



# Virtual Reality-based Game Development for Musical Instrument Training

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**ABSTRACT:** The experience and duration of musical instrument training are often constrained by several practical and pedagogical limitations, including restricted physical space, high costs of instrument acquisition and maintenance, and reliance on traditional, instructor-centered teaching methods. These challenges can limit accessibility, reduce practice opportunities, and hinder learner motivation, particularly for beginners and individuals without access to formal music education environments. This study explores the potential of VR to enhance musical instrument experience and training by providing users with interactive, virtual environments where multiple instruments can be accessed and practiced without the need for physical resources. Through VR, learners are able to engage in diverse training scenarios, experiment with different instruments, and receive immediate feedback in a controlled and customizable setting. Furthermore, VR-based musical training integrates elements of gamification such as challenges, rewards, and progression systems, which can significantly increase learner engagement, motivation, and persistence. By transforming practice into an interactive and enjoyable experience, VR has the potential to address common barriers associated with repetitive and monotonous training routines. In addition, VR platforms can support self-paced and individualized learning pathways, accommodating users with varying skill levels and learning preferences. The findings of this study suggest that VR-based musical training not only enhances user engagement but also contributes to improved learning outcomes, particularly in terms of skill acquisition, retention, and confidence building. The immersive and interactive features of VR enable learners to develop motor skills, auditory perception, and performance techniques in a more intuitive and experiential manner. This research highlights the transformative potential of VR in redefining musical education by making it more accessible, cost-effective, and engaging. It underscores the role of emerging technologies in overcoming traditional barriers and expanding opportunities for music learning across diverse populations.

**KEYWORDS:** Virtual Reality; musical instrument training; immersive experience; interactive learning

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## 1. Introduction

Virtual Reality (VR) is a technology that immerses users in a simulated environment, often through the use of specialized headsets, gloves, or other equipment. This technology uses computers to generate virtual environments with related wearable devices to simulate an interactive three-dimensional view [1]. This was achieved through the combination of hardware and software, including head-mounted displays (HMDs), motion tracking sensors, and immersive audio. After long periods of development, this technology has been widely used in various areas, from gaming and entertainment to education, healthcare, and training simulations, providing an engaging and interactive way to experience digital content [2].

In engineering education, the use of VR technology resulted in cognitive and pedagogical benefits for students [3]. Instead of traditional whiteboard lectures, VR applications successfully improved students' understanding of complex fluid mechanics problems [4, 5]. Similar progress was observed in mathematics and geography using tools such as Construct3D, which helped students visualize three-dimensional objects [6]. The latest VR technology, including devices such as Vision Pro, enabled collaborative problem-solving and blurred the line between physical and virtual spaces in education. While research had been conducted on immersive musical education in VR [7], there remained limited focus on fully interactive instrument experiences.

Thus, the primary objective of this study was to design and implement a VR game that offered a comprehensive and immersive platform for musical instrument training. It provided an innovative approach to musical education and practice by expanding the range of experiences beyond what traditional physical instruments could offer. Due to its unique immersive experience, lack of space constraints, ability to accommodate various instrument modes, and relatively lower cost than real instruments [8], VR stood out as a versatile and accessible tool for musical experience and training [9–11]. This technique was actively integrated into the learning and experience of various musical instruments, including piano performance [12], drum practice [7], and others. Different from traditional VR games, this paper proposed a musical game with different instruments. Additionally, movable musical notes were created for interaction, featuring diverse training scenarios tailored to different learning styles and preferences, thereby enhancing the educational experience. Furthermore, the game incorporated gamification elements such as achievements, levels, and rewards to boost student engagement and motivation. These game-like incentives were designed to transform the learning process into an interactive and enjoyable experience, encouraging students to practice more consistently and effectively. This paper detailed the development process of the VR training game, including the design and implementation of its key features. The proposed system addressed traditional challenges in musical education while transforming the learning experience, making it more accessible, engaging, and effective for students from diverse backgrounds.

## 2. VR Mode and Game Design

During our field research at a local music school, we observed students learning musical instruments using traditional methods. These methods involved following verbal instructions from their teachers. This early stage of learning was essential for building basic skills and fostering a lasting interest in music. However, we found that despite their teachers' guidance,

students, especially younger children, often lacked motivation and remained relatively inactive, even though they could practice independently. To address this issue, we identified an opportunity to develop an engaging VR-based training game. This game was designed to inspire and guide students through active learning exercises, thereby boosting their enthusiasm and participation. Additionally, it enabled teachers to oversee multiple students simultaneously and accurately track their progress.

