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Design and Development of e-MARZ: A Practical Guide to Implementing Cost-Effective VR Experiences for Music Education

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ABSTRACT

The study introduces e-MARZ, a Virtual Reality (VR) software designed to tackle challenges faced by music educators in enhancing music appreciation lessons within the Malaysian lower secondary school music curriculum. The research aims to improve student engagement, provide immersive and interactive learning experiences, and develop a user-friendly VR application. A video production process was employed to create 360-degree music performance videos, which were integrated into the e-MARZ software via interactive modules. This article mainly discusses the development and evaluation aspects, utilising the modified ADDIE Instructional model, m-ADDIE, during the development phase. The e-MARZ prototype underwent evaluation using the System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ) for quantitative data collection and analysis to assess usability, with a sample of five music education experts and 82 secondary school music students. Limitations of the study include the use of 360 media of live performances tailored for secondary school students' music appreciation and employing 3DOF (degrees of freedom) instead of the more advanced 6DOF, potentially impacting the generalisability of findings and the scope of achievable VR experiences. Despite these limitations, the high usability scores obtained during the evaluation, as measured by SUS and PSSUQ, indicate the software's effectiveness in addressing its intended challenges. The e-MARZ software offers an immersive, user-friendly VR experience that is cost-effective and compatible with various devices. This research provides insights into producing cost-effective, user-friendly VR applications using 360 media, promoting accessible VR application development in education. As a result, the study transforms students' engagement with music appreciation, fostering a more immersive, interactive, and enjoyable learning experience.

1. Introduction

The emergence of innovative technologies has greatly impacted the educational landscape, with Virtual Reality (VR) standing out as a particularly transformative force [1]. VR's potential to revolutionise learning experiences across various disciplines is increasingly being recognised by

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educators and researchers alike [2,3]. By immersing users in a three-dimensional, computer-generated environment, VR offers unparalleled opportunities for experiential and interactive learning, which can significantly enhance students' engagement, motivation, and comprehension [4].

The integration of VR in education transcends traditional classroom boundaries, fostering immersive experiences that cater to diverse learning styles and preferences [5]. Through the creation of realistic simulations and environments, VR enables learners to explore, experiment, and visualise complex concepts, ultimately resulting in deeper understanding and long-lasting retention [6]. Furthermore, by facilitating collaboration and communication, VR paves the way for the development of critical soft skills and global competencies, which are essential in the rapidly evolving world [7].

As the affordability and accessibility of VR technology continue to improve, its adoption within educational settings is expected to accelerate [8]. This, in turn, will stimulate further research and innovation in the realm of VR-enhanced learning, opening up new horizons for educators and students alike. By examining the potential of VR in education, this article aims to elucidate the process of developing cost-effective and interactive VR applications, specifically focusing on an interactive module designed to foster music appreciation. This exploration will demonstrate the transformative impact of such technology on teaching and learning across various disciplines, emphasising its potential to revolutionise music education and other specialised subjects.

The integration of Virtual Reality (VR) technology in music education has attracted considerable interest in recent years, with numerous studies investigating its impact on learning outcomes and innovative approaches to teaching. For instance, Han, [9] proposed a constructivism-based vocal music education system using the Moodle platform and VR technology to enhance the intuitiveness and interactivity of lessons. Similarly, Lian *et al.,* [10] presented a VR and IoT-based pipeline for online music learning using a graph neural network (GNN) algorithm, which displayed competitive performance compared to state-of-the-art methods. Furthermore, Sai, [11] conducted a study comparing VR-supported learning using the VR4EDU application to traditional online music lessons, demonstrating statistically significant improvements in the former .

Other researchers have explored the use of VR in various aspects of music education, including curriculum innovation, social virtual reality robots, pitch perception training, and vocal training. Xiao, [12] found that 72.2% of students considered the implementation of digital multimedia VR art courses to be effective. Shahab [13] observed a general upward trend in the musical ability of children with high-functioning autism when utilising social virtual reality robots for music education. Furthermore, Yang [14] combined shooting elements with a pitch perception training game in a VR environment to enhance motivation in music learning.

Similarly, a qualitative study by Doganyigit & Islim [15] investigated the impact of virtual reality on vocal training for music students at a Fine Arts Faculty. Through semi-structured interviews with eight students and secondary data from three voice trainers, the researchers found that virtual reality contributed to more natural breathing control, the opening of resonance gaps, and the production of a more powerful voice with greater ease. Additionally, students were able to produce a voice at an upper level with vibrato more comfortably. These studies highlight the diverse applications of VR technology in music education and its potential to significantly enhance learning experiences.

The growing interest in integrating VR technology into music education has led to extensive research highlighting the potential benefits of this innovative approach. Many studies have focused on the effects of VR on learning outcomes, student engagement, and the development of new teaching methods. However, the technical aspects of creating cost-effective VR applications that support learning various music genres through immersive experiences of real-life visuals or venues remain relatively unexplored. In response to this, this study focuses on the design and development of e-MARZ, a cost-effective and interactive VR module for learning music appreciation. This research aims to provide guidance for educators and developers looking to incorporate VR technology into music education programmes.

