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The Application Research of Digital Twins in Art Education

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Abstract. Digital twin based on virtual reality (VR) technology can construct complex objects from real space to virtual digital space and depict the dynamic characteristics of objects in real time through information linkage. In order to explore the application path of digital twin technology in art education such as fine arts, music, dance and drama, impact on learners' immersive experience, this study first identifies the relevance of digital twin technology to art education and build hypotheses around the impact of VR on learner immersion experience. Secondly, a measurement questionnaire is constructed based on the cross-media Sensory Scale and the validity is tested by confirmatory factor analysis. Finally, an immersion experience model composed of nine factors is constructed through the analysis hierarchy process (AHP) method to verify the hypothesis. The results shown that the application of digital twin in art education can improve learning efficiency and experiential sensation through interactivity, compatibility and authenticity.

Keywords: Digital twins, Art education, Immersive experience, Analytic hierarchy process.

1. Introduction

With the information technology developed and digital application expand, the digital twin technology has emerged relying on virtual reality technology. Digital twin is referring to giving the attributes of the physical entity to a virtual mirror image [1]. This powerful digital technology can restore the historical attributes of physical entities and simultaneously calibrate, optimize, and predict their virtual mirror images, creating new value through the application and innovation of data (as shown in Figure 1). This new concept originated from the "information mirror model" concept proposed by Professor Grieves in the United States, mainly used in the military and aviation fields, and was formally defined by the National Aeronautics and Space Administration of the United States in 2012 [2]. As its application scope continues to expand, in 2016, digital twin technology was listed as one of the top ten strategic technologies. With the continuous development of intelligent technology, the concept of digital twin is becoming clearer, and digital twin technology is constantly advancing. Presently, digital twin technology mainly revolves around the fusion of data and models, achieving precise digital mapping of physical objects in real time in the digital space, and enabling intelligent decision-making and control throughout the entire lifecycle of physical objects. Based on this, introducing digital twin technology into the process of assisting art education in universities can effectively improve the course efficiency of art education, increase the diversity and interest of the implementation of art education, and provide a new direction and an effective path for the dissemination of art and culture, the training of artistic talents, and the construction of national aesthetic education.

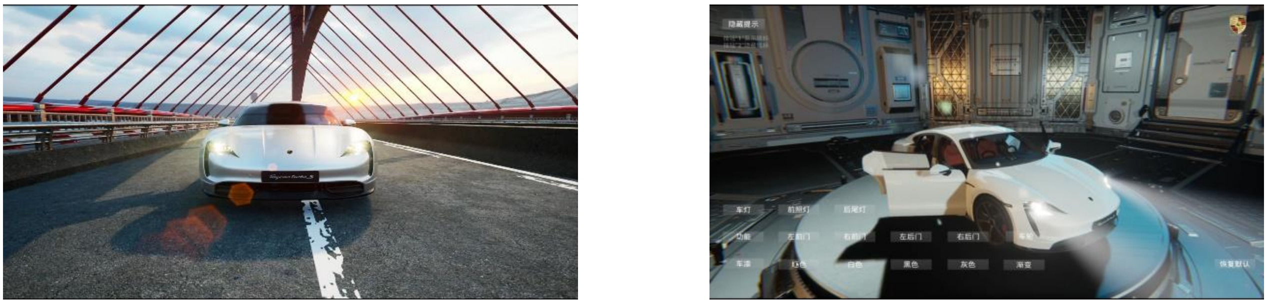

Figure 1. Driving simulation based on VR environment (Designed by Tan Jiaxing).

Art education, distinct from traditional academic education, emphasizes strong perceptual thinking abilities, prominent self-expression awareness, high levels of aesthetic ability, and advanced creativity and innovation capabilities [3]. Therefore, traditional teaching methods such as single theory teaching and one-sided teacher demonstrations are no longer suitable for the field of art education. Instead, greater emphasis should be placed on classroom interaction and experiential learning, the connection between theory and practice, the intriguing nature of knowledge transmission, flexibility in time and space, digitalization and efficiency of teaching content, as well as the innovation of thinking and technology. The innovative teaching mode of applying digital twin technology to art education can not only strengthen the learning atmosphere through sensory interactive immersive experiences, but also stimulate students' enthusiasm for learning, enhance their interest and efficiency in acquiring new knowledge, and help them achieve ideal learning outcomes, effectively resolving the difficulties in art professional teaching (as shown in Figure 2). Furthermore, it can promote the creative transformation and innovative development of traditional culture, drive sustainable design of traditional culture, and create new possibilities for the dissemination strategies and methods of excellent culture and innovative design.

Figure 2. Intangible cultural heritage digital exhibition space (Designed by Tan Jiaxing).

