



Virtual museums: a tool for studying traditional Indonesian musical instruments

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Abstract. *Introduction.* The integration of virtual reality (VR) platforms into educational museum spaces plays a crucial role in preserving and promoting traditional music. However, the declining interest among young people in traditional Indonesian musical instruments emphasises the need for innovative pedagogical strategies. Museum-based VR platforms offer a promising tool to enhance interactivity, accessibility, and relevance in learning. *Aim.* The present study aims to identify the key factors influencing the implementation of VR technologies in the educational processes of museums, utilising the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technological Pedagogical Content Knowledge (TPACK) framework. *Methodology and research methods.* The study employed partial least squares structural equation modelling (PLS-SEM) to examine the influence of technological competence, cultural factors, behavioural attitudes, and pedagogical knowledge on the effectiveness of using VR. *Results and scientific novelty.* The critical role of teacher training in enhancing their technological and pedagogical qualifications was confirmed. The PLS-SEM results demonstrate that technological competence and pedagogical knowledge significantly influence behavioural intentions, which, in turn, are the strongest predictors of the actual use of VR technologies. *Practical significance.* Practical recommendations are provided for educators, developers of educational programmes, and specialists in cultural heritage concerning the integration of VR into learning and exhibition contexts. It is demonstrated that the pedagogically informed application of VR technologies to culturally significant materials enhances engagement and learning effectiveness, thereby contributing to the preservation of traditional Indonesian music.

Keywords: virtual reality, virtual museum, Indonesia, traditional musical instruments, Technological Pedagogical Content Knowledge (TPACK), Unified Theory of Acceptance and Use of Technology (UTAUT)

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Виртуальные музеи как способ изучения традиционных музыкальных инструментов Индонезии

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Аннотация. *Введение.* Интеграция платформ виртуальной реальности (VR) в образовательное музейное пространство играет важную роль в сохранении и популяризации традиционной музыки. Однако снижение интереса молодежи к традиционным индонезийским инструментам актуализирует поиск новых педагогических стратегий. Музейные VR-платформы представляют собой перспективный инструмент повышения интерактивности, доступности и актуальности обучения. *Цель.* Определение ключевых факторов, влияющих на внедрение VR-технологий в образовательный процесс музеев, с использованием Единой теории принятия и использования технологий (UTAUT) и модели технологическо-педагогического содержательного знания (TPACK). *Методология, методы и методики.* В исследовании применено моделирование структурными уравнениями методом наименьших квадратов (PLS-SEM). Анализировалось влияние технологической компетентности, культурных факторов, поведенческих установок и педагогических знаний на эффективность использования VR. *Результаты и научная новизна.* Подтверждена решающая роль подготовки педагогов для повышения их технологической и педагогической квалификации. Результаты PLS-SEM демонстрируют, что технологическая компетентность и педагогические знания значимо влияют на поведенческие намерения, которые, в свою очередь, являются сильнейшим предиктором фактического использования VR-технологий. *Практическая значимость.* Сформулированы практические рекомендации для педагогов, разработчиков образовательных программ и специалистов в области культурного наследия по интеграции VR в учебный и выставочный контексты. Показано, что педагогически обоснованное применение VR-технологий к материалам культурного содержания повышает вовлеченность и эффективность обучения, способствуя сохранению традиционной музыки Индонезии.

Ключевые слова: виртуальная реальность, виртуальный музей, Индонезия, традиционные музыкальные инструменты, технологическо-педагогическое содержательное знание (TPACK), объединенная теория принятия и использования технологий (UTAUT)

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Introduction

Rapid technological developments have transformed education, including the fields of cultural heritage and music education [1]. M. M. Asad, A. Naz, P. Churi et al. [2], and E. Hu-Au and J. J. Lee [3] state that the emergence of Virtual Reality (VR) as a pedagogical tool represents a major innovation, while G. Makransky, N. K. Andreassen, S. Baceviciute et al. [4] affirm that this tool can enhance the learning experience. Learning musical instruments using VR-based museum in Indonesia highlights a revolutionary educational method, which makes the interaction between users and their cultural heritage happen in an unprecedented way. VR offers users a unique experience and also enhances their perception and feelings, in which they can feel as though they are in a virtual environment. Virtual museums are essential in preserving and advancing intangible cultural heritage of Indonesian musical instruments, which are often threatened to be displaced by globalised contemporary cultural expressions. In accordance, D. Miharja [5] conveys that Indonesian people consider their musical traditions manifest artistic innovation and their spiritual and historical identity. P. Hronček, B. Gregorová, D. Tometzová et al. [6] state that virtual products are typically used for reconstruction of tourism and cultural heritage, also for preservation [7], documentation [8], and cultural heritage [9]. Understanding technology acceptance is becoming increasingly important as global education embraces new technologies. The Unified Theory of Acceptance and Use of Technology (UTAUT) model, developed by V. Venkatesh, J. Thong, and X. Xu [1], provides a comprehensive framework to explain this phenomenon. According to UTAUT, there are four fundamental factors influencing technology acceptance: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FCs) (see Figure 1 below). These factors affect an individual's propensity to adopt and use technology.