By examining the practical considerations of creating affordable and accessible VR applications like e-MARZ, this research aims to bridge the gap between the positive outcomes reported in existing studies and the real-world implementation of VR in music education. The development of e-MARZ seeks to overcome challenges associated with traditional music appreciation learning methods, such as attending live performances, grasping the nuances of music through text-based learning, and limited access to diverse musical styles [16].

VR offers an innovative solution to these challenges by providing immersive, interactive, and experiential learning environments that significantly enhance music appreciation education. By exploring VR's potential in music appreciation and presenting the e-MARZ, this study aims to contribute to the development of more accessible, efficient, and engaging learning experiences for students across various disciplines. Through the introduction of e-MARZ, we anticipate a significant advancement in the practical implementation of VR technology in music education, setting the stage for further research and development in this field.

Despite the promising potential of VR in enhancing educational experiences, a significant gap remains in the literature regarding the practical aspects of creating and implementing VR applications in various educational contexts. The development of customised VR applications often requires high costs and technical expertise, which presents challenges for educators with limited resources and technological proficiency [17]. Consequently, educators, lacking the expertise to create applications, require supplementary tools to support their use in the classroom [18], highlighting the need for future research to address the practical aspects of VR application development, focusing on user-centred design, cost-effective solutions, and intuitive platforms. As a result, educators may find it difficult to adopt and effectively integrate VR into their teaching practices without accessible and user-friendly tools. This lack of focus on the practicalities of VR application development highlights the need for research that addresses the practical aspects of VR application development, focusing on user-centred design, cost-effective solutions, and intuitive platforms.

Building on this identified need, this research aims to fill the gap in the literature by addressing the practical aspects of VR application development for music appreciation education. By focusing on user-centred design, cost-effective solutions, and intuitive platforms, this study seeks to empower educators with the necessary tools and strategies to create and adapt VR content for their specific pedagogical needs. Through the development and evaluation of e-MARZ, a cost-effective and interactive VR module for learning music appreciation, this research will contribute to a more comprehensive understanding of the practical implications of VR integration. Ultimately, this study strives to facilitate the effective adoption of VR technologies in education, thereby harnessing the full potential of virtual reality to enhance learning experiences across diverse educational contexts.

2. Methodology

2.1 Instructional Model

The methodology for this research is centred around the ADDIE model, a modified and improved version of the widely used ADDIE instructional design model. The original ADDIE model is popular for product development due to its generic features that can be easily adapted to suit the needs of a study [19,20]. Developers or students who use the model to develop instructional materials, however, face difficulties in determining the tasks that need to be executed in every phase due to the model's architecture being represented by words, requiring a detailed explanation of each phase to comprehend it accurately, which may also cause confusion since the explanation of each phase may vary from one author to another [21,22]. In this research, a more specific development model for multimedia products, m-ADDIE, was chosen to guide the development of e-MARZ.

The m-ADDIE model, an acronym for Analysis, Design, Development, Implementation, and Evaluation, is unique in that it incorporates sub-tasks within each phase to more effectively elucidate its function, a feature not commonly found in existing instructional design models. The "m" in m-ADDIE represents instructional multimedia, and each stage of the model comprises various subtasks that provide a detailed understanding of the purpose of each phase, with a particular focus on instructional multimedia resources [23]. Consequently, the m-ADDIE model was employed for the creation of the VR application e-MARZ in this study (see Figure 1), while also referencing the traditional ADDIE model to further validate the development process.

Each phase of the m-ADDIE model contains several sub-tasks that further clarify the function of each phase, offering more specificity compared to most existing instructional design models. For the analysis phase, the sub-tasks include objective, user, content, method, platform, and software. In the design phase, the sub-tasks consist of flowcharts, interfaces, and storyboards. The development phase encompasses principles, tangible interactions, intangible interactions, and instructions as its sub-tasks. The implementation phase involves installation, configuration, training, and execution, while the evaluation phase comprises information and effectiveness as its sub-tasks.

