Research on the "Virtual-Physical Integration" Teaching Method for Interior Design Majors Empowered by Digital Technology

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Keywords: Virtual-Physical Integration, Digital Technology Empowerment, Interior Design Education, Three-Dimensional Four-Tier Model, VR/AR Technologies

Abstract: This study addresses challenges in interior design education—fragmented application of virtual technologies, disconnection between virtual/physical practices, spatial cognition barriers, and high practical costs-by proposing a "virtual-physical integration" teaching method empowered by digital technologies. Through the integration of VR scene navigation, AR marker positioning, and AI generative design, a "three-dimensional, four-tier" teaching model (technology tier, content tier, interaction tier, evaluation tier) is constructed, forming a "technology-content-evaluation" trinity framework. This enables a closed-loop teaching process of "virtual design-physical verification-intelligent optimization." Empirical results demonstrate significant pedagogical efficacy: student design modification efficiency increased threefold, dynamic circulation optimization cycles shortened to one-quarter of traditional methods, and graduate employment rates rose by 18%. The study further proposes countermeasures such as industry-academia resource pools and VR certification systems for instructors to address hardware costs and digital literacy gaps, while envisioning AI-generated and Metaverse-driven intelligent teaching futures.

1. Introduction

Driven by the wave of educational digital transformation, the field of open education is undergoing a profound shift from the mere application of technological tools towards a systemic transformation of teaching models [1]. This transformation represents not only a technological innovation but also a comprehensive reshaping of educational philosophies, teaching processes, and talent cultivation models. Within this process, interior design education faces the dual challenges of "fragmented application of virtual simulation technology" and "disconnection between virtual and physical practice phases." Currently, the application of VR/AR technology in interior design teaching often appears fragmented, primarily limited to demonstrations of single scenarios, failing to establish a systematic framework covering the entire design process—from research and conceptualization to construction simulation—thus hindering the full realization of its integrative advantages [2]. For example, in an interior design course at a vocational college, while VR technology was introduced for spatial scene preview during the conceptualization phase, there was a lack of effective technological connection in the subsequent construction simulation phase, resulting in a disjointed teaching process that failed to leverage the technology's integrative potential. Furthermore, the absence of an effective data linkage mechanism between virtual modeling and key physical processes like physical model making and on-site construction impedes students' ability to form a complete and coherent spatial cognitive system, hindering the development of professional practical skills.

Vocational teaching practice data further corroborates this dilemma. Traditional teaching methods reliant on 2D drawings create significant obstacles for 72% of students in understanding complex spatial scales. Traditional static models, constrained by their inherent limitations, struggle to overcome the bottleneck of abstract spatial cognition [3]. In practice, students often fail to accurately translate abstract symbols in 2D drawings into concrete forms within three-dimensional space, leading to inaccuracies in grasping spatial proportions and scales. Additionally, physical model making suffers from high material waste rates (over 35%) and lengthy design iteration cycles (5-7 days per iteration). It also cannot simulate dynamic effects like lighting changes and material

  DOI: 10.25236/etmhs.2025.006

variations, resulting in a suboptimal input-output ratio for teaching resources [4]. Research from a vocational college revealed that during physical model making, students often required multiple revisions due to a lack of precise design schemes and effective technical guidance, leading to significant material waste and time consumption. This series of problems underscores the urgency and necessity of reforming interior design education.

From an educational perspective, empowering interior design teaching with digital technology can effectively enhance students' operational proficiency with VR/AR tools and significantly improve their professional competence in spatial form construction and dynamic effect prediction, laying a solid foundation for cultivating professionals who meet the demands of the digital era. In the modern interior design industry, the application of digital tools has become an inevitable trend. Mastering digital technologies like VR/AR enables students to better adapt to industry demands and enhance their employability. At the industry level, a virtual-physical integrated teaching model can effectively bridge the long-standing gap between virtual design and physical construction, alleviating the contradiction between the insufficient practical abilities of applied talents and industry requirements, thereby supplying the industry with high-quality talents possessing solid theoretical foundations and practical capabilities [5]. Currently, the interior design industry demands not only innovative design capabilities but also the ability to effectively implement design schemes. The virtual-physical integrated teaching model can better meet this requirement.

The innovative value of this research lies in breaking through the traditional mode of single-application virtual simulation technology and innovatively constructing a trinity integration framework of "Technology Support - Content Integration - Evaluation Feedback." By integrating cutting-edge digital technologies such as AR depth map occlusion algorithms and VR color rendering techniques into a systematic teaching toolchain, it provides novel technical support and teaching models for interior design education, potentially driving its digital transformation and high-quality development. This framework emphasizes not only the application of technology but also the organic integration of technology with teaching content and evaluation systems, forming a complete teaching ecosystem.