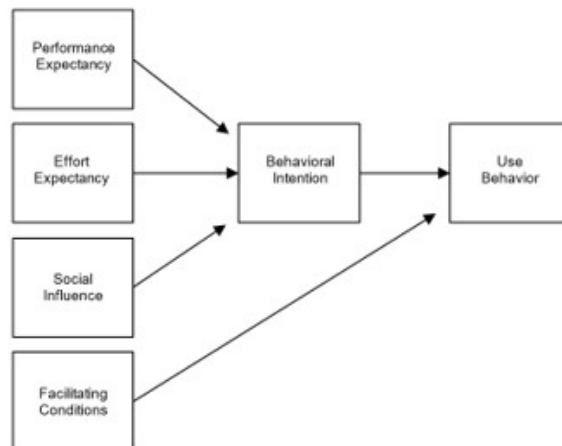


Fig. 1. Two stylised images of the cycle of recycling (cited from N. M. Suki and N. M. Suki [10])

Within the above framework, W. Moughal, S. M. Nordin, R. Salleh et al. [11] state that PE relates to the perceived benefits of technology in improving job performance, while EE addresses the ease of use of the technology. In comparison, H. Khechine, B. Raymond, and M. Augier [12] highlight that SI emphasises the importance of the perspectives of peers and significant others in the adoption process, while L. L. Zhou, J. Owusu-Marfo, H. Asante Antwi et al. [13] demonstrate that FCs are associated with the availability of resources and support systems that enable the effective use of technology. A study by Z. Tong [14] reports that research in music education reveals that musicians generally display favourable attitudes towards technology. A significant gap exists in understanding how teachers, especially in non-Western contexts, modify tools like VR for classroom use. This is particularly relevant in Indonesian music education in which traditional methods might need modernisation to keep up with contemporary technology.

In addition to UTAUT, Technological Pedagogical Content Knowledge (TPACK) provides an essential perspective for analysing the convergence of technology, pedagogy, and content knowledge [15]. According to F. Cipta, Y. Sukmayadi, R. Milyartini et al. [16], TPACK is particularly relevant in music education, and D. Stoilescu [17] supports that TPACK allows teachers to manage the intricacies of teaching musical concepts while skilfully integrating technology into their teaching. Indonesian music teachers must be able to play and teach Indonesian musical instruments and be proficient in using technologies to enhance their students' learning experience. However, M. M. A. Latif and M. M. Alhamad [18] raised an issue related to unproficiency in technology devices, training, and support becomes an issue faced by teachers, obstructing the successful technology integration in their classrooms such as unfamiliarity with technological devices and inadequate training and support. Thus, a successful implementation of VR-based museums necessitates a comprehensive understanding technology acceptance factor and learning strategies. According to C. K. Galla [19], VR has been used in cultural education to duplicate historical settings, imitate investigation of archaeological, and bring extinct language back. These implementations underline capacity of VR to improve learning through interactivity and memory [20]. However, the implementation of VR in teaching traditional music, especially Indonesian traditional music, remains relatively unexplored. Additionally, M. Lui, R. McEwen, and M. Mullally [21] affirm that the main focus of VR in education studies is on its cognitive benefits, including improved memory retention and conceptual understanding, but neglecting the cultural and emotional aspects of learning. Therefore, integrating VR into Indonesian music education requires a framework addressing both technological and pedagogical complexities. The transition to modern teaching methods poses significant challenges in preserving traditional music. Innovative tools are needed to engage modern learners and present traditional music in relevant ways. Despite this, S. Williams¹ reports that there has not been an interactive virtual museum specifically dedicated to showcasing West

¹ Williams S. Current developments in Sundanese popular music. *Asian Music*. 1989;21(1):105–136. doi:10.2307/834075

Javanese traditional music, and younger generations often prefer globalised contemporary genres to local ones. Leveraging UTAUT and TPACK, VR-based museums offer valuable insights into Indonesian music teachers' perceptions and adoption of technology. This study examines how these frameworks support Indonesian music teachers in integrating VR, fostering engagement, and preserving cultural heritage.

Literature Review

Experiential Learning Approaches to Traditional Music in Indonesia

Interactive learning is grounded in the constructivist and experiential learning theories proposed by D. A. Kolb, R. E. Boyatzis, and C. Mainemelis [22]. It aims to enhance interactive methodologies by fostering experiential learning, reflection, and active exploration. In music education, it helps learners to improve their technical skills and cultural appreciation in which they can engage with musical instrument directly [21]. By providing multimodal experiences, such as interactive technology within this framework, the learning outcomes can be enhanced [24]. Learners can interact with auditory, visual, and tactile stimuli and facilitate the development of cognitive and emotional associations with music. VR and augmented reality (AR) [23] are some of the most promising technologies allowing learners to learn traditional musical instruments virtually, engage with their digital versions, and practice playing them in a virtual environment that mimics the acoustics and ambiance of the cultural context. A study by T. Nurjatisari, Y. Sukmayadi, and T. Nugraheni [26] highlights the benefits of technology-assisted learning environment, particularly for young people accustomed to digital interfaces. In accordance, VR-based musical instrument learning, gamification platforms, and mobile applications enhance students' engagement, facilitate self-paced learning, and enable progress monitoring. M. Ahmed, H. Ragab, and S. Shaker [27] emphasise 3D modelling and sound synthesis to teach traditional musical instruments overcome learning challenge and geographical limitations, and widen access to historical musical traditions.

Figure 2 below provides an overview of interactive music learning, illustrating how technological elements can enhance a more dynamic and engaging music learning experience.

