Development of AR Marker-Based Tracking to Support Preservation of Local Culture Using Waterfall Method

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Abstract: Culture is a set of values, beliefs, and habits of a group of people to interact in an environment. Culture can influence individuals' and groups' attitudes and behaviours towards the environment. In Bogor City, cultural values have been instilled in various forms, including local wisdom such as traditional clothing, musical instruments, special foods, and local community traditions. The introduction of local culture needs to be done creatively so that its preservation is maintained and not eroded by the flow of global information and the influx of foreign culture. This needs to be maintained, given the need for interactive, interesting education on Bogor culture for the younger generation. Therefore, research with a local culture approach in Bogor, integrated with the development of augmented reality-based applications, is an option for preserving local culture educationally and engagingly. With the waterfall method, the research succeeded in producing an introduction to Bogor culture in a representative, interesting, and educational marker-based augmented reality application for the preservation of Bogor City's culture. It is suggested that this AR prototype be scaled up to achieve greater impact, especially among young people.

1. Introduction

Culture is a way of life developed by a group of people. Culture has many definitions, viewpoints, dialogues, and practices. According to Lehmann et al. [18], culture is a set of knowledge and practices within a system that includes norms, values, beliefs, viewpoints, social organisations, and human relationships with nature and the places where humans live and contribute. But in general, culture is shaped by ecosystems, environments, and social relationships among individuals. A group of people interacting with one another will reach an agreement. Agreements can create a local culture. Culture is formed through social interaction; for example, teachers who interact continuously with their students can foster positive behaviour and a positive

culture in the educational environment [24]. Instilling positive values through cultural education is important in the era of globalisation, like in Mongolia, where cultural elements such as ecology, psychology, and spirit culture can be applied to both modern and traditional education [27]. Therefore, cultural education is important to be carried out as an effort to preserve regional identity and ensure its continued existence from generation to generation. Where the identity of an area is inseparable from the history of the area [15].

Constantin and Popescu [11] add that the local cultural environment is also shaped by geography, culture, the strength of local identity, and the emotional relationships of its people. Bogor has a unique and diverse local culture. The people of Bogor are predominantly ethnic Sundanese, with a strong command of the Sundanese language. The Bogor area is thick with its agrarian nuances. So that it can still be found at several locations of Serentaun and Sidekah Bumi Traditional Ceremony activities. Bogor culture has its own unique features, including traditional clothes such as pangsi and kebaya, the tradition of Ngubah Tugu Kujang monuments, musical instruments such as cucurak and flute, and typical foods such as doclang and asinan. Pangsi is a traditional men's clothing consisting of a simple shirt-shaped top and loose pants, generally black, and is complemented by a headband (bendo) [3]. Ngumbah Tugu Kujang is an effort to preserve the physical monument, promote cultural education, and strengthen the collective identity of Bogor residents [17]. Cucurak is performed as an expression of gratitude for the sustenance received. Still, over time, this tradition has come to be seen as a spiritual and social form of welcoming the month of Ramadan [20]. The flute not only complements but also serves as the main melody carrier in various forms of performance, such as the Sundanese Cianjuran song, kawih wanda anyar, and classical degung [16]. Doclang is part of the culinary identity of the people of Bogor [13].