The application effect of digital twinning in art education is influenced by multiple factors, and currently, there is relatively little research on the application of digital twinning technology in art education. Therefore, this study will identify the correlation between digital twin technology and art education through literature research. It will define the set of indicators that affect the teaching effect of digital twin technology applied in the process of art education and establish research hypotheses. Surveys will be conducted, and data will be collected to verify these hypotheses using the Analytic Hierarchy Process. The study will investigate its impact on learners' immersive experiences and hopes to explore the application path of digital twin technology in art education, find teaching models more suitable for the current status of art education, and provide reference significance for future research.

2. Preliminary Construction of the Indicator Set

2.1. Questionnaire Design and Implementation

Based on literature from the past 5 years and classic literature on the application model of digital twin technology, combined with the characteristics of art education courses in art colleges, a preliminary set of indicators affecting the application of digital twin technology in the process of art education in art colleges was extracted.

After organizing existing literature, a "Research Survey on the Application of Digital Twin in Art Education" was designed from three dimensions: perceptual level, equipment level, and experiential level. A total of 23 questionnaires were distributed to art college ideological and political teachers and students, requiring teachers to have more than 1 year of teaching experience and students to have a satisfactory or above annual assessment. The questionnaire set includes 18 items, including 6 items for operational feelings, 6 items for presentation effects, and 6 items for experiential feelings, clearly defining the meaning of each skill and setting questions. The questionnaire uses a 5-point scale, with a numerical value from 1 to 5, where 1 represents "extremely unimportant" and 5 represents "extremely important." A total of 23 questionnaires were distributed, with a 100% recovery rate and a 100% valid rate.

2.2. Questionnaire Reliability Analysis

The Cronbach's α internal consistency coefficient of this survey is 0.951, which is greater than 0.9, indicating that the reliability of the research data is very high. The Spearman-Brown split-half reliability coefficient value is 0.917, also greater than 0.9, indicating that the reliability of the research data can be used for the analysis of the application research model of digital twins in art education.

3. Construction of Comprehensive Evaluation Model Based on AHP Method

3.1. Initial Indicators

Based on the model of digital twin technology application and existing principal components, and drawing on domestic and foreign reference materials, an AHP hierarchical analysis model is established to structure the evaluation indicators into three levels, namely the goal layer, the criterion layer, and the sub-criterion layer (as shown in Figure3). The goal layer of the hierarchical structure model is the application research of digital twins in art education, the criterion layer includes perceptual aspect B1, equipment aspect B2, and experiential aspect B3. The indicators under B1 are perceptual usefulness C1, ease of use perception C2, and immersive perception C3; the indicators under B2 are interaction C4, real-time C5, and spatial C6; the indicators under B3 are authenticity C7, comfort C8, and convenience C9.

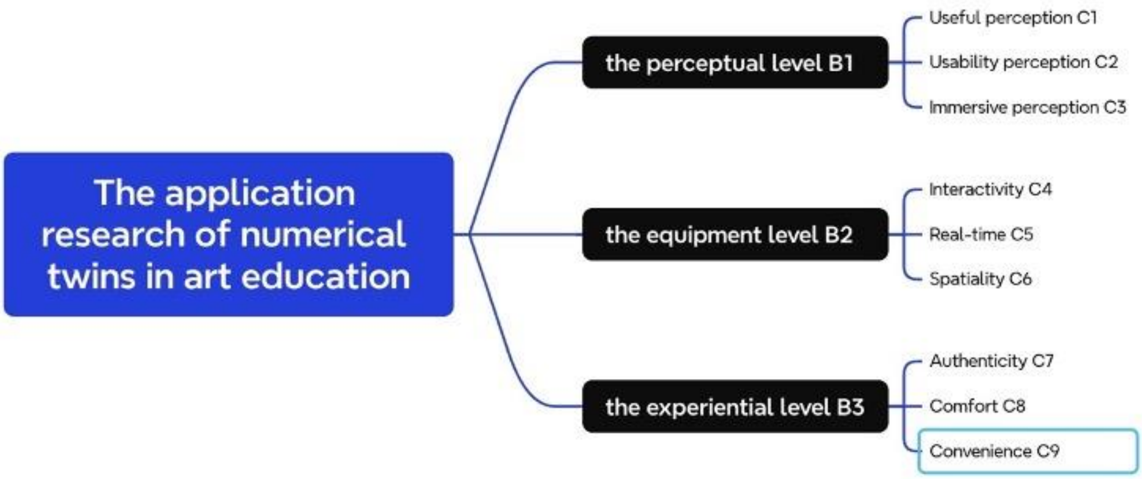

Figure 3. The hierarchical model of digital twins in art education application.

3.2. Questionnaire Design and Implementation

A second questionnaire is conducted for the application research model of digital twins in art education, targeting university art teachers with more than 2 years of experience. The questionnaire consists of three levels and 9 indicators, with corresponding items set and assessed using the 1-7 scoring method to judge the importance of each level indicator, where 1 represents extremely unimportant and 7 represents extremely important. 32 questionnaires were distributed and all 32 were returned, yielding a 100% response rate.