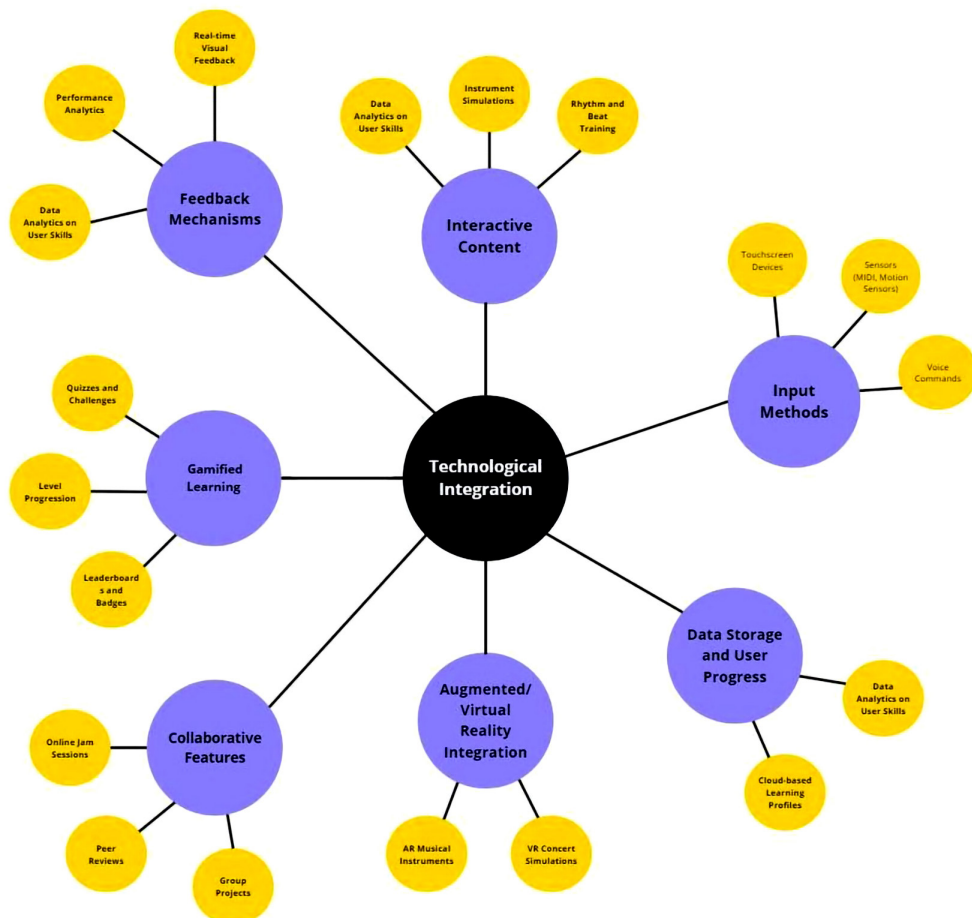


Fig. 2. Technological approach to interactive music learning

Virtual Museum Concept on Traditional Musical Instruments of West Java using Virtual Reality

Virtual museums enable visitors to engage with digital representations of historical and cultural artefacts and their contextual environments in ways unattainable by traditional museums [28], thus, several factors are to be considered include: VR make a replica of real world in which authentic artefacts are occasionally restricted and out of reach [29]. The virtual museum enables visitors to engage remotely with 3D renderings of musical instruments, including *gamelan degung*, *tarawangsa*, *angklung*, and others. These contents are presented in forms of historical timeline, video interviews with traditional musicians, cultural stories, animated instrument explanations, and interactive quizzes, as elaborated below.

- VR integrates multimedia content into cultural and historical themes [30]. The instruments' significance in West Javanese culture can be highlighted through cultural stories, historical timelines, and video interviews with traditional musicians as exhibits in a virtual museum [31]. In addition, UNESCO states that it is also listed on the Representative List of the Intangible Cultural Heritage of Humanity [32], signifying its role in the culture.

- VR offers global accessibility, allowing anyone with internet access and a VR headset to explore cultural heritage from anywhere, which is crucial for preserving culture [33, 34], while I. Bollati and M. Spanevello [35] state that virtual museums act as digital archives, protecting artefacts and their cultural significance for future generations.

VR's capacity to carry out interactive and immersive learning experiences has been made it a technology with significant potential to improve the quality of education. VR is a distinctive technology that allows users to engage in a virtual environment in a fully immersive instrument.

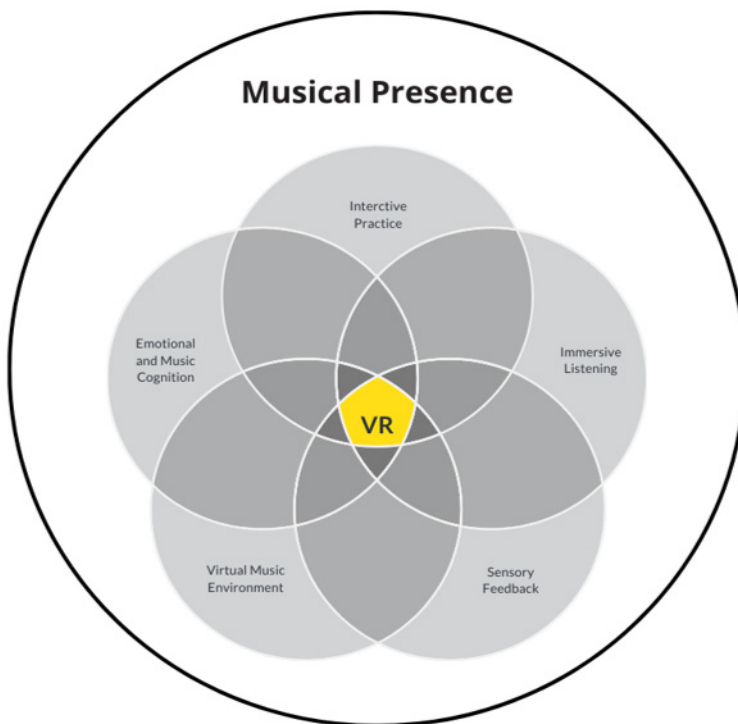


Fig. 3. Virtual Immersive-Based Education Model (VIBE Model)