Another important factor in a VR learning environment was how the content was presented. Previous research focused on using visual cues for musical instrument systems, particularly for keys or strings [13]. For example, Johnson augmented the theremin with visual cues to provide guidance and feedback on note positions [14]. We hypothesized that visual cues could assist students in improving their playing skills by following the notes, as musical instruments feature different pitch arrangements on their strings, keys, or surfaces. Serafin et al. noted that visual cues could help musicians perform better and enhance their overall aesthetic experience, such as by converting discrete keys into continuous moving musical note sequences [10]. Despite this, the impact of visual cues on students' learning of musical instruments remained relatively underexplored. Therefore, this paper also examined the significant role of visual cues in the design.

### 2.1. Hardware VR device.

Based on these observations, we designed a VR game concept using the PICO4 device to motivate students to complete their practice sessions. Students used two controllers, each weighing 185 grams, while wearing a headset. By gripping these controllers, they interacted with virtual musical instruments and practiced under the guidance of tutors and the instructions provided within the game. The PICO4 device's screen-mirroring feature allowed the VR display to be shared on televisions, computers, and smartphones. This capability enabled teachers to provide real-time guidance, support, and monitoring of student performance (Figure 1).



**Figure 1.** VR Device: PICO4.

### 2.2. Integrated system.

In our study, advanced VR headsets and controllers, combined with sophisticated game design elements, formed the core components of the system. Key aspects of the game design included an accuracy detection system, control actions and movement, haptic feedback, scene display,

and overall game structure. These elements were essential for creating an immersive and interactive VR training environment. The accuracy detection system and control mechanisms were critical for evaluating the effectiveness of VR training. They ensured precise and effective user interactions within the virtual environment by accurately tracking user actions and movements. This precision was vital for tasks such as translation and perspective changes in the VR space, allowing users to navigate and interact with the virtual world seamlessly. By providing detailed feedback on user performance, the system assessed the effectiveness of the training and identified areas for improvement.

Haptic feedback and scene display contributed significantly to user immersion. Haptic feedback provided tactile responses that simulated real-world sensations, thereby enhancing the sense of presence and engagement in the virtual environment. Meanwhile, realistic scene display ensured that the visual experience was convincing and immersive, further reinforcing the feeling of being in a different reality. These elements worked together to create a more lifelike and compelling VR experience, which was crucial for effective training. Overall, the integration of advanced hardware and thoughtful game design aimed to achieve several key targets, including VR training evaluation, seamless transformation and perspective changes, and deep immersion, as illustrated in Figure 2.

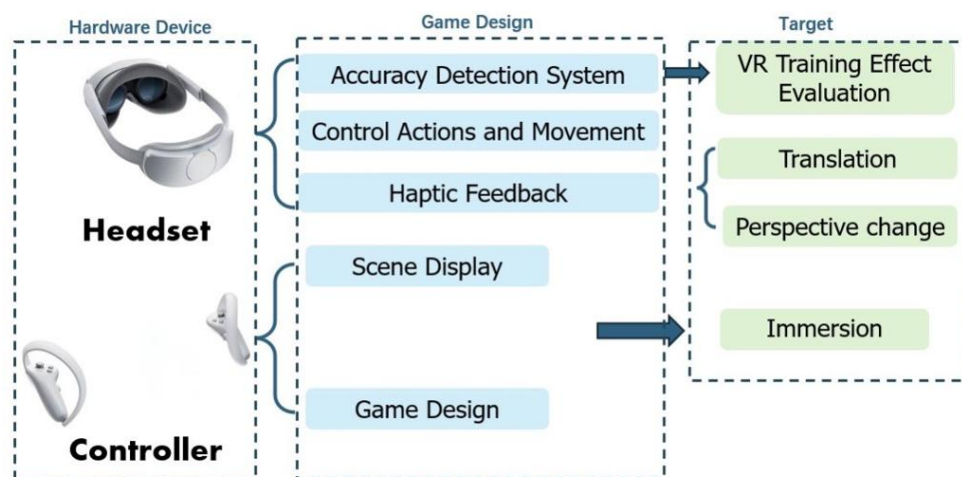
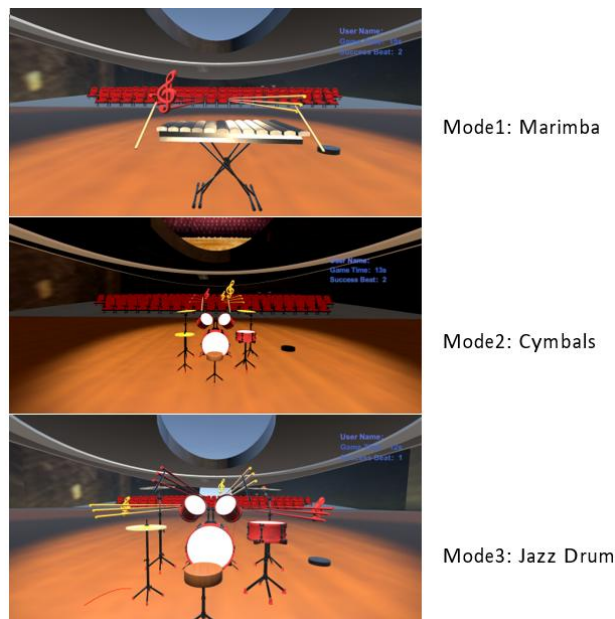