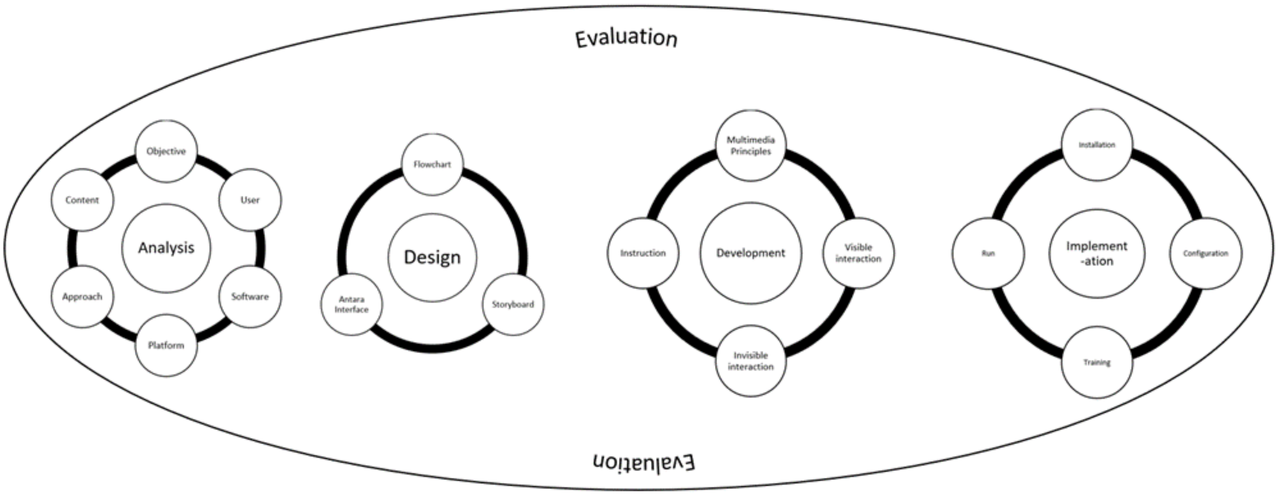

Fig. 1. m-ADDIE model

2.2 Video Production Process

Among the essential components in the module to be developed is a 360° music ensemble video. The 360° video will be used in the e-MARZ module software and be utilised by users to watch music ensemble performances more realistically through a first-person perspective. This method also allows users to interact more precisely with the interactive elements found in the virtual world [24]. The use of 360° video is seen as the best alternative for more effective teaching and learning using VR technology, apart from computer-generated graphics [25,26]. Therefore, in developing the 360° music performances video, the researcher will go through the pre-production, production, and post-production processes which is a standard process for creating video [27,28]. The following Table 1 shows the process of developing the 360 music performances video production.

Table 1
Video Production Process

Stage	Task	Description
Pre-Production	1. Concept Development	Develop the creative concept and story for the 360-degree video music performance, considering aspects like visual aesthetics, camera positioning, and audience engagement.
	2. Scripting & Storyboarding	Create a detailed script and storyboard, outlining the performance, camera movements, and visual effects. This will serve as a visual guide for the entire production process.
	3. Talent & Crew Selection	Select and hire the musicians, performers, director, and crew members required for the production.
	4. Location Scouting	Scout and secure appropriate locations for filming the 360-degree video, considering factors like acoustics, visual appeal, and accessibility for equipment set-up.
	5. Technical Planning	Plan the technical aspects of the shoot, including camera and audio equipment, lighting, rigging, and any necessary permits or licences.
	6. Rehearsals	Conduct rehearsals with the performers and crew to ensure smooth execution during production.
Production	7. Camera Set-up & Rigging	Set-up the 360-degree camera(s) and any necessary rigging systems to capture the performance from all angles.
	8. Audio Recording Set-up	Arrange the audio recording equipment to capture high-quality audio from the performers, including microphones, mixers, and recorders.
	9. Lighting Set-up	Set up lighting equipment to create the desired atmosphere and aesthetic, ensuring even illumination throughout the 360-degree space.
	10. Filming	Record the music performance, capturing multiple takes, if necessary, while closely following the storyboard and script. The director should provide guidance to the performers and crew to ensure the desired outcome.
Post-Production	11. Video Editing	Stitch together the recorded video clips and edit them to create a seamless 360-degree video, following the storyboard and script. Apply colour grading, visual effects, and transitions as needed.
	12. Audio Editing & Mixing	Edit and mix the recorded audio to achieve the desired sound quality and balance between the different audio elements (e.g., vocals, instruments, ambient sound). Synchronise the audio with the edited video.
	13. Adding Spatial Audio	If applicable, incorporate spatial audio into the video to create a more immersive experience for the viewer. This involves positioning audio sources within the 360-degree space, so the sound appears to come from the correct direction relative to the visuals.
	14. Quality Assurance & Review	Review the edited video and audio for quality and consistency, ensuring they meet the desired creative vision and technical specifications. Make any necessary revisions before finalising the project.
	15. Exporting & Encoding	Export the final 360-degree video in the appropriate format for distribution, ensuring compatibility with various playback devices and platforms (e.g., VR headsets, YouTube 360, Facebook 360).

2.3 Video Recording Concept

Determining a video concept before recording is crucial for streamlining the production process, fostering effective communication among team members, and simplifying post-production tasks. A well-defined concept not only leads to a more efficient production process but also helps create a coherent message that resonates with the target audience. Moreover, having a clear concept in place makes it easier to plan and organise the necessary resources, budget, and time for a successful video project [29,30]. The video concept used is that the viewer is positioned in the middle surrounded by musicians. One of the other goals of this concept is to provide an immersive audio experience, such as using the Ambisonic format. Ambisonic is the best spatial audio recording technique in terms of sound field based on the location of the sound source [31,32]. The audience will be able to hear the audio produced dynamically based on the position of the sound source. For example, if the audience is looking directly at the desired musician, the sound played by that musician will be heard louder and more balanced than the other musicians. Figure 2 shows an illustration of the camera and objects positioning concept for the video recording, while Figures 3 show the actual recordings made in this study.