Figure 3 depicts the VIBE (Virtual Immersive-Based Education) model as a fundamental component contributing to “musical presence” in VR. The term “pres-

ence” refers to the sensation experienced by users during VR interactions or when situated within a non-physical environment [36]. Technologically, the virtual museum platform can be accessed through computers, laptops, or VR headsets, providing sufficient flexibility. Thus, creating a virtual museum for Indonesian musical instruments should involve the following components:

i. Interactive VR practice: allows users to explore and engage with traditional instruments like *gamelan degung*, *tarawangsa*, and *angklung* through hand tracking. Users experiment with techniques, getting feedback and developing skills in a virtual environment, enhancing experiential learning and musical skill development, which aligns with constructivist learning.

ii. Immersive listening: simulates spatial and realistic soundscapes, enabling users to explore the acoustic properties of Indonesian musical instruments like *gamelan* in a 3D space. Sound interacts with the user’s positions in which it enables them to understand tonal quality and ensemble effects. Also, it connects users to the cultural and technical things of Indonesian music.

iii. Sensory feedback: integrates haptic feedback (physical sensations), visual feedback (instrument details), and auditory feedback (authentic sounds). This multimodal experience enhances user involvement, reinforces proper practice, and expands understanding of rhythm, tempo, and techniques. It also boosts user’s confident and skill development.

iv. EduLaras Virtual Museum: offers an immersive space with *gamelan*, *degung* classes, interactions between students and teacher, and gamified experiences. Here, users can explore, learn, and study Indonesian music in a flexible framework, which makes learning more interesting and interactive.

v. Emotional and musical cognition: utilises historical narratives, animated instrument explanations, and interactive elements like quizzes to encourage active learning, memory retention, and a comprehensive understanding of the technical and symbolic elements of Indonesian music.

EduLaras Virtual Museum, a VR-based platform developed to showcase traditional West Javanese musical instruments, was created using the Unity development platform and is compatible with the Meta Quest VR headset. This tool allows users to play the instruments, listen to audio samples, and explore the historical background of these musical traditions. Figure 4 below shows a screenshot of the EduLaras Virtual Museum app, which illustrates how West Javanese musical performances are presented through virtual reality learning.



Fig. 4. *Gamelan Degung* instrument learning classroom in the EduLaras Virtual Museum (Source: Screenshot from the EduLaras Virtual Museum app)

Unified Theory of Acceptance and Use of Technology (UTAUT)

V. Venkatesh, M. G. Morris, G. B. Davis et al. [37] define UTAUT as a broad theoretical framework examining how people behave when using technology. UTAUT exemplifies the Technology acceptability Model (TAM) and how it assesses user's technology acceptability [38]. TAM is predicated on utilising information technology in globalisation [39].

In UTAUT, performance expectancy, effort expectancy, and social influence affect behavioural intentions in using technology, while behavioural intentions and facilitating conditions determine technology utilisation. Additionally, Y. K. Dwivedi, N. P. Rana, A. Jeyaraj et al. [40] state multiple combinations of the four factors were hypothesised and identified as moderating specific UTAUT connections. In employing VR-based museums for Indonesian traditional music learning, four critical factors to consider are:

- **Performance Expectations.** Teachers believe VR can enhance learning outcomes by improving students' understanding of musical concepts, facilitating interaction with traditional instruments, and developing skills more effectively than traditional methods.
- **Navigation Simplicity.** For effective use of VR-based museums, students and teachers need simple navigation, accessible resources, and intuitive interaction.
- **Cultural and Professional Endorsement.** Support from professors, music professionals, or cultural leaders, such as Indonesian cultural figures, can legitimise VR and encourage student acceptance.
- **Enabling Conditions.** Successful usage of VR depends on access to headsets, technical support, and reliable internet. Limited resources in rural areas can hinder participation and inclusion in VR-based education.

Technological Pedagogical and Content Knowledge (TPACK)

TPACK encompasses the integration of technology and pedagogy to create effective educational content [41] and to support effective teaching [42]. It consists

of key knowledge domains: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK). TPACK continues to evolve, with the work of M. Koehler and P. Mishra [42] providing a comprehensive explanation.

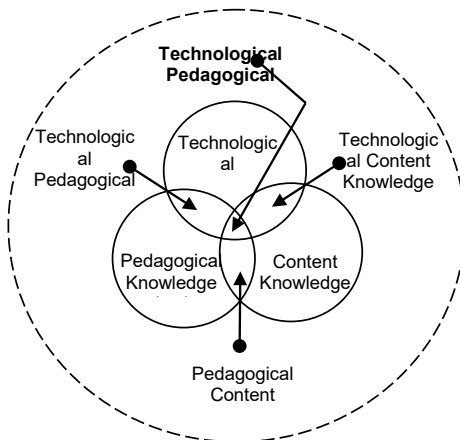


Fig. 5. The TPACK framework and its constituent knowledge²

Figure 5 illustrates that the TPACK framework comprises:

- Content Knowledge (CK) denotes the teacher's comprehension of the subject they teach that reflects the cultural heritage of Indonesian music. In VR-based museums, this includes a profound comprehension of Indonesian traditional music [43], such as its historical context, cultural significance, musical instruments, rhythms, and performing techniques.
- Pedagogical Knowledge (PK) denotes a teacher's comprehensive understanding of teaching and learning. According to P. Tamir³, pedagogical knowledge encompasses multiple facets, including education's aims, principles, and objectives. Teachers employing VR in Indonesian music have to employ pedagogical strategies that capitalise VR's immersive qualities. M. S. Y. Jong, C. C. Tsai, H. Xie et al. [44] exemplify that teacher assigns students to play a musical instrument virtually, providing a more experiential learning method than conventional lectures or reading materials.
- Pedagogical Content Knowledge (PCK) is the foundation of teaching, learning, curriculum, assessment, and reporting [45]. Teachers must assess the most effective approaches for imparting the complexities of Indonesian traditional music and its cultural significance by synchronising traditional content with innovative instructional methods that encourages culture appreciation.