The potential of Asinan Ahauw as a culinary tourism attraction in Bogor City demonstrates that traditional food can contribute to local tourism development and the preservation of regional culinary culture [9]. In reality, along with open access to information, it has enabled the flow of information, including from outside culture, into people's lives. Today, social life has been colored by the values of outside cultures. It is therefore important for immigrants to adapt to local identities, not the other way around [8]. This can be seen from the cross-cultural interaction that enters through various community activities. This kind of openness can threaten the sustainability of local culture. According to Barkat et al. [6], the community needs to re-identify the uniqueness of local culture to preserve it. In addition, strategic steps are needed to preserve local culture so it can be passed down to future generations. One strategic step is to use creativity and technology in local cultural education. In today's digital era, the development of information and communication technology has brought significant changes across various aspects of life, including education and cultural preservation [14]. One of the rapidly growing technologies is Augmented Reality (AR), which merges the virtual and real worlds to create an interactive experience for users [1]. According to data from Emarketer, Figure 1 illustrates the evolution of the number of virtual reality and AR users in the United States from 2021 [25].
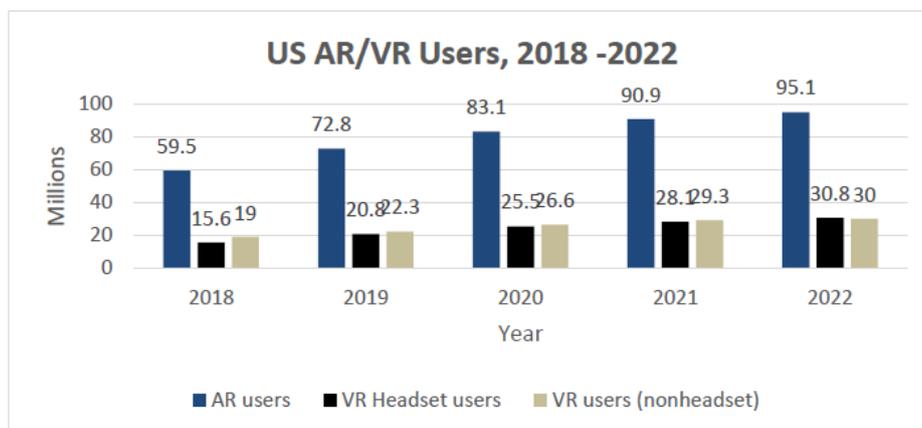

Figure 1: Statistics regarding AR and VR users in the United States [25]

One widely used method in AR development is Marker-Based Tracking [22]. This tracking technique uses visual markers to render virtual objects when detected by devices such as smartphone cameras. This method offers advantages in terms of accuracy and ease of implementation and has been applied across a wide range of educational and cultural preservation applications. This research is supported by Abdurrahman and Gustalika [2], who developed an AR application using Marker-Based and Markerless Tracking methods to introduce the culture of Mendut Temple, achieving a usability of 79.28% and indicating a high level of user satisfaction in understanding cultural information through this technology [2]. Other research shows that marker-based AR can enhance students' understanding of traditional Indonesian houses [23]. However, most research is still limited to national-scale culture or popular cultural sites, rather than specific local wisdom in areas such as

Bogor City. Local culture is part of the regional identity that needs to be preserved and introduced to the younger generation and tourists.

Bogor City, as one of the cities in West Java Province, has a rich cultural heritage, ranging from traditional music, traditional clothing, local food, and traditions to historical sites, which have not been used as Augmented Reality-based educational media. According to data from the Central Statistics Agency (BPS) of West Java Province, the number of tourist visits to tourist attractions in Bogor City increased from 1,302,470 in 2021 to 2,646,662 in 2023 (West Java Provincial Tourism and Culture Office), indicating strong potential in the tourism and culture sector. However, the younger generation's interest in local culture remains low. This is shown in a study by Dewi et al. [12] in the Journal of Social and Cultural, which found that more than 50% of adolescent respondents preferred foreign cultures to their regional cultures. The lack of interactive learning media is also a factor that causes low appreciation of local culture [12]. Therefore, this research aims to develop a platform for local cultural education in Bogor with an augmented reality approach to preserve local culture. Using AR technology, it is possible to explore culture through 3D visual displays [5]. Based on the description above, this study applies the Marker-Based Tracking method in Augmented Reality technology to introduce local culture in Bogor City, creating an interesting cultural education facility that is relevant to current technological developments.

Unlike previous research, which focused on general or popular cultural sites, this study targets local wisdom typical of Bogor, such as Bogor traditional clothing, traditional Sundanese musical instruments, and local food traditions. With a visual and interactive approach, the AR application is expected to be an effective and attractive educational medium for the younger generation while supporting efforts to preserve regional culture. There is a lot of research on cultural introduction using the AR approach, such as the design of a framework for cultural heritage site education that emphasises the learning experience and comfort when visiting cultural sites with AR [19]. AR simulation for game-based Indonesian cultural diversity education for elementary school students demonstrated a positive influence and improved cultural understanding after play [4]. In the cultural heritage sector, AR contributes to the interpretation of heritage, preservation, inclusive engagement, the preservation of intangible traditions, and the introduction of cultural artefacts and sites [10]. The use of AR and VR for cultural introduction in India can increase interactivity and engagement for learners [26]. Among the many studies, there has been no specific research on the introduction of AR technology into cultural contexts in Bogor City. This is a novelty in this study because the uniqueness of culture in each place requires a special approach to AR development tailored to each area.