3.3. Weight Calculation

Based on the selected indicator framework, a complete hierarchical structure is formed, and through the involvement of domain experts, the key importance of the indicators is determined. Pairwise comparison matrices are then generated and weights calculated.

Step 1. Establishment of Judgment Matrix

Matrix $A=(a_{ij})_{n\times n}$ representing the relative importance of n indicators, where a_{ij} is the expert's evaluation of the importance of factor *i* relative to factor *j*.

$$\boldsymbol{A}=\begin{Bmatrix} a_1 & a_2 & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{Bmatrix} \tag{1}$$

The relative weights of the compared elements with respect to the hierarchical elements are calculated by the judgment matrix. Let the maximum characteristic root be $\lambda_{max,}$ and its corresponding characteristic vector be used in the formula.

$$\omega_i = \frac{\omega_i}{\sum_{j=1}^{n} \omega_j} = 4.015516998 \tag{2}$$

Step 2. Calculating Consistency Index

The weight vector is calculated using the judgment matrix, requiring the judgment matrix to have a rough consistency. It is necessary to calculate the consistency index (*C.I.*) and the consistency ratio (*C.R.*).

$$C.I. = \frac{\lambda_{max} - n}{n-1} = 0.000 \tag{3}$$

Calculate the consistency ratio (consistency ratio, *C.R.*)

$$C.R. = \frac{C.I.}{R.I.} = 0.000 \tag{4}$$

It is considered that the consistency of the judgment matrix is acceptable When $C.R.<0.1$. Since $0.000<0.1$, it proves the rationality of the consistency test of the matrix. Similarly, using the same method to calculate and arrange the factors at the indicator level, the weight values of the indicator level are obtained and arranged, as shown in Table 1.

Table 1. Weight of Influencing Factors on the Application Effect of Digital Twins

Factors at Regulatory level	Guideline Weight	Weighted Rank	Indicator Former Factors	Indicator Layer Weights	Weighted Ranking	C.R.
B1	0.31968	3	C1	0.10568	8	0.000
			C2	0.10238	9	
			C3	0.11162	6	
B2	0.34215	1	C4	0.11361	3	0.000
			C5	0.11261	3	
			C6	0.11493	1	
B3	0.33818	2	C7	0.11295	5	0.000
			C8	0.11096	7	
			C9	0.11427	2	

4. Discussion

The weight values of the B-layer factors are in the order of B2 > B3 > B1. According to the analysis of the weight values, the application effect of digital twins in art education depends first on the equipment level, with a criterion layer weight of 0.342. The most important factor in the equipment level is spatiality, with a weight score of 0.11493, also ranking first among all factors. The spatiality refers to the depth of field in the scene, the distance between objects, the position of the mover and the three-dimensional sound effects. Precise equipment can create a spatial sense in the virtual space that is almost indistinguishable from the real world. If users can feel the real spatial changes and experience stunning depth effects and lifelike sound effects during the use of digital twin devices, it will greatly enhance the realism and immersion of the digital experience, playing a decisive role in both the experiential and perceptual levels. When applying digital twin technology to the arts such as performance and music, the full utilization of spatiality can greatly enhance the visual and auditory impact of artistic presentations on the audience, achieving a multiplier effect with half the effort. The weight values of interactivity and real-time are both 0.11361, ranking second at the device level and tied for third among all indicators. Strong interactivity often comes with advantages such as clear and perfect instructions, strong interaction, rapid response, and convenient remote communication. The interactive technology in digital twin technology is an important link to integrate theory and practice. Only by real-time recording and display of the interactive process and its data can the utility of interaction be truly demonstrated. Therefore, the equal weight of interactivity and real-time is not incidental.

The hardware devices of digital twins can record the data changes in the operation process in real time, capture the changes in actions of teachers and students in a timely manner, and record the information generated during human-computer interaction. When the operator proficiently utilizes digital twin technology to digitize the process of each creation, real-time and effective recording of operation data can be achieved through computer backend, which can lead to scientific planning and optimized resource allocation, reducing waste of time and manpower [4]. The real-time display of learning progress, creative achievements and sound and timely evaluation mechanism can greatly give students a sense of timely achievement, stimulate students' enthusiasm and initiative in learning, and enable students to engage more independently in learning activities.