² Adapted from <http://tpack.org> (© 2012 tpack.org)

³ Tamir P. Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education*. 1988;4(2):99–110. doi:10.1016/0742-051X(88)90011-X

- Technological Knowledge (TK) goes beyond computer literacy, which requires a thorough comprehension of IT, its effect on goals, and how to adapt to technological advancements. TK exemplifies teachers' comprehension of VR resources utilisation to create immersive learning environments. Effective utilisation of VR requires teachers to have technological skills in how to operate the platform, maintain VR tools, and resolve any issues. It requires understanding of creating or curating virtual content, which can captivate students in learning Indonesian traditional music.

- Technological Content Knowledge (TCK) refers to comprehending the interplay and limitations between technology and content [46]. VR technology offers a distinctive approach to showcasing Indonesian musical instruments and their auditory characteristics, which are challenging to express using traditional media.

- Technological Pedagogical Knowledge (TPK) refers to the way teaching and learning are changed into strategic implementation of certain technologies [47] by integrating VR's immersive features, such as virtual museum tours, with pedagogical methods such as problem-solving and practical experience, providing experiences that cannot be gained in a traditional classroom.

Methodology

This study adopted a mixed-method approach in evaluating the usage of VR-based virtual museums for teaching Indonesian traditional music. It determined user acceptance and technological prototype using the UTAUT and TPACK as a guide. Qualitative methods examined challenges in traditional music education, gathered teacher insights, and examined VR's potential. Quantitative analysis evaluated the intervention's effectiveness through a 37-item questionnaire, addressing variables from UTAUT and TPACK, providing a comprehensive understanding of VR's role in preserving and teaching Indonesian music.

The study involved 24 art and culture teachers from junior high, senior high and vocational high schools from West Java Province, Indonesia, who were assigned to experience and test the virtual museums during the trial phrase. They had diverse teaching experiences in arts education, enriching the study's discussions and fostering experience-sharing. To ensure relevance and expertise, intentional sampling was employed, selecting participants with suitable backgrounds to obtain a robust foundation for evaluating the VR-based approach and its potential impact on Indonesian music education.

A standardised questionnaire based on the UTAUT was developed to assess user acceptance of VR technology to evaluate performance expectancy, simplicity of use, and the availability of facilitating conditions such technology access and assistance. Furthermore, a TPACK-based rubric was created to evaluate teacher's integration of technology, pedagogy, and content knowledge. It focuses on how effective they use VR to improve their teaching of Indonesian musical instruments. Semi-structured interviews with teachers provided qualitative insights into their perceptions and experiences of using VR in teaching traditional music. The study proceeded in

the following phases: identifying teaching challenges, partnering with experts to ensure content authenticity, testing the VR platform with 24 teachers, and administering the survey to assess the prototype's effectiveness. After the quantitative data from the survey were collected, they were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM), and thematic analysis was used to examine the qualitative data obtained from open-ended survey responses and teacher observations. The aims of this analysis were to identify recurring themes regarding the application of VR in the education and the challenges teachers when adopting new technology.

Results

This study explores the behavioural intentions of music teachers in Indonesia towards using VR-based museum technology by involving 24 art and culture teachers of junior high and senior high schools/vocational schools in West Java Province, Indonesia, consisting 50% male and 50% female respondents. The obtained results comprise five variables that are hypothesised to have a significant influence on the adoption of VR technology for learning traditional musical instruments, namely:

1. Technology Competence (TC) refers to the user's ability to effectively operate VR technology. Higher competence facilitates smoother access and utilisation of VR for learning Indonesian musical instruments.

2. Cultural Aspect (CA) represents the cultural elements influencing VR adoption in learning. Supportive cultural environments, such as schools or communities valuing traditional culture through technology, enhance interest and predict VR usage for learning Indonesian music. This aligns with F. Febriyani and Y. Sukmayadi [23], who state that VR is a promising technology that enables learners to virtually study traditional musical instruments.

3. Behavioural Intention (BI) denotes user's intention to adopt VR in learning, which is influenced by the notion that it improves understanding of Indonesian musical instruments. It is a main predictor of actual technology use, as explained in the UTAUT framework. This is why M. Lui, R. McEwen, and M. Mullally [21] elaborate that improving students' understanding through VR in education is linked to cognitive benefits, but it should not neglect the students' behavioural intention.

4. Pedagogical Knowledge (PK) is aligned with the teacher's ability to integrate VR technology into learning. The TPACK framework emphasises the role of pedagogical competence in maximising technology's potential in education. Thus, strong pedagogical knowledge ensures the effectiveness and success of VR implementation for teaching Indonesian musical instruments.

5. Technology Use Prediction (TUP) shows how users use VR technology in the classroom, in which they are influenced by their intention, technological skill, and cultural background.

6. The results obtained from PLS-SEM are depicted in Figure 6. It measures various constructs (latent variables) associated with the acceptance and prediction of utilising VR technology in learning Indonesian musical instruments.