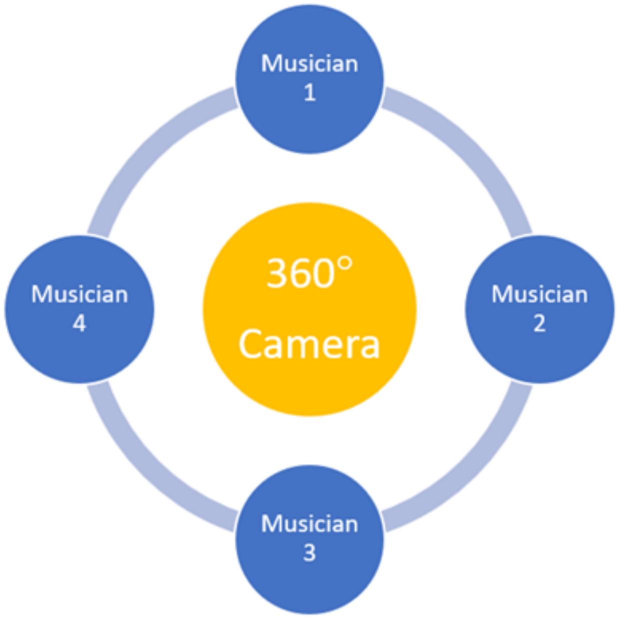

Fig. 2. Illustration Camera and objects positioning concept

Fig. 3. Actual Camera and objects positioning for Caklempong and Jazz Ensembles

2.4 Video Recording Equipment

To produce 360° visuals, a camera capable of capturing images in either Monoscopic or Stereoscopic format is required, with Monoscopic images are preferred for their ease of handling and cost-effectiveness in 360° imaging [33]. A fish-eye lens 360° camera is a suitable choice for capturing monoscopic images. There are various 360° cameras on the market, divided into two types: those for general consumers and those for professionals. For this study, a consumer-grade 360° camera will be employed because it is more affordable, provides satisfactory image quality, and is user-friendly as shown in Figure 4. Additionally, to tackle the issue of visible camera equipment, such as a giant hand or tripod [34], an invisible stick as tripod can be utilized to eliminate the appearance of these elements in the final images, thereby offering a more immersive and seamless viewing experience.

Fig. 4. Insta 360 ONE X 360-Degree monoscopic camera with invisible stick

2.5 Audio Recording Equipment

To achieve a more immersive experience for the auditory senses, Ambisonic audio can be used. The audio equipment used in conjunction with the video recording session for this study is a portable Ambisonic microphone. Ambisonic technology has been supported by popular online platforms such as Google, Youtube, Facebook, and some post-production audio and video editing software as well as the latest VR gaming software. The advantage of this Ambisonic technology lies in the microphone's ability to record surrounding audio through four audio channels. This advantage allows for sound or audio rotation using headphones, VR head mounted display, and also through mobile devices [31]. The microphone model used for the recording session is the Zoom H3-VR. This microphone is economical and capable of recording Ambisonic, binaural, stereo, and mono audio formats. This microphone is designed specifically to produce immersive VR audio quality in Ambisonic format. The features available on this microphone provide the option for researchers to use various audio formats during post-production. Audio is also recorded using the microphone available on the 360° camera. Figure 5 shows the type of microphone used for recording purposes.

Fig. 5. Zoom H3-VR Ambisonic audio recorder

2.6 Lighting Equipment

In terms of illumination, the research team opted to employ a portable light-emitting diode (LED) lighting system. Such a system was selected owing to its efficiency, cost-effectiveness, and mobility. Four LED lamps were utilized as lighting instruments in this study. The aforementioned lighting system was instrumental in ensuring optimal visibility of objects under investigation. To ensure that the objects were clearly visible, the team paid particular attention to the variables of exposure, illusion of depth, and mood during the recording session [35]. However, in the event that the recording session is conducted outdoors, natural lighting can also be leveraged as a viable alternative. Figure 6 provides a visual representation of the lighting instruments used in this study.

Fig. 6. Onsmo Lumipanel 320 Lighting Panel Series. (n.d.). Retrieved January 13, 2023, from https://onsmo.com/led

2.7 Post Production Editing Software

During the post editing phase of 360° media production, software selection is crucial in ensuring successful project completion. In this study, we utilised two primary software applications for post-production, namely Adobe Premiere Pro 2019 and Adobe Audition 2019. These software tools were chosen due to their ability to support 360° media editing for video (insv), images, and Ambisonic audio. Although Adobe Premiere Pro and Adobe Audition are widely used and provide extensive features and functionality, it is worth noting that there is other 360 media editing software solutions available, such as Insta360 Studio, which is free to use. However, the selection of software ultimately depends on the specific needs and requirements of the project, and thus, careful consideration should be given to determine the most suitable option for the project at hand.