2. Methods

This research uses a descriptive qualitative approach. The data for this research were collected through interviews with expert staff at the Bogor City Communication and Information Office and through observation to obtain primary and secondary data. The research was conducted for 3 months, from May 2, 2025, to July 11, 2025. The research was conducted at the Boash Indonesia Digital Polytechnic Campus, and the results were tested in a computer laboratory. The development of a local cultural education platform in Bogor uses Unity and Vuforia integration, with a marker-based approach. The digital assets are 3D cultural objects developed in Blender. This research used the Waterfall system development approach. According to Pressman [21], the waterfall approach is feasible for system development when the system's needs and the problems to be solved have been well defined. This research was conducted as a follow-up to the internship activities at the Bogor City Communication and Information Office. So that the definition of problems and the collection of system needs have been carried out during the internship activities. Therefore, the waterfall approach is considered appropriate for developing AR for cultural preservation education in Bogor City, with a working period of about 3-4 months. The Waterfall approach has stages, as presented in Figure 2: analysis, design, implementation, testing, and maintenance.
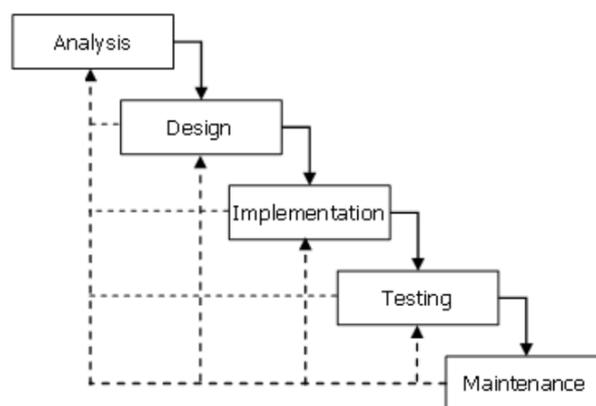

Figure 2: Waterfall model [7]

At the analysis stage, the research began by exploring the need for a more engaging approach to introducing Bogor City culture. In the current system, the introduction of the Bogor culture occurs only at certain events, such as the Bogor Anniversary (HJB), cultural festivals, or government events. The documentation of the activity was submitted through the social media of the relevant agencies. Therefore, a more interactive approach is needed to preserve Bogor's culture and prevent it from being eroded by modernisation. The analysis that needs to be carried out is data analysis, namely, looking for data and information about various types of local wisdom in Bogor City, 2D and 3D models of development needs, functional needs, namely related to the features needed in AR applications, and non-functional needs related to system quality, performance, and technical limitations of the developed application. In this phase, functional and non-functional analysis is required as follows (Table 1).

Table 1: Functional and non-functional needs analysis

No.	Functional Needs	No.	Non-Functional Needs
1.	Displaying Main Menu	1.	System Runs Offline
2.	Navigation Between Menus	2.	Responsive and Lightweight
3.	Deteksi Marker	3.	Compatible Android
4.	Displaying 3D Objects	4.	User Friendly
5.	Displaying Information Pop-Ups	5.	Camera Access
6.	Features of Cultural Quizzes		
7.	Exit Button		

At the design stage, the system is designed in terms of interaction flows, user interfaces, and the required data structure. The system design is outlined using various UML diagrams (Use Case Diagram, Activity Diagram, Sequence Diagram, and Deployment Diagram). The main page of the application has a menu of Sundanese cultural information, quizzes, instructions, about, and logout. Next, there are pages for the culture category, the sub-category of culture, and the display of the AR camera. The selection of cultural categories (traditional clothing, musical instruments, traditions, and local food) is carried out based on direct requests from the Communication and Information Office. In contrast, the determination of sub-categories (kebaya, pangsi, flute, kendang, ngubah tugu kujang, cucurak, asinan, and doclang) is based on the popularity of the cultural type. Because this research only develops application prototypes, the chosen cultural subcategory represents many types of culture in Bogor City. At the implementation stage, application development is carried out using Unity as the primary platform, with the Vuforia SDK for Marker-Based Tracking integrated. 3D assets used in the application are designed in Blender and output as .fbx files. While setting up the interaction logic, menu navigation, and user data processing requires the C# programming language. The test was carried out using a computer with a Ryzen 5 5600GT processor, 16 GB RAM, and a 1 TB hard disk to test the program's flow, and a smartphone with Android 7.0 Nougat OS and a camera that supports gyroscope, accelerometer, and magnetometer technology. The test is conducted using the black-box testing method. The test focuses on the functionality of the built AR application. This research is limited to the testing stage, while usability testing, distribution, and maintenance can be carried out in subsequent research.