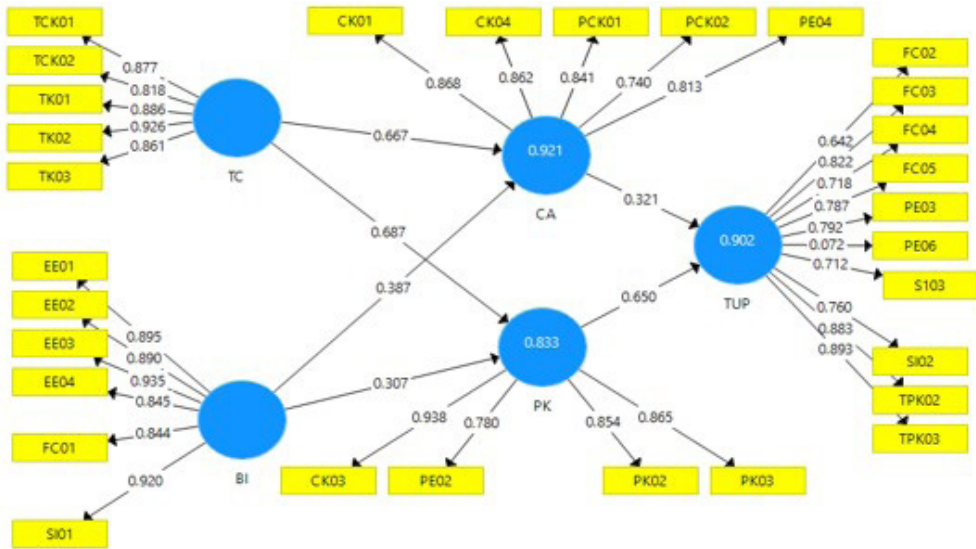


Fig. 6. The path diagram with PLS-SEM

Figure 6 presents the following:

- TC shows the user's technological proficiency, which determines how well users (teachers or students) can use VR technology. Based on the figure, TC has indicators TCK01 to TK03, with fairly high loading factor values (all above 0.8), showing that these indicators have a significant role in determining technological proficiency.
- CA has indicators such as CK01, CK04, PCK01, and others with high loading factors, showing that cultural factors are relevant to this concept. The R-squared (R^2) for CA is 0.921, indicating that 92.1% of the variability in cultural aspects is explained by factors that influence CA, especially TC, which has a path coefficient of 0.667.
- BI has indicators, such as EE01 to FC01, with strong loading factors. High loading factor values indicate that these indicators highly represent behavioural intentions. TC also affects BI with a path coefficient of 0.687, indicating that the higher the technological competence, the higher the intention to use VR.
- PK has indicators such as CK03, PE02, and PK02, with good loading factor values, indicating that these indicators are relevant in measuring pedagogical knowledge. BI influences PK with a path coefficient of 0.387, indicating a relationship between the intention to use VR and increased pedagogical knowledge in the context of learning.
- TUP has various indicators, such as FC02 to TPK03, with good loading factors. TUP has an R-squared (R^2) of 0.902, indicating that 90.2% of the variability in predicting technology use can be explained by other factors in this model, especially CA, BI, and PK.

There are several influences were found after examining the relationship between those variables in the context of VR and learning Indonesian musical instruments. These include:

- **Technology Competency (TC).** Teachers' higher technological competence with VR significantly increases their intention to use it for learning Indonesian musical instruments (BI). A path coefficient of 0.687 highlights this strong relationship, aligning with UTAUT, where self-efficacy enhances users' acceptance to adopt new technologies. Confident and skilled users are more inclined to use VR effectively in educational contexts.
- **Cultural Aspect (CA).** Cultural encourage affects the prediction of VR use (TUP) but with a moderate impact (path coefficient 0.321). While a supportive cultural environment can encourage VR adoption, it remains a secondary factor compared to pedagogical knowledge or intention to use the technology. Schools promoting VR for cultural appreciation provide foundational encouragement, but this alone may not ensure its adoption.
- **Pedagogical knowledge (PK).** Strong pedagogical knowledge (path coefficient 0.650) significantly drives both BI and TUP. Teachers who are adept at integrating VR into teaching have higher intentions to use it and greater likelihood of adoption. Additionally, BI influences PK (path coefficient 0.387), as users motivated to adopt VR are inclined to enhance their pedagogical skills. TPACK emphasises PK as a vital variable for meaningful technology integration, making sure that teaching Indonesian instruments is done in a practical application.
- **Behavioural Intention (BI).** BI is a direct predictor of TUP, with a path coefficient of 0.650. Throughout UTAUT, intention highly correlates with actual or expected technology use. Teachers or students with high BI are more likely to adopt VR in learning Indonesian musical instruments, highlighting the role of intention as a main determinant of long-term technology adoption.

Table 1 contains Discriminant Validity data often used in PLS-SEM analysis to test whether the constructs in the model have significant differences. It presents AVE (Average Variance Extracted) values on the main diagonal and the correlations between latent variables on the bottom, allowing us to evaluate discriminant validity.

Table 1

Discriminant validity

Construct	BI	CA	PK	TC	TUP
BI	0.889				
CA	0.809	0.826			
PK	0.742	0.902	0.861		
TC	0.633	0.912	0.881	0.874	
TUP	0.782	0.907	0.940	0.922	0.743

The main diagonal values (e.g. 0.889 for BI, 0.826 for CA, 0.861 for PK, 0.874 for TC, and 0.743 for TUP) represent the square root of the AVE, which indicates the variance explained by each construct compared to measurement error. High AVE values indicate good internal consistency and discriminant validity. Values outside the diagonal are construct correlations, such as 0.809 between BI and CA and 0.940 between PK and TUP. To meet Fornell-Larcker criteria, the square root of the AVE (diagonal values) must surpass the other constructs' correlations, ensuring that each construct better measures its variable than others.