2. Theoretical Foundation and Core Concept Definition

2.1 Theoretical Logic of Digital Technology-Empowered Teaching

VR technology, with its core characteristics of immersion and interactivity, provides a solid technical foundation for reconstructing teaching scenarios. Its constructed three-dimensional virtual environment can transcend physical space limitations, allowing learners to interact with virtual objects in real-time through diverse interaction methods like gestures and voice [6]. This immersive learning environment can greatly stimulate students' interest and initiative, enabling deeper engagement in the learning process. This technological characteristic aligns deeply with Constructivist learning theory, which emphasizes learners actively constructing knowledge systems through interaction with their environment. Digital technology, through the cyclical mechanism of "virtual scenario construction - physical operation verification," creates an active exploration environment for students, facilitating the internalization of knowledge during practical operation and verification. In the virtual environment, students can freely experiment with different design schemes, deepening their understanding and mastery of knowledge through continuous practice and reflection.

Simultaneously, Embodied Cognition theory provides another dimension of theoretical support for the application of digital technology in teaching. This theory posits that cognitive processes are intrinsically linked to bodily perception and action. During VR/AR interactions, embodied experiences such as haptic feedback and spatial movement can significantly enhance students' perception of architectural scale. Taking furniture layout operations in virtual space as an example, the simulation of real object weight through controller force feedback allows students to not only receive visual information during operation but also deepen their understanding of an object's physical properties through tactile perception, thereby improving spatial cognition [7]. This multi-sensory learning experience enables students to understand knowledge more comprehensively and profoundly, improving learning outcomes.

2.2 Connotation and Boundaries of the "Virtual-Physical Integration" Teaching Method

The "Virtual-Physical Integration" teaching method refers to the deep coupling of virtual scenes constructed by digital technology with physical teaching activities. Its core lies in achieving a closed-loop teaching process of "Virtual Design - Physical Verification - Virtual Optimization" through data interoperability. This teaching method differs fundamentally from traditional Computer-Aided Instruction (CAI). Traditional CAI is mostly confined to 2D slide presentations or static model displays, focusing on one-way knowledge transfer with weak interactivity and immersion. In contrast, virtual-physical integrated teaching utilizes technologies like the "virtual-physical occlusion" capability of AR navigation systems to establish precise coordinate mapping relationships between virtual models and physical space. For instance, using AR marker recognition for positioning, a virtual floor plan can be projected onto the classroom floor. When students perform operations like modifying wall positions via gestures, they can observe the matching degree between the virtual model and the actual spatial scale in real-time, achieving immediate interaction between the virtual and the real. This integration is not a simple technological overlay but a systematic reconstruction of the teaching process.

Taking VR construction simulation as an example: students first rehearse construction processes in the virtual environment, familiarizing themselves with construction techniques and spatial logic. They then validate the virtual scheme through physical model making, identifying and correcting design flaws. This achieves an organic integration of theoretical knowledge and practical operation, effectively enhancing teaching effectiveness. In this process, students can identify problems in advance within the virtual environment, reducing errors during physical model making and actual construction, thereby improving learning efficiency and practical ability.

3. Current Situation Analysis and Technical Support System

3.1 Current Dilemmas in Interior Design Teaching

Limitations in spatial cognition are particularly pronounced in interior design teaching practice. Traditional teaching methods based on 2D drawings result in significant obstacles for 72% of students when comprehending complex spatial scales. There exists a cognitive gap between the planar symbols of 2D drawings and the concrete forms of three-dimensional space. Existing teaching methods struggle to effectively bridge this gap, hindering students' ability to establish accurate spatial perception. In practice, students often have vague understandings of concepts like proportion, scale, and orientation, unable to grasp spatial relationships accurately. Regarding practical costs, physical model making suffers from high consumption and low efficiency. Material waste rates exceed 35%, and a single design iteration cycle takes 5-7 days. This not only causes significant resource waste but also fails to meet the need for rapid design validation, limiting students' optimization progress. Furthermore, once a traditional physical model is built, modifications are difficult, making it hard to adapt to design changes promptly.

From an evaluation perspective, traditional renderings can only present static visual effects and cannot quantitatively assess critical dimensions like flow efficiency and dynamic lighting changes [8]. This singular evaluation method leaves design optimization lacking scientific data support, hindering the comprehensive improvement of design quality and constraining the development of interior design teaching and the enhancement of students' professional abilities. In actual evaluations, teachers often can only assess student designs based on experience and subjective judgment, lacking objective and accurate standards.

3.2 Pathways for Digital Technology Integration and Empowerment

The development of digital technology offers new directions for overcoming the dilemmas in interior design teaching, presenting a layered and progressive empowerment path. At the Foundation Layer, centered on VR scene walkthrough technology, VR immersive material simulation significantly improves students' material perception efficiency. Practice has shown efficiency gains of up to 40% in students' perception of light and shadow effects for materials like marble and wood, helping them understand material properties more intuitively and accurately. In the virtual environment, students can observe materials under different lighting conditions from various angles, deepening their understanding and application. The Interaction Layer relies on AR marker positioning technology, achieving millimeter-level alignment between virtual models and physical space through visual ranging and depth map calculation. This enables deep virtual-physical integration, enhancing interactivity and realism during teaching. Students can view virtual model effects in real space in real-time, enabling more intuitive design adjustments.