3. Results and Discussion

3.1. Results

The Marker-based AR application for Bogor Cultural Introduction Education runs using the following workflow: users run applications installed on Android smartphones. After the application runs, the system displays the main page with four menus: Sundanese culture, instructions, about, and exit. If the user chooses the Sundanese culture menu, the system will display a sub-menu of traditional clothing, traditions, musical instruments, and food. If the user chooses one of these sub-menus, for example, traditional clothing, the system will display an image of traditional clothing and a view button. When the user presses the view button, the system displays the camera and scans the marker to trigger the display of a 3D model of traditional clothing. The system also displays interactive buttons for history, meaning, and location, as well as in other menus and sub-menus. The instructions menu contains instructions for using the application; the about menu contains information about the application; and the exit menu allows you to exit the application. Here's a look at the use case diagram from designing an AR application: The use case diagram of the Bogor Cultural AR Application shows that the actor interacts directly with the system, namely, the actor can run the application. Then the system will display the main page, which contains the local culture menu, hints, quizzes, and hints about the exit. Then the actor can choose a menu. If the actor chooses the local culture menu, the system will display sub-categories of traditional clothing, musical instruments, traditions, and local food. Then the actor will choose one of the sub-categories (Figure 3).
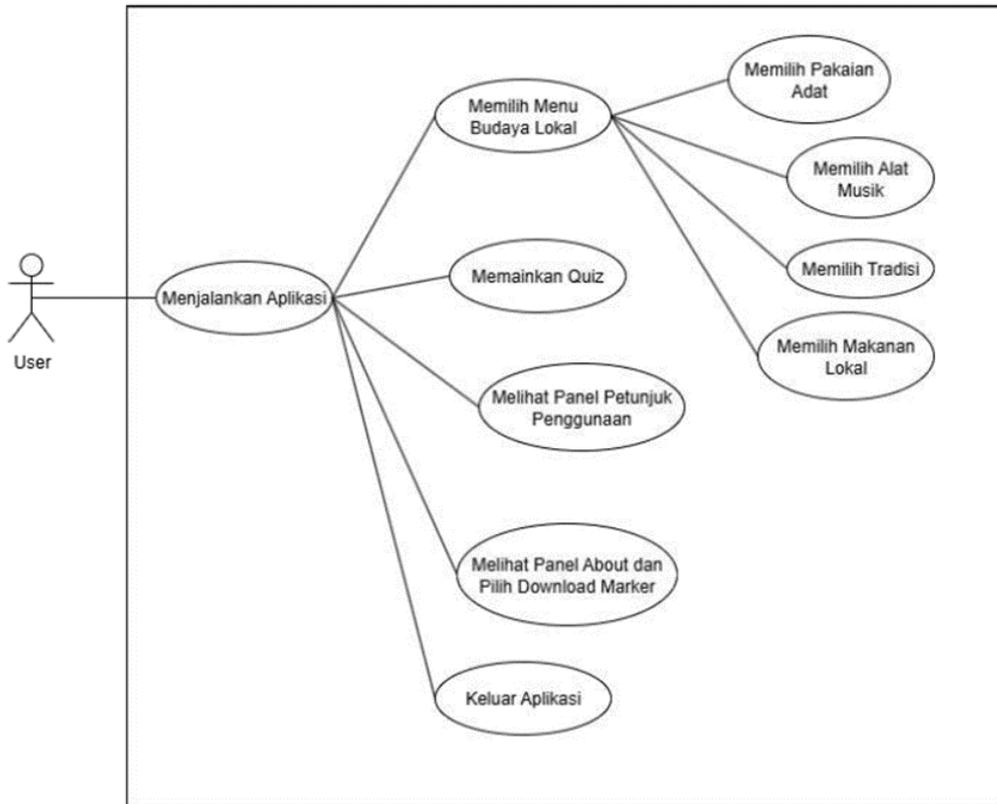
Figure 3: Use case diagram