3. Results and Discussion

3.1 Design and Development of Interactive VR Application e-MARZ

3.1.1 Analysis phase

The objective of developing the VR e-MARZ application is to introduce Traditional Malaysian Music and Popular Music to students through VR technology. This approach enables students to gain knowledge about various aspects of music through the software and in-class activities. The users of the VR e-MARZ software application targeted to music stream students in Form 1 and 2 as well as Music Education Teachers in Malaysian Public Schools.

The software used for developing Interactive VR e-MARZ application is 3DVista Virtual Pro. The 3DVista Virtual Tour Pro software offers a no-coding approach, making it easy for developers to create immersive, interactive and engaging music appreciation experiences. This software has also been utilised for various educational purposes across different disciplines [36-38]. By incorporating 360° performance videos, audio, text, and images into the virtual environment, the software enables students to explore various aspects of music appreciation in a more comprehensive and interactive manner. This multimedia approach allows for a deeper understanding of musical concepts, techniques, and historical contexts, while fostering a greater appreciation for the art form. Figure 7 illustrates the user interface of the 3DVista Virtual Tour Pro software.

Fig. 7. 3DVista Software

3.1.2 Design phase

The design phase of application development in m-ADDIE refers to the process of visually describing the flowchart, interface, and storyboard aspects in more detail as a guide for the development process. The prototype software and VR e-MARZ application begins with an introduction screen. From the introduction screen, users are required to choose the type of music they wish to explore. The way users interact with the display menu is through the control on the touch screen of their smartphone in non-immersive mode. If users use the immersive mode, which is a smartphone device and HMD, the motion gaze technique can be used by looking at the centre point or pointer in the centre of the screen for a few seconds. After selecting the type of music, users will be taken to a specific main menu screen about the selected music type. In this main menu, interactive icons or symbols will be displayed that allow users to watch music ensemble performance videos, music backgrounds, access information about musical instruments, and so on. Users can also choose to return to the introduction screen through this main menu screen. For example, if a user wants to watch a performance video, they will see a camera or play symbol until they are taken to a new display screen for viewing the video. After the video ends, users will be returned to the main menu display. For users who want information about musical instruments, they only need to look at the selected instrument and media will appear in the form of images, audio, and text containing information about the musical instrument. The developed prototype software and VR e-MARZ application involves a combination of linear and non-linear navigation as described in Figure 8. The linear navigation structure has a sequential story set where users can only see one topic or stage at a time. The non-linear navigation allows users to return to the main menu for review or choose a different new menu.

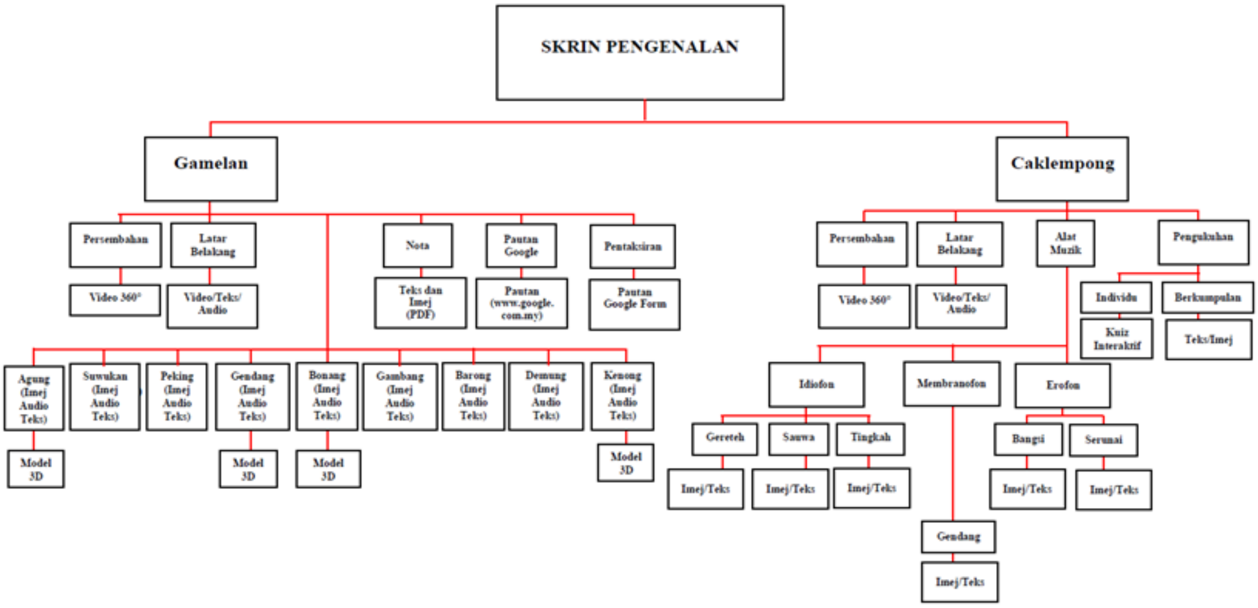

Fig. 8. Flowchart for Gamelan and Caklempong Modules

The user interface and storyboard of e-MARZ differs from conventional software interfaces in terms of layout. While the 360° visual aspect provides a wider layout space, designing a user interface and storyboard for 360° medias presents unique challenges [39]. Unlike traditional videos that have a fixed perspective, 360° videos allow users to explore the environment in any direction. This means that designers must consider how the interface will look from multiple perspectives and ensure that important information is always visible to the user. The 360° visual aspect provides a wider layout space compared to conventional software, which is more limited, as shown in Figure 9.

