris App	34	15	49
	Total		**55**	**31**	**86**

In addition, the mean, median, mode, and standard deviation of the pre-and post-test of both studies were analysed (Table 2). Table 2 depicts that the mean of the pre-test scores in the controlled group of the first study is higher than the experimental group, while it is reversed in post-test scores. Similarly, the median and mode of both groups in pre-test scores are the same (40), while the post-test scores show the control group has the same median and mode (50), but the experimental group's median and mode are not the same. The standard deviation of the experimental group has significantly increased in the post-test, while it has decreased in the post-test of the control group.

Table 2 also shows that the mean of the pre-test scores in the controlled group of the second

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study is higher than the experimental group, while it is reversed in post-test scores. Similarly, the median of both groups in pre-test and post-test scores are the same (40), and (50), respectively. The mode in the pre-test of the control group is lower than the experimental group (30 < 40), while post-test scores are the same (50), and (50), respectively. The standard deviation of both groups has increased in the post-tests.

This change indicates an improvement in the experimental group, which shows the effectiveness of the AR Keris App.

Table 2: The mean, median, mode and standard deviation of the pre-and post-test of both groups

	Group	Controlled Group		Experimental Group	
	Test	Pre	Post	Pre	Post
Study 1	Mean	40	54	39	63.5
	Median	40	50	40	60
	Mode	40	50	40	50
	Std. Dev	16.54	13.53	10.21	17.25
Study 2	Mean	41.53	58.47	40.62	59.2
	Median	40	50	40	50
	Mode	30	50	40	50
	Std. Dev	15.95	17.30	15.61	17.17

Figure 2 below shows the frequency scores of both groups' pre-test and post-test scores. It is clear from Figure 2 that in pre-tests, the highest frequency for both groups is 40, while in the post-test, it is 50 for both groups. Similarly, it also shows that the control group's highest score on the pre-test was 70, while the highest post-test score was 80. On the other hand, the experimental group's highest pre-test score was 60, while the highest post-test score was 100. Both groups showed improvement after learning about the Keris Bali.

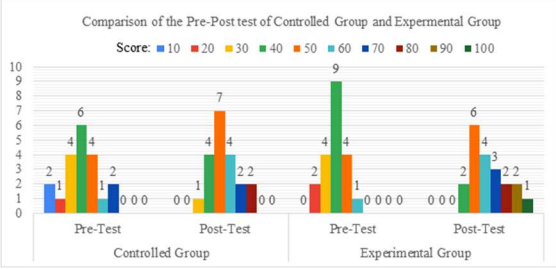

Figure 2: Comparison of the Pre-Post test of Controlled Group and Experimental Group of Study 1

Similarly, Figure 3 also shows that the post-test score of the experimental group is higher than the control group of Study 2. Both groups showed improvements after learning about the Keris Bali.

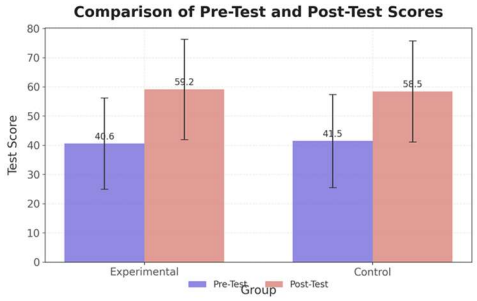

Figure 3: Comparison of the Pre-Post test of the Controlled Group and Experimental Group of study 2.

Overall, both groups improved their understanding of the Keris Bali. However, the experimental group in both studies appears to have shown more significant gains based on their highest post-test score, which shows the effectiveness of the AR Keris App.

3.2 Statistical Data Analysis

We conducted Levene's test before the paired sample t-tests and ANCOVA analysis to see whether the variances of the pre-test and post-test scores were equal or not. The p-value of the pre-test scores is 0.0999, and the post-test score is 0.2907, both more than 0.05. This means that the variances of both types of scores are equal, which indicates the assumption of homoscedasticity is not violated and allows researchers to carry on with paired sample t-tests and ANCOVA analysis.

For the paired sample t-tests, these tests enable researchers to make assumptions on the effectiveness of using printed articles or the AR Keris App to acquire information regarding the artefact (Keris Bali). For the control group, the researchers assumed that the printed materials given were effective in learning about the artefact. The researchers also thought the AR Keris App was effective for learning about artefacts. Table 3 shows the effect of the printed materials on learning about an artefact, while Table 4 shows the effect of the AR Keris app on learning the artefact.

Table 3: Results of the effect of the printed materials on learning the artefact

Post-test		Pre-Test			Paired Sample t-test		
Mean	SD	Mean	SD	t	df	p-value	η^2

54	13.191	40	16.125	5.217212 35	19	4.3488E-05	0.593939

Table 3 above shows that the control group's mean for the pre-test is more than the post-test mean. The control group's p-value of the paired sample t-test was less than 0.05, showing that printed materials are also suitable for learning. The value of η^2 (0.593939) shows a large effect size referring to Cohen's guidelines [38]. It can be concluded that printed materials also affect learning about artefacts.

Table 4: Results of the effect of the AR Keris App on learning the artefact

Post-test		Pre-Test			Paired Sample t-test		
Mean	SD	Mean	SD	t	df	p-value	η^2
63.5	16.815	39	9.950	6.427908 66	19	3.55206E-06	0.686

Table 4 shows a drastic increase in the mean of the pre-test to the experimental group's post-test. The p-value of the paired sample t-test of the controlled group was less than 0.05, indicating a significant effect of using the AR Keris App on learning the artefact. The value of η^2 (0.686) shows a considerable impact, referring to Cohen's guidelines [38]. It can be concluded that the AR Keris App significantly affects learning the artefact.