The guidelines for the experiential layer have a weight of 0.338, ranking second in weight order. The convenience factor has a weight value of 0.11427, ranking first in experiential layer and second among all factors. The convenience of digital twinning technology is evident in its ability to operate without limitations of location, time, and resources, reducing the burden on teachers during the teaching process. It provides an anytime, anywhere learning experience and expands creative space. In the teaching process, operators can use digital twinning technology to simulate teaching content, view and learn repeatedly, reducing the teacher's repetitive operations, lightening the teaching burden, optimizing classroom progress management, improving classroom time utilization, effectively enhancing course efficiency. It also reduces resource waste and repetitive work in the creative process, making art creation more efficient. Its importance should not be underestimated. The authenticity, which ranks second only, has a guideline layer weight of 0.11295, ranking fifth overall. The authenticity of three-dimensional space, image color saturation and contrast can enhance the authenticity of art teaching, strengthen teaching effectiveness, generate strong student interest in learning content, enhance student immersion and concentration in the course, and improve classroom quality and teaching efficiency. Therefore, the authenticity of the digital virtual space is an important indicator for determining scene immersion.

Comfort, ranking third, is positioned seventh in overall weight, with a weight value of 0.11096. The improvement of comfort mainly needs to address issues such as avoiding dizziness, motion blur, inaccurate focus, unstable images, and audio-video asynchronization to enhance the operator's experience. The enhancement of comfort can shorten the fatigue cycle during the teaching and learning process between teachers and students, highlighting its importance in enhancing course efficiency.

Perceptual weighting ranks third in priority, with a guideline weighting of 0.320. Immersive perception holds the highest weight value of 0.11162 within the dimension, ranking sixth overall. In fact, the degree of immersive perception reflects the effects on both the device level and the experiential level mentioned above. Good equipment can bring about a superior experiential feeling, which is precisely the prerequisite for immersive perception. The degree of immersive sensory experience, which determines the degree of immersion in the learning process for teachers and students, is indisputably important. Useful perception, ranked eighth among all factors and second within the dimension, carries a weight value of 0.10568. Useful perception refers to the perceived effectiveness of VR, digitalization, and other technologies in enhancing teaching quality for teachers and students. Understanding this is guiding in practice; therefore, useful perception is the first step in guiding people to apply digital twinning technology to art education, as well as a crucial step in stimulating the interest of teachers and students in learning about digital twinning technology. With a weight value of 0.10238, usability perception ranks third within the dimension. It is an important indicator for guiding people to attempt the application of digital twinning technology in art education, enhancing usability perception, and guiding people to try using digital twinning technology in art education. Usability perception refers to the perceived difficulty of operating VR and other technologies. Despite ranking ninth among all indicators, its importance should not be overlooked. Improving usability perception can not only stimulate the interest of teachers and students in learning about digital twinning technology, cultivate enthusiasm for learning, and enhance learning initiative but can also indirectly improve the efficiency of teachers and students' practical abilities and training under the implied impression that the equipment is easy to operate, thus improving the effects of art education courses.

The perception of usability, though arising from the subjective experience of teachers and students with digital twin technology, is also a requirement for the operability of hardware devices within the technology. Therefore, in the process of practical teaching, the setup of hardware facilities needs to ensure that teachers and students can personally engage and immerse themselves in completing various tasks, in order to maximize the effectiveness of applying digital twin technology in art education [5].

5. Conclusion

This paper established the indicators and their weights that impact the application effect of digital twins in art education based on the AHP method. It is argued that the digital twin technology in practical teaching can not only compensate for the lack of theoretical and practical connections in traditional teaching models, but also meet the efficient teaching needs of teachers and students in the art education process. This has a positive effect on improving the quality of higher education teaching, fully reflecting the necessity and superiority of applying digital twin technology in artistic education. Digital twin technology application in art education, could focusing on students as the subject and practical improving the overall quality of artistic talents, perfecting the construction of the artistic design industry and increasing the output of high-quality artistic works.

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References

[1] Wongon Kim, Sunuwe Kim, Jingyo Jeong, Hyunjae Kim, Hyeonchan Lee, and Byeng D. Youn. Digital twin approach for on-load tap changers using data-driven dynamic model updating and optimization-based operating condition estimation. *Mechanical Systems and Signal Processing*, vol. 181, 2022.

[2] Michael Grieves and John Vickers. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems, In: Kahlen, J., Flumerfelt, S., Alves, A. (eds) *Transdisciplinary Perspectives on Complex Systems*. Springer Cham, 2017: 85–113.

[3] Kevin Tavin and Jerome Hausman. Art Education and Visual Culture in the Age of Globalization. *Art Education*, vol. 57, no. 5, pp. 47–52, 2004.

[4] Xiuyu Chen. Research on the Reform of Hybrid Teaching Mode Based on Digital Twin. In: *Proceedings of the 2021 16th International Conference on Computer Science & Education*. ICCSE 2021. pp. 672–675, 2021.

[5] Aditya P. Mathur. Reconfigurable Digital Twin to Support Research, Education, and Training in the Defense of Critical Infrastructure. *IEEE Security & Privacy*, vol. 21, no. 3, pp. 51–60, 2023.