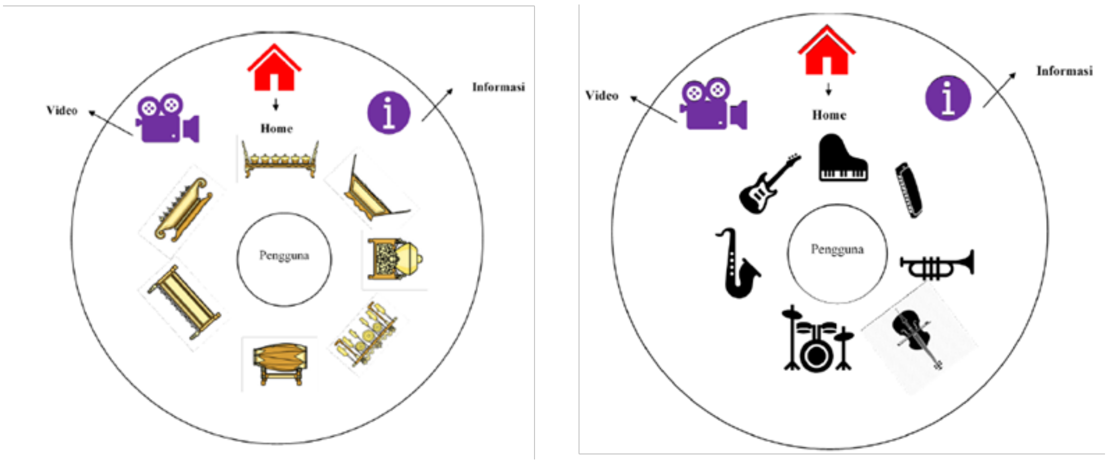

Fig. 9. User interface for Gamelan and Blues Modules

3.1.3 Design phase

The development phase of the VR e-MARZ application is based on the accuracy of the design phase through the review of literature on multimedia principles. Ali & Ramlie, [23] explained that in the development phase, the screen design aspects, which consist of several multimedia principles such as text, graphics, audio, video, and colour, must be fulfilled as best as possible. Reference to the flowchart, interface, and storyboard sketches in the design phase must be followed consistently in presenting the content throughout the education software development process. Figures 10 are the examples of e-MARZ interface.

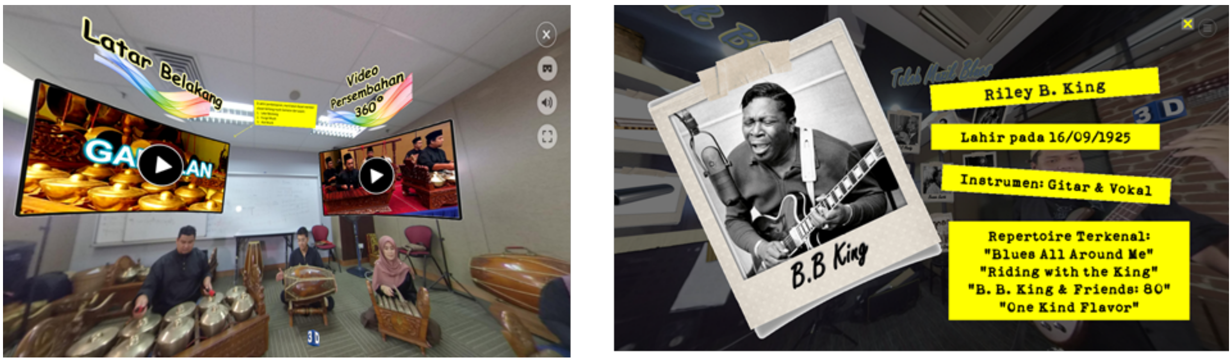

Fig. 10. Gamelan and Blues modules prototype interface

3.1.4 Implementation phase

The implementation phase of the e-MARZ platform encompasses four distinct steps: installation, configuration, instruction, and utilization. Initially, the software is made accessible via an online platform, facilitating straightforward access for educators and learners by means of a hyperlink or QR Code scan. Subsequently, the VR Head Mounted Display or compatible smartphone, in conjunction with a Mobile VR Headset, is configured; devices equipped with a gyroscope are recommended for optimal performance. In the following stage, a comprehensive set of guidelines outlining the platform's usage is supplied to educators, allowing students to engage with the modules independently or under the guidance of their teacher as shown in Figure 11. In the final stage, the software is employed during the instructional process, with students having the liberty to review the material at their leisure beyond the confines of the school day. By adhering to these procedures, the platform's features are assured to function seamlessly and effectively, consequently delivering an immersive and efficacious learning experience for students.