To compare which learning approach is more effective, the researchers refer to the value of η^2 and conduct an ANCOVA analysis. Both paired t-tests indicated that printed materials and the AR Keris App are effective, but the AR Keris App is more effective based on the value of η^2. As for ANCOVA analysis, the researchers assumed that the experimental group's performance was significantly better than the control group's. Using Excel's Data Analysis Toolpak to conduct ANCOVA analysis, the p-value (0.0229) indicated that it was less than 0.05. Therefore, it supports the statement that the experimental group performs significantly better than the control group. This highlighted that the AR Keris App is more effective than printed materials in learning artefacts.

3.3 Discussion

This research addressed one of the main issues for museums, which is displaying artefacts in a traditional, manual way, especially with the rise of Gen Z and Generation Alpha. Based on our first objective of building an AR framework to improve the presentation of museum artefacts, we have designed and developed an AR Keris App for Museum Pusaka to reduce the gap. The application consists of an AR feature (AR image target), where visitors can use the app to scan the image target to interact with the artefact. Figure 4 shows the image target, where the digitised version (3D) of the artefact will appear on the app when the image target is scanned. Then, the visitor can interact with the artefacts.

Figure 4: The Image Target of an Artefact

Figure 5 shows the various features of the mobile AR application. Visitors can observe the 360-degree view of the artefacts via the 3D models. They can read more about the different parts of the artefacts by tapping on the labels, and they can even listen to the information using the audio option. Visitors can immersively enjoy the artefacts by zooming in to reveal the hidden details.

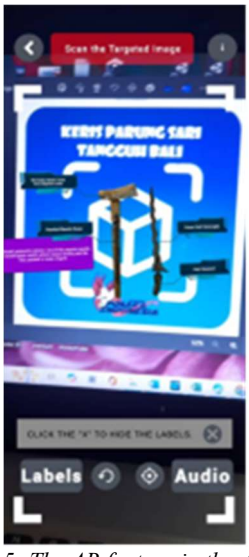

Figure 5: The AR feature in the AR Keris App

The aim of this research was to develop and validate the effectiveness of Mobile AR applications in visitors' learning and engagement.

Therefore, we used an applied empirical research design and conducted a non-equivalent pre-post-test approach. The analysis of pre-test and post-test scores shows that the AR Keris App has a transformative impact on studying the artefacts. The post-test scores and the result of the paired sample t-test of the experimental group clearly show the student's engagement as well as learning efficiency.

The ANCOVA analysis of the pre-test and post-test of the controlled group and experimental group also shows the effectiveness of the mobile AR application. The experimental group got higher post-test scores than the control group, which shows that the mobile AR application engaged the students in learning. These results support the concept that AR can engage visitors in the museum context, which ultimately results in cultural dissemination and the transfer of cultural values to the next generation.

3.4 Comparison with Prior Research

This study represents applied empirical research that deployed Augmented Reality (AR) technology for learning about the Keris Bali artifact, rigorously comparing its effectiveness against traditional printed materials. It provides specific evidence confirming AR's ability to boost engagement and learning outcomes concerning cultural heritage, notably for Gen Z and Gen Alpha audiences. The "AR Kris" application itself serves as a practical case study, illustrating a specific AR approach that uses image targets to activate interactive 3D models accompanied by audio descriptions. Within the active research area of AR in museums, this study quantitatively validates that AR significantly improves learning about museum artifacts, such as the Keris Bali, compared to traditional print, evidenced by higher learning scores in the AR group. This finding is crucial for engaging digital natives (Gen Z/Alpha) and highlights how interactive features like 3D models and audio can inform the design of more engaging museum exhibits. This research distinguishes itself from prior work through its specific focus on the Keris artifact, its explicit linkage to Gen Z/Alpha expectations, its robust quantitative comparison of learning outcomes via pre/post-testing, and its consideration of AR as a potential pre-visit promotional tool beyond typical in-situ museum applications.

4. CONCLUSION

In conclusion, the museum artefact presentation was improved using AR Framework where visitors are able to view the 3D version of the Keris, zoom in or rotate the 3D object to see the details of the artifacts and listen to the audio of the explanation of the artefacts when scanning the image target of the Keris Bali. In addition, the pre-test and post-test scores collected from the experimental group indicates that the AR framework is effective in enhancing visitors' understanding and engagement with the Keris collections, where the majority of the participants scored significantly higher during the post- test compared to the pre-test. As for the third objective of the research, the outcome shows that the experimental group that used the AR Kris application scored significantly higher than the control group that used printed paper-based information about the artefacts. The AR framework of this research adjusted well to the expectations of Gen Z and Gen Alpha, who are familiar with interactive, technology-driven daily experiences. The findings of this study recommend that including interactive technologies, like AR applications, in museum settings can significantly enhance visitors' experiences by providing immersive and engaging experiences. However, the testing of the AR framework was held in the school, the researchers have not conduct research where participants use the app in the physical museum due to the limited timeframe. The use of the AR app outside the museum acts as a strategy to promote and attracted the students to visit the actual museum to see the real Keris Bali.

As the advancement of the AR technology continue, future researchers are encouraged to explore all types of AR formats and learning styles before designing or developing AR applications that are both user-friendly and sustainable. They can conduct the research in TMII to see the usability of the app when visiting the physical museum. This would promote a better understanding of the country's artefacts and history. This study's findings depict the potential of AR as a tool to improve educational outcomes and contribute an innovative approach to learning about cultural heritage. It can contribute as one of the examples where AR can enhance the artifacts in the museum fields for attracting digital natives (Gen Z and Gen Alpha).

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