Figure 2. Illustration of integrated system.

### 2.3. Modes designed.

According to existing literature and previous research, the drum and keyboard were among the most common modes used for in-game instruction in musical instrument training. As the number of training tracks increased, the instrument composition became more complex, thereby increasing the level of difficulty for students. Therefore, as shown in Figure 3, the game was designed with three modes: Mode 1 – Marimba (similar to a keyboard), Mode 2 – Cymbals (two tracks), and the most complex mode, Mode 3 – Jazz Drum (drum set). The marimba, cymbals, and jazz drums presented significant challenges for students due to their high cost and specific spatial requirements. Many students found it difficult to access these instruments for learning purposes. These percussion instruments required ample space and acoustically treated environments, along with fixed locations for rehearsals, which were often costly and limiting.



**Figure 3.** Design of 3 modes.

In response to these challenges, the proposed VR system design seeks to democratize access to these instruments. By creating virtual environments for the marimba, cymbals, and jazz drums, students can explore and practice without the constraints of physical space or the expenses associated with these instruments. VR technology allows for realistic simulations of playing conditions, including varying acoustics and spatial configurations, thereby providing an immersive learning experience regardless of real-world limitations. Moreover, integrating these instruments into a single VR platform promotes versatility in musical exploration. Students can seamlessly switch between marimba melodies, cymbal rhythms, and jazz drum beats within the same session, enhancing their understanding of percussion ensemble dynamics and solo performance techniques. The aim is to empower students from diverse backgrounds to engage freely with these instruments, nurturing their musical talents without the traditional barriers of space, venue, or expense. This innovative approach not only broadens accessibility to percussion education but also inspires creativity and proficiency in aspiring musicians worldwide. A scoreboard is also designed to record the student's name, game time, and count of successful beats so that tutors can better monitor their practice and performance. The output of success count is one of the important indexes for evaluating the practice effects of students quantitatively.

### *2.3.1. Mode1: marimba.*

The marimba is a keyboard-like percussion instrument. Playing the marimba requires a thorough understanding of its fundamental elements, including pitch, rhythm, and technique. This percussion instrument, consisting of wooden bars and struck with two mallets, produces diverse melodies. Each strike of the mallets generates a distinct timbre, contributing to a harmonious ensemble suitable for both orchestral performances and solo repertoire. In the design of a VR game, we integrate virtual marimba mallets with VR controllers, allowing users to replicate the physical motions and striking techniques of real mallets. This seamless connection between physical actions and virtual feedback significantly enhances the learning experience, providing students with a simulated environment resembling actual instrument performance. As music plays, digital notes appear above corresponding bars on the virtual

instrument, moving according to a predefined score. These visual cues prompt students to strike the correct bars precisely, strengthening their sense of rhythm and timing. The immersive nature of virtual reality captivates student attention and provides immediate feedback on their performance.