The AVE values for the constructs indicate strong discriminant validity. The AVE for BI is 0.889, greater than its correlations with other constructs (e.g. 0.809 with CA, 0.742 with PK), confirming BI's good discriminant validity. Similarly, CA has an AVE of 0.826, higher than its correlations with other constructs (e.g. 0.809 with BI, 0.902 with PK), ensuring CA's discriminant validity. PK's AVE value of 0.861 is also greater than its correlations with other constructs, showing good discriminant validity. TC has an AVE of 0.874, greater than all correlations (e.g. 0.633 with BI, 0.912 with CA), indicating good discriminant validity for TC. TUP's AVE value of 0.743, greater than its correlations (e.g. 0.782 with BI, 0.907 with CA), confirms TUP's discriminant validity, even with the high correlation (0.940) with PK. Overall, all constructs have adequate discriminant validity, as their AVE values exceed their correlations with other constructs, encouraging the model accuracy and its implementation in analysing VR integration in learning Indonesian musical instrument.

Discussion

UTAUT can Understand Virtual Reality Adoption

In the context of teaching traditional Indonesian music, the UTAUT application provides a systematic perspective on the factors influencing teachers' adoption of technology. The four main dimensions of UTAUT – Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC) – provide significant perspectives for evaluating VR technology acceptance in the community of education, particularly in a common field including Indonesian music. This aligns with the assertion by V. Venkatesh, J. Thong, and X. Xu⁴ that understanding technology acceptance is crucial for the global adoption of technology. At the same time, this study extends existing literature by applying the UTAUT model to a culturally specific and artistic domain that has been underrepresented in prior research. Practically, these results suggest that professional development and policy initiatives should emphasize both pedagogical value and technical support to encourage VR adoption in music education. However, the study is limited by its contextual scope and reliance on self-reported data, which may affect generalisability.

PE, in this context, refers to teachers' perceptions of the benefits of VR in enhancing Indonesian music learning outcomes. Beyond technical skills, Indonesian music embodies deep cultural and spiritual meanings, which VR can help students grasp more profoundly. Similarly, incorporating VR into Indonesian music educa-

⁴ Venkatesh V., Thong J., Xu X. Unified theory of acceptance and use of technology: a synthesis and the road ahead. *Journal of the Association for Information Systems*. 2016;17:328–376. doi:10.17705/1jais.00428

tion can yield cognitive and emotional benefits by allowing students to delve deeper into their cultural heritage and develop better music appreciation. M. S. Y. Jong, C. C. Tsai, H. Xie et al. [44] state that virtual musical instrument can help teachers create a more experiential learning. Consequently, teachers perceive VR not merely as a technological tool but as a means to enhance holistic music education, nurturing both the intellectual and affective development of students. Furthermore, linking these perceptions to existing literature can provide insight into how VR-based learning aligns with or extends current understanding of technology-enhanced music education, highlighting potential areas for further research and practical application.

Traditionally, Indonesian music has been taught orally and through participation, which presents a challenge for teachers unfamiliar with digital tools when transitioning to VR-based methods. Therefore, Z. Tong [13] reveals the same ideas that Indonesian music education needs modernisation to keep up with contemporary technology. Crafting an intuitive, user-friendly VR platform is essential to make sure teachers feel confident and competent, overcoming the technological knowledge gap highlighted in TPACK literature. Another crucial role in technology adoption is social influence, as music teachers may face pressure from peers, students, or authorities to embrace innovations. Community support is vital for preserving cultural heritage while integrating modernisation. Thus, teachers must assess the most effective approaches for imparting the complexities of Indonesian traditional music and its cultural significance by synchronising traditional content with innovative instructional methods that encourages culture appreciation. Lastly, the adoption of VR depends on enabling conditions, such as adequate resources, infrastructure, and training. Accessibility challenges in less developed areas of Indonesia highlight the need for government, institutional, and private sector collaboration to ensure equitable and widespread adoption. This point is elaborated by M. M. A. Latif and M. M. Alhamad [18], who note that limited proficiency with technological devices, combined with insufficient training and ongoing support, creates substantial barriers for teachers, preventing them from fully utilising VR as an educational tool. Addressing these challenges requires not only investment in technology but also systematic capacity-building initiatives that empower teachers to confidently integrate VR into their teaching practices, ultimately promoting more inclusive and effective learning experiences.

TPACK can Connect VR to Educational Practices and Content

Technological Knowledge (TK) refers to teachers' ability to operate and integrate technology into their teaching. In this regard, Indonesian music teachers are expected to have a sufficient understanding of VR technology, including hardware such as VR headsets and the software that allows access to virtual museums. Lack of technological knowledge is often a barrier, as indicated by several studies stating that technological ignorance and lack of training are major obstacles in technology-based teaching.