Fig. 11. e-MARZ User Manual

3.1.5 Evaluation phase

There are numerous methods for evaluating the usability of a digital product to ensure it meets the needs and expectations of its users. One such approach for assessing the e-MARZ module's usability involved utilizing usability questionnaires, with expert practitioners and high school students serving as the study's participants and respondents. The questionnaires employed for this assessment were the System Usability Scale (SUS) [40] and the Post Study System Usability Questionnaire (PSSUQ) [41]. The SUS, a widely used questionnaire for examining product usability, was created by John Brooke in 1986 [42]. The SUS and PSSUQ instruments are standard questionnaires frequently employed in research to gather feedback on user satisfaction and system usability [42].

Assessing the usability of a product with four to five users can detect up to 80% of its usability issues [43,44]. Therefore, for the evaluation of the e-MARZ module prototype system, five field experts were selected as participants. These experts were music teachers with over five years of experience in teaching music at the secondary school level, chosen using purposive sampling as suggested by Berliner [45]. The next step involved evaluating the usability of the module with lower secondary students as end-users. Total of 82 students were chosen for this study and given four weeks to use the module during their music lessons, under the supervision of their music teacher. The students used the e-MARZ module system on their smartphones both immersive and non-immersive. The Post Study System Usability Questionnaire (PSSUQ) was used to evaluate the module by the students.

To determine the validity and reliability of the questionnaire as a research tool, an extensive assessment was conducted by a team of four experts in the fields of language, information technology, and curriculum. The Content Validity Index (CVI) calculation technique was utilized to evaluate the validity of the content within the SUS and PSSUQ questionnaires, yielding an average I-CVI value of 1 [46]. Despite the established high reliability value of the PSSUQ and its extensive application in previous studies [47], a pilot test was conducted to further verify the instrument's reliability and suitability within the context of this research. The pilot study engaged 30 respondents, who were not part of the main study, to evaluate the Cronbach's Alpha coefficient (α) for the PSSUQ instrument. The obtained coefficient (α) value of 0.89 aligns with assertion that a coefficient (α) ≥ 0.7

signifies high reliability in educational research, thereby demonstrating the PSSUQ instrument's robust overall reliability value with a coefficient (α) of 0.89 [48]. The reliability assessment was not conducted on the SUS instrument since it involved only five respondents and utilized percentiles. Meanwhile, the PSSUQ was employed with the students to evaluate the usability of the e-MARZ, using descriptive statistics.

After testing the module, five selected experts in music education and technology completed the SUS questionnaire to assess the e-MARZ module's application system. Based on the expert panel's evaluation usability (see Figure 12 for SUS results), the usability test revealed that the e-MARZ software had achieved a commendable level of usability [49].

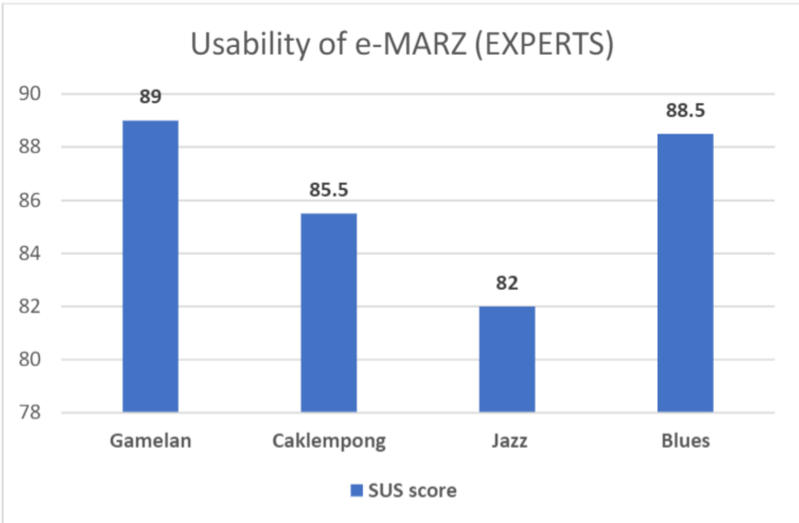

Fig. 12. The analysis of the overall SUS score findings

An in-depth analysis of the expert panel's responses for each sub module was conducted, with the following results: Gamelan (89), Caklempong (85.5), Jazz (82), and Blues (88.5). Figure 12 provides a comprehensive summary of the SUS usability test for each sub module. Concurrently, the PSSUQ questionnaire was employed to evaluate the opinions of 82 students on the application system's usability and their satisfaction after using the e-MARZ app on their smartphones (see Figure 13 for PSSUQ results).