Then the system will display information, 3D images of the culture, and other interactivities that can be selected, such as location, meaning, and history (Figure 4).
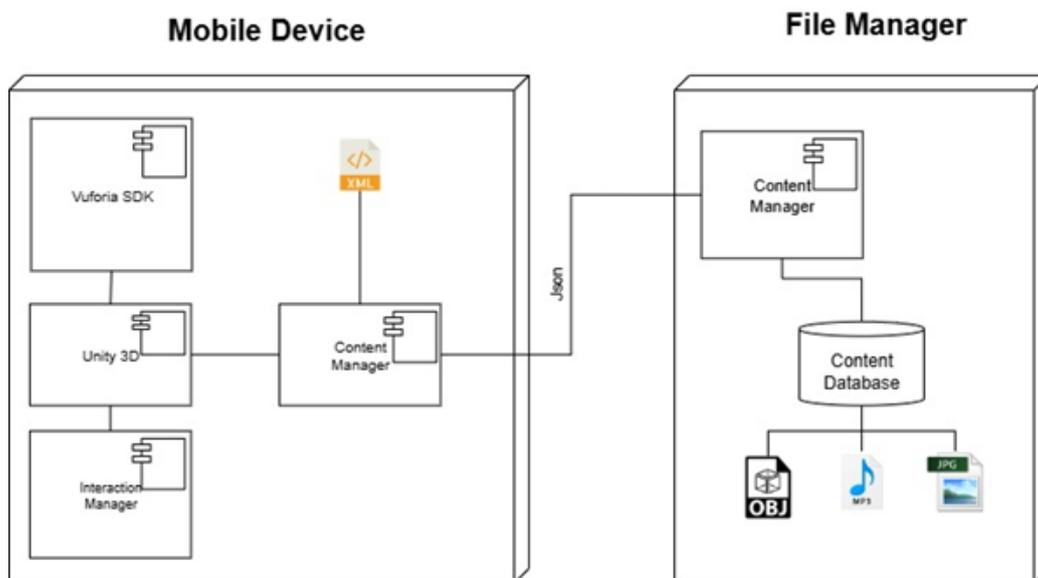

Figure 4: Deployment diagram

Here's what the AR app looks like (Figure 5):

Figure 5: Home page of the Bogor cultural AR application

On the main page, the system displays a menu of local culture, quizzes, hints, about, and exit. The app must first be installed on the Android smartphone to run (Figure 6).

Figure 6: Cultural menu display

When the user selects the local culture menu, the system will display the culture category page. On this page, several menus will be presented, namely traditional clothing, traditions, musical instruments, and local food (Figure 7).

Figure 7: Display of the traditional clothing category

When users choose traditional clothing, the system will display two types of traditional clothing as the starting point for this first development. The display provided shows an image of the culture type and the next action button (Figure 8).

Figure 8: Custom clothing 3D object display

When the traditional clothes button is selected, the system displays the camera view from the cellphone. Then, the user is asked to scan the marker, which is provided as a 2D image. Then the system will detect the marker, and a 3D object will appear along with its information and interactivity. The testing scenario for the Bogor Cultural AR Application is as follows (Table 2).

Table 2: Blackbox testing scenario on the Bogor cultural AR application

Test Scenarios	Test Actions	System Functions	Expected Results	Test Results
Buttons on the main menu and subcategory pages	Click the Button on the entire application page	To display the camera page	Display camera page	Succeed
Button on the AR Camera page	Click the History, Meaning, Location Button	To display the information in a pop-up panel	Displays a pop-up panel with information	Succeed
3D objects and Cultural information	AR camera scans markers	Bring up 3D objects and cultural information	Display 3D objects and their information	Succeed
Button on the quiz menu	Click the answer button	To answer questions	Display true and false feedback and move on to the next question	Succeed

The quality of markers in Marker-Based Tracking-based Augmented Reality applications significantly affects the system's ability to detect and display virtual objects. The main parameters used to assess marker recognition performance in this study include detection accuracy, optimal distance, and light intensity.

3.1.1. Marker Detection Accuracy

Marker detection accuracy indicates the system's ability to consistently recognise markers. Based on the test results, the markers used in this app can be well recognised by the Android device's camera as long as the markers are intact, unobstructed, and have clear visual contrast. The system can display 3D objects with stable position and orientation when markers are detected, indicating high accuracy. Interference, such as marker creasing, excessive light reflection, or blurry marker images, can reduce detection accuracy.