### 2.3.2. *Model2: cymbals.*

Playing the cymbals is integral to the comprehensive study of percussion instruments. Cymbals, due to their versatility in sound production, offer a wide range of tones influenced by the force, technique, and point of impact applied during strikes. Mastery of these variables is crucial for developing a percussionist's technical skills and musical expression. In our VR game design, the integration of cymbal play introduces a dynamic and immersive learning experience. By connecting the mallets to VR controllers, performers gain unprecedented control over the mallets' movements, orientations, and positions using both hands. This technological innovation not only simulates the physical act of striking cymbals but also enhances the educational process by providing immediate visual and auditory feedback. In VR, performers engage with virtual cymbals that respond realistically to their actions. As they strike the cymbals with varying force and technique, the VR system accurately reproduces corresponding sounds, reinforcing the connection between physical gestures and auditory results. Moreover, digital interfaces can display real-time analytics on performance metrics such as timing accuracy and intensity of strikes, enabling performers to track their progress and refine their skills effectively.

### 2.3.3. *Model3: jazz drum.*

The jazz drum set is a popular choice among beginner musicians. Often featured in band performances, the jazz drum is one of the most accessible and commonly introduced percussion instruments. A typical drum set comprises various components, including the snare drum, hi-hat, cymbals, and bass drum, requiring students to develop multi-faceted coordination and playing skills involving their hands, feet, and eyes. In our VR game, we have meticulously designed note-playing prompts on each drum and cymbal. These prompts guide students through their practice sessions, helping them hone their skills and experience the instrument comprehensively. By visualizing each strike's exact timing and location, students can learn to synchronize their movements with precision, enhancing their overall musicality and technical proficiency. The VR environment provides an immersive and interactive platform replicating the experience of playing an actual drum set. Students can practice different rhythms and beats in a controlled, feedback-rich setting, allowing them to correct mistakes and improve their technique in real time. This innovative approach ensures that learners can achieve a high level of proficiency even without access to a physical drum set.

## 3. Preliminary Testing

Preliminary testing was conducted with a group of volunteers and relatives to evaluate the usability and effectiveness of the proposed VR-based percussion training system. Before the experiment, participants received brief training on how to operate the VR equipment and interact with the virtual musical instruments. A structured user-experience questionnaire was developed to collect demographic information and evaluate participants' perceptions of the VR

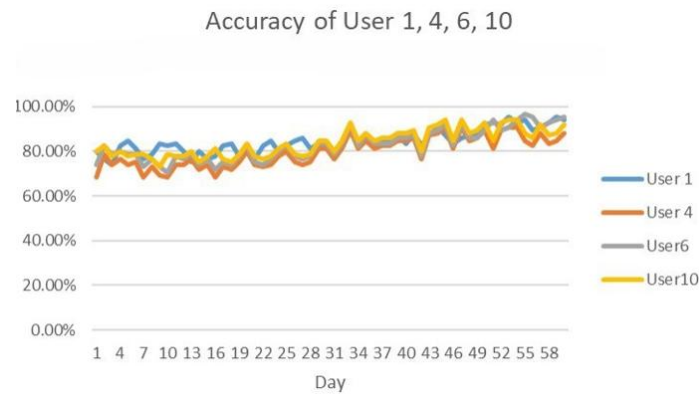
training environment. Following recommendations from the instructors, the evaluation focused on three primary performance indicators: (1) the number of successful strikes, (2) the continuous sequence of accurate beats, and (3) the level of immersion and realism perceived by users during gameplay. The questionnaire structure and variable coding scheme used in the study are summarized in Table 1.

**Table 1.** Survey questions and variable coding.

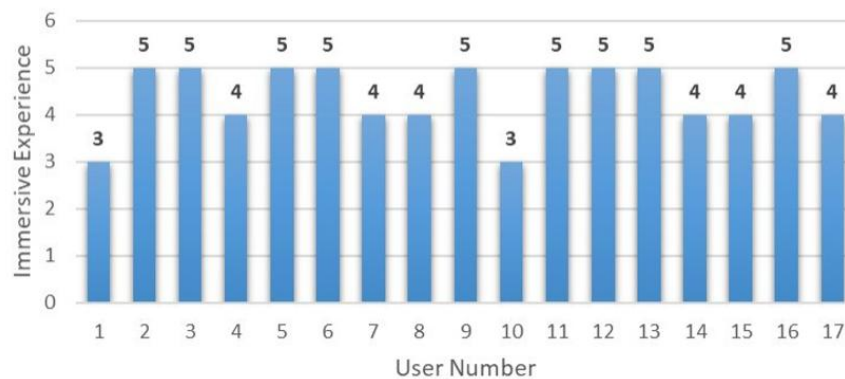
Variable	Question / Description	Coding / Options
Gender	Participant gender	0 = Male; 1 = Female
VR Experience	Have you ever used virtual reality (VR) before?	0 = No; 1 = Yes
Subjective VR Experience	Participant evaluation of the VR experience quality	1 = Terrible; 2 = Bad; 3 = Simple; 4 = Good; 5 = Excellent
Mode	Experimental mode used in the study	1 = Mode 1; 2 = Mode 2; 3 = Mode 3
Beat Count (A)	Number of beats detected during the observation period	Variable A
Total Beat Rate	Ratio of total available beats	Total Available Beats / A
Continuous Beat Rate	Ratio of continuous beat occurrences	Continuous Beat Count / A