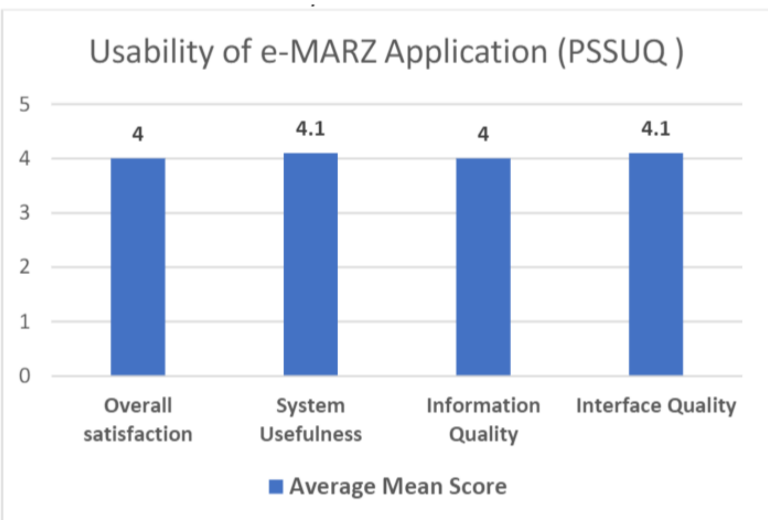

Fig. 13. The overall analysis of the PSSUQ mean score findings

3.2 Issues and Challenges

In this study, several issues and challenges have been identified while recording 360-degree videos, capturing spatial audio, and developing virtual reality (VR) applications utilizing the 3Dvista platform. These challenges can potentially impact the overall quality and effectiveness of the resulting VR experiences.

One challenge in recording 360-degree videos is the seamless stitching of footage captured by a single camera equipped with two fisheye lenses. Imperfections in the stitching process can result in visible seams, misalignments, or ghosting artefacts in the final video, impacting the overall immersive experience for the viewer [50]. To overcome this, a careful planning and execution of camera placement are crucial to ensure that the camera is positioned at an optimal distance from the scene or subject, minimizing parallax errors that can lead to stitching imperfections [51]. Utilizing calibration tools or methods provided by the camera manufacturer can also help optimize camera settings and lens parameters for better stitching outcomes. Finally, conducting thorough pre-production tests, such as shooting sample footage, can identify potential stitching issues in advance, allowing for adjustments to camera settings, placement, or other factors before capturing the final video.

Spatial audio recording, essential for creating an engaging VR experience, also faces its own set of challenges. Accurate synchronization of the spatial audio with the visuals can prove to be a difficult task, as any misalignment between the two can disrupt the immersive experience. Additionally, capturing high-quality, distortion-free audio in environments with fluctuating noise levels or reverberations requires specialized equipment and expertise. To address these challenges, utilizing specialized spatial audio recording tools and techniques, as well as conducting thorough post-production audio editing and synchronization, can help achieve a more immersive audio-visual experience.

Another challenge encountered in this study is the need for VR Head-Mounted Displays (HMDs) for testing and conducting usability tests to ensure a greater immersive experience. The availability of HMDs and compatibility with various devices can pose a significant challenge, as not all users may have access to the required hardware. To overcome these challenges, a two-tiered approach to usability testing can be adopted. For group testing, affordable VR cardboard devices can be used, which, while not providing the highest quality immersive experience, can still offer valuable insights into usability and accessibility. For smaller groups or individual testing sessions, higher-end HMDs like the Oculus Quest 2 can be employed to obtain more detailed feedback on visual quality and control experience.

When developing VR applications with 3Dvista, platform compatibility and optimization are critical aspects to consider. Ensuring that the developed application runs smoothly on various devices, such as standalone VR headsets, mobile VR devices, and PC-based VR systems, may necessitate extensive testing and fine-tuning to address performance disparities. Moreover, optimizing the application for different hardware specifications, including processing power, graphics capabilities, and storage, can be time-consuming and necessitate striking a balance between visual fidelity and performance. To tackle these issues, adopting a modular and scalable design approach, as well as leveraging optimization tools and techniques, can help achieve compatibility and optimal performance across various devices.

In summary, the primary challenges and issues faced during the creation of 360-degree videos, spatial audio recording, and VR application development using the 3Dvista platform include seamless video stitching, spatial audio synchronization, and platform compatibility and optimization.

Addressing these challenges effectively requires careful planning, testing, and optimization to deliver a captivating and immersive VR experience.

4. Conclusions

The e-MARZ module development process, outlined in this paper, offers valuable insights and serves as a valuable resource for other researchers aiming to create affordable, interactive, and engaging VR software. By assuming the role of an educator instead of a computer programmer, the researcher emphasizes the importance of a pedagogical approach in the development process. Faced with limited technical knowledge about complex VR software development techniques, the researcher embarked on an investigative journey to find innovative solutions. This quest led to the findings presented in this study, which were derived from a careful examination of prior research and the identification of novel approaches to VR software development. The result was a user-friendly and cost-effective VR software development methodology that prioritizes simplicity and accessibility. This breakthrough led to the establishment of a systematic procedure for creating VR applications utilizing 360° media technology, which can be easily adapted and customized to various educational contexts. The careful selection of hardware components, such as recording equipment, software, and other tools, is thoroughly discussed to provide future researchers with a comprehensive guide for their own endeavours. Moreover, this study highlights the importance of interdisciplinary collaboration between educators, software developers, and subject matter experts in order to create effective VR learning experiences. By bridging the gap between these fields, the e-MARZ module development process offers a blueprint for future research and development in the realm of educational VR applications.

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