3.1.2. Optimal Distance of Marker Detection

The distance between the camera and the marker also affects the marker's recognition performance. The test results show that the marker can be optimally detected at a distance of about 20–50 cm from the camera. At that distance, the marker is still clearly visible, and the system can easily recognise the details of the marker pattern. If the distance is too close, some of the markers are not captured in their entirety by the camera, while if they are too far, the details of the markers become less clear, which can lead to detection failure.

3.1.3. Light Intensity

Light intensity is an environmental factor that greatly affects marker recognition performance. Markers are well recognised in medium to bright lighting conditions, both indoors and outdoors. In low-light conditions, the system has difficulty detecting markers because visual contrast decreases. On the other hand, light that is too bright or light reflected directly onto the marker can also interfere with the detection process. Uneven, non-excessive lighting is therefore the ideal condition for using this application. Overall, the markers used in this study are of good quality and can support optimal performance of Augmented Reality applications, provided they are used at appropriate distances and under appropriate lighting conditions.

3.2. Discussion

One way to introduce local culture creatively is to use augmented reality technology. The system developed in this study is an Augmented Reality (AR) application based on Marker-Based Tracking that serves as an interactive medium for introducing the local culture of Bogor City. The app is designed for the Android platform and is easily accessible to general users on smartphones. This system has the main feature in the form of visual marker scanning, which, when recognised by the device's camera, will display 3D objects of local culture such as traditional clothes (Pangsi and Kebaya), traditional musical instruments (Suling and Kendang), local food (Doclang and Asinan Bogor), and traditions (Ngumbah Tugu Kujang and Cucurak). In addition to 3D objects, the system presents information in the form of history, meaning, and cultural locations, as text, and includes an interactive quiz feature to strengthen users' understanding of the culture displayed. The development of AR applications in this study can be a strategic step toward preserving local culture, especially the Bogor Culture. This application is developed independently and statically, meaning it does not depend on a server or an internet connection to display content, except for the download marker feature, which uses cloud storage (Google Drive), and the map view on the location panel, which uses Google Maps.

The test results showed that the navigation buttons on each menu worked well, the AR camera feature detected local cultural markers effectively, the cultural 3D objects appeared at the appropriate position and scale, the interactive quiz feature worked well, and the information pop-up appeared clearly and was easy to close again. Thus, all modules in the application have been successfully implemented and tested, yielding valid results, without any critical bugs or functional glitches. This shows that the Augmented Reality application developed is ready to be used as an interactive medium to introduce the local culture of Bogor City through Android devices. This test also demonstrates that the system development process follows the appropriate principles for the waterfall method, resulting in an application that is stable, easy to use, and can visually and interactively display local cultural information. It is hoped that this research can make a significant contribution to awareness of the local cultural richness that researchers need to preserve and pass on to future generations. The model of applying AR for local cultural education can also be replicated in other regions in Indonesia. This is a contribution to science.

4. Conclusion

Based on the results of the development and testing of the Augmented Reality (AR) application using the Marker-Based Tracking method for the introduction of the local culture of Bogor City, the following conclusions were obtained:

- An Augmented Reality application based on Marker-Based Tracking was successfully designed and developed in Unity 3D and the Vuforia SDK to display local cultural objects as interactive 3D visuals.
- The application was successfully implemented on Android devices in an offline environment. Local cultural markers are well recognised, and the system can display cultural objects in real time. This application provides cultural content on traditional clothing, musical instruments, typical foods, and the traditions of Bogor City.
- The introduction of local culture has been successfully carried out in a more creative, immersive manner. It can contribute to the preservation of local cultural wealth by applying advanced AR technology.

In research on media applications for introducing Local Culture in Bogor City, several shortcomings remain to be addressed. Some suggestions for further development are as follows:

- There is a need to add 3D objects, such as Bogor batik, other musical instruments, and cultural sites, for display in the application.
- Usability testing is needed to target the younger generation and obtain more specific user experience input.
- The 3D models and sound effects can be improved in quality to provide a more immersive experience for users.
- It is necessary to add simple animations, such as musical instrument movements during play, traditional simulations, or clothing movement effects when spinning, to increase the app's visual appeal and interactivity.

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