Pedagogical Knowledge (PK) is linked to ways to adopt Indonesian music learning through direct and collaborative experiences. Therefore, teachers leverage VR to align with this strategy. Music teachers must formulate immersive teaching strategies that utilise the advantages of VR, for example, by creating virtual scenarios where students can learn how to play Indonesian musical instruments in an authentic cultural context. According to C. K. Galla [19], virtual reality has been applied in cultural education to recreate historical environments, simulate archaeological exploration, and revive extinct languages. These applications highlight VR's potential to enhance learning by promoting interactivity and strengthening memory retention [20]. By integrating VR into pedagogical practice, teachers can provide students with experiential and culturally rich learning opportunities that support both skill development and deeper understanding of Indonesia's musical heritage. Content Knowledge (CK) is a TPACK dimension related to teachers' understanding of traditional Indonesian music content. Teachers must deeply understand Indonesian musical instruments, history, and cultural significance; hence they can present Indonesian music content more in-depth and visually. By combining this expertise with technology, teachers can create visually and experientially enhanced lessons that allow students to explore Indonesian music more comprehensively. This is supported by D. Stoilescu [17], who states that TPACK equips teachers with the ability to manage the complexities of music instruction while effectively incorporating technology into their teaching practices. The convergence of Technological Pedagogical Knowledge (TPK) allows teachers to integrate VR into effective teaching strategies. It refers to the manner in which teaching and learning are transformed through the strategic application of specific technologies [47]. By leveraging TPK, educators can design immersive learning experiences that go beyond traditional classroom methods, promoting active engagement and collaboration. For instance, VR can replicate a gamelan ensemble, allowing students to assume various roles in a virtual environment, fostering collaboration and experiential learning. In Technological Content Knowledge (TCK), teachers leverage VR to deliver specific subject content. In the case of Indonesian music, this could involve exhibiting the sounds functionalities of instruments in a virtual museum, providing students with an engaging way to examine content that traditional classrooms cannot provide. According to C. S. Chai, J. H. L. Koh, C. C. Tsai [46], TCK involves comprehending the interaction and limitations between technological tools and subject matter content. By applying TCK, teachers can create lessons that not only deliver accurate musical knowledge but also immerse students in culturally rich, multisensory experiences that deepen their appreciation and comprehension of Indonesian music. Pedagogical Content Knowledge (PCK) emphasises on aligning teaching strategies with subject matter by organising lessons to include cultural context and musical practices, ensuring that the VR experience is both educational and culturally significant. Pedagogical Content Knowledge (PCK) serves as a fundamental framework for effective teaching, learning, curriculum planning, assessment, and reporting [45]. By combining pedagogical approaches with deep content knowledge, teachers can leverage VR to create immersive learning experiences that foster both skill development and cultural understanding.

Limitations

The limitations of this study are as follows. Firstly, the variables employed could be refined in future research. Although the UTAUT framework suggests that facilitating conditions (FC) influence technology adoption, this study did not fully explore FC's role in VR integration. Improved access to infrastructure, such as funding, training, and technical support, could enhance VR adoption. Secondly, moderators such as gender, age, teaching experience, and volunteerism were not examined due to sample limitations. Expanding the sample and investigating these factors is essential. Thirdly, to mitigate potential bias arising from the diverse music education cultures across Indonesia, broader regional coverage is required, as data collection was limited to a few regions. Finally, this study relied solely on quantitative data; incorporating qualitative methods, such as interviews, would provide deeper insights into teachers' perspectives.

Conclusion

This study highlights how integrating VR technology can effectively preserve and teach Indonesian traditional music. The utilisation of the UTAUT and TPACK frameworks explores the factors influencing VR adoption among music teachers in West Java. The findings suggest that technological competence, cultural aspects, behavioural intention, and pedagogical knowledge play important roles in the acceptance of VR technology. High technological competence not only enhances users' intention to adopt VR but also fosters a more supportive cultural environment. However, cultural factors are less influential than pedagogical knowledge and behavioural intention. Behavioural intention is a strong predictor of technology adoption, and teachers with solid pedagogical knowledge are more likely to incorporate VR into their teaching practices. The study emphasises the significance of TPACK training in increasing VR adoption, as it equips teachers with the skills to use technology effectively in music education.

Practical Implications

The findings offer practical implications for the development of VR technology in cultural learning, particularly in Indonesian music: (1) to enhance VR acceptance, educational institutions should provide training programmes that strengthen teachers' technological competence and teach the fundamentals of VR for classroom application; (2) although cultural factors have less impact, community and school support can foster a conducive environment for innovation and increase teachers' confidence in using VR; (3) pedagogical knowledge is as important as technological competence, as teachers with a strong pedagogical understanding can design more interactive and immersive learning experiences.

Training should utilise instructional strategies specifically designed for VR. For VR technology to be used sustainably, supportive factors such as infrastructure, technical support, and access to VR devices is essential. These findings lead to several recommendations for teachers in colleges and universities to strengthen

the quality of music teacher training: they should participate in continuous professional development, collaborate with the community and cultural institutions, balance pedagogical and technological competence, and advocate for institutional support systems to ensure the sustainable use of VR in music education. In addition, future research is recommended to develop comprehensive learning guidelines for music teachers that outline how museums can be effectively integrated into both intracurricular and extracurricular learning. Such guidelines could provide structured approaches for incorporating museum resources into classroom instruction, project-based activities, and cultural enrichment programmes, thereby enhancing students' understanding of music and cultural heritage while positioning museums as active partners in education.

Theoretical Implications

This study provides theoretical contributions to understanding technology adoption in cultural education. Integrating the UTAUT and TPACK frameworks give new insights into the way of technological competence, behavioural intentions, pedagogical knowledge, and cultural aspects influence each other in the context of technology adoption. The integration of UTAUT and TPACK produces a comprehensive model for evaluating VR technology acceptance in education and measures technological intentions and competence and considers pedagogical knowledge and cultural support in teaching.

Ethical Consideration

This study adhered to the British Psychological Society (BPS) Code of Human Research Ethics. Informed consent was obtained from all participants, who were assured that they could withdraw at any time without any consequences. Data collection methods, including surveys, interviews, and observations, ensured the confidentiality and anonymisation of personal information. The study received approval from the Institute for Research and Community Service at Universitas Pendidikan Indonesia (UPI), with measures implemented to minimise risks to participants. Throughout the process, the study emphasised respect for participants, research integrity, and honest reporting.

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