The results of the preliminary experiment are illustrated in Figure 4 and Figure 5. As shown in Figure 4, both the accuracy rate and the continuous accuracy rate demonstrate a gradual improvement throughout the experimental period (60 days). This trend indicates that participants were able to progressively improve their performance through repeated interaction with the VR percussion training system. In addition to performance metrics, participants reported positive perceptions regarding the immersive quality of the virtual environment. As illustrated in Figure 5, the majority of participants indicated that the realism and immersion of the VR gameplay closely resembled actual instrument training conditions. These findings suggest that VR-based training environments can effectively support different learning styles and preferences. The adaptability of VR technology enables the creation of customized training scenarios that respond to individual user needs, thereby enhancing the overall learning experience.

To further validate the observed trends, a time-series analysis using the Autoregressive Integrated Moving Average (ARIMA) model was conducted. The model results confirmed the stability and rationality of the observed improvement patterns in accuracy and continuous beat performance over time. Moreover, most participants provided positive qualitative feedback after completing the experiment. Many noted that the space-independent training mode represents an innovative approach to musical instrument learning. Participants emphasized that the system offers substantial convenience, particularly for beginners who may lack access to physical instruments or suitable practice environments. The VR system's ability to provide precise and immediate feedback on performance metrics—such as timing accuracy and strike intensity—represents a significant advantage compared with traditional teaching methods [10].



**Figure 4.** Case 1: Accuracy of some users.



**Figure 5.** Immersive Experience Feedback.

Instructors who evaluated the system also expressed positive opinions regarding the VR training platform. They highlighted its potential to support continuous engagement in musical practice and to facilitate diverse training exercises within a controlled and interactive environment. Overall, the preliminary testing demonstrates that VR-based percussion training has considerable potential as an innovative educational tool. While the results are promising, further research involving larger participant groups and longer experimental periods is necessary to fully evaluate its educational effectiveness. Continued development and refinement of VR applications in music education may lead to more engaging, accessible, and inclusive learning experiences for students worldwide. This approach not only addresses existing limitations in traditional music training but also opens new opportunities for technology-enhanced teaching methods.

#### 4. Conclusion

This study demonstrates the potential of Virtual Reality (VR) as an innovative platform for musical instrument training. By integrating immersive environments with interactive learning mechanisms, VR can effectively address several limitations associated with traditional music education, including physical space requirements, equipment costs, and logistical constraints. The developed VR system enables students to practice instruments such as the marimba, cymbals, and jazz drums within a simulated environment that replicates realistic playing conditions while remaining accessible and flexible. The proposed VR game design incorporates visual guidance, real-time performance feedback, and gamification elements, which together enhance user engagement and motivation. These features allow learners to

receive immediate feedback on key performance indicators—such as strike accuracy and timing—facilitating continuous improvement during practice sessions. In addition, the system supports diverse learning styles by enabling customizable training scenarios, which may contribute to more effective skill acquisition compared with conventional practice methods. Results from the preliminary testing suggest that VR-based training can increase learner engagement and improve performance accuracy over time, indicating its potential as a complementary tool for music education. The immersive nature of VR environments also promotes sustained practice and provides a novel approach to instrument training, particularly for beginners who may lack access to physical instruments or suitable practice spaces. Overall, VR technology offers a promising and cost-effective solution for expanding access to musical training and enhancing the learning experience. Future research should involve larger participant samples, longer experimental periods, and comparisons with traditional training methods to further validate the educational effectiveness of VR-based music learning systems. Continued development in this area may contribute to more accessible, scalable, and technology-enhanced approaches to music education.

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### Competing Interests

The authors declare no competing interests.

### Author Contributions

All authors contributed equally to this work.

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