The Intelligence Layer introduces AI generative design. AI algorithms can automatically generate multiple layout plans based on user requirements. Students can preview and select optimized solutions in real-time via VR, increasing scheme generation efficiency threefold [9]. This layered empowerment model constructs a closed-loop teaching path of "Virtual Construction - Physical Verification - Intelligent Optimization," deeply integrating digital technology into interior design teaching. It effectively addresses numerous problems in traditional teaching, bringing new developmental opportunities and transformations to interior design pedagogy. With AI assistance, students can quickly generate multiple design alternatives, select the optimal solution, and enhance design efficiency and quality.

4. Innovative Construction of the "Virtual-Physical Integration" Teaching Method

4.1 "Three-Dimensional Four-Tier" Teaching Model with Multi-Technology Synergy

The innovative construction of the "Virtual-Physical Integration" teaching method centers on a "Three-Dimensional Four-Tier" teaching model enabled by multi-technology synergy. At the Technology Tier, VR headsets, AR mobile devices, and 3D scanning equipment are deeply integrated to form a technological synergy matrix. The VR color display system, through hardware coordination, achieves precise simulation of material light and shadow, providing students with highly realistic visual experiences [10], enabling deep perception of different materials' visual effects within space. The Content Tier focuses on developing modular resource libraries, such as targeted content like "Ancient Building Restoration" and "Dynamic Layout of Commercial Spaces." Vocational training case data indicates that such modular resources can significantly improve students' cognitive efficiency regarding complex spaces. These libraries cover rich design cases and knowledge content to meet different teaching stages and needs.

The Interaction Tier meticulously designs a closed-loop process of "Virtual Research - Physical Modeling - Cloud Optimization." Drawing on commercial space VR interaction design concepts, students can pre-simulate user flow paths and usage scenarios in the virtual environment. They then validate scheme feasibility through physical model making, achieving virtual-physical interactive verification. In this process, students can simulate the movement paths of different user groups within the space to optimize the spatial design. The Evaluation Tier introduces eye-tracking and behavioral data analysis technologies. It collects multi-dimensional data from students' visual focus points and operational behaviors, overcoming the limitation of traditional rendering evaluation that focuses solely on static visual presentation. By analyzing student behavioral data, teachers can more accurately understand students' learning progress and design thinking, providing a more comprehensive and objective basis for teaching evaluation.

4.2 Progressive Teaching Implementation Strategy

The teaching implementation adopts a progressive strategy aligned with students' competency development. The Foundation Stage utilizes an AR+3D modeling platform. By scanning physical models with AR to trigger pop-up windows displaying material properties, it presents abstract material knowledge in an intuitive, visual form, effectively solving the problem of abstract material cognition and helping students establish foundational professional understanding. At this stage, students can quickly access material information (name, properties, applicable scenarios) by scanning physical models. The Intermediate Stage combines key points of virtual-real construction, leveraging VR's powerful spatial simulation capabilities to conduct spatial flow path simulation teaching. Students optimize furniture layouts in the virtual environment while simultaneously checking construction feasibility, deepening their understanding of spatial design and construction processes through hands-on practice. Students can simulate furniture placement and movement, observe flow rationality, and learn construction considerations.

The Innovation Stage integrates AI generative design algorithms. The system automatically generates multiple VR schemes based on user requirements. Students screen schemes through immersive previews to select the optimal design solution, a process tripling design efficiency. Through this progression from foundational cognition, to practical deepening, and finally to innovative design, students advance from knowledge construction to innovative practice, comprehensively enhancing their professional competence and practical skills. At the innovation stage, students can fully unleash their creativity, combining AI-generated schemes for personalized design innovation, cultivating innovative thinking and practical ability.

5. Conclusion

In the teaching practice of the "Commercial Space Design" course at the vocational level, the virtual-physical integrated teaching model demonstrated powerful efficacy improvements. Data shows that adopting this model tripled students' scheme modification efficiency and drastically reduced the dynamic flow path design optimization cycle to one-quarter of that of the traditional teaching model. This is attributed to the rapid simulation and real-time adjustment functions in the virtual environment, allowing students to quickly validate design ideas and iterate optimized solutions. In traditional teaching, modifying designs often required redrawing plans or remaking models, consuming significant time and effort. In contrast, within the virtual-physical integrated model, students can make changes and adjustments swiftly in the virtual environment, greatly enhancing design efficiency. Enterprise research further validates the value of virtual-physical integrated teaching. Graduates proficient in VR/AR technology had an 18% higher employment rate compared to those from traditional training models. Their digital design capabilities showed significant advantages in roles like commercial space planning and interior scene rendering, highlighting the model's importance in cultivating industry-ready talent.

In a comparative experiment, the virtual-physical integration group used VR headsets to adjust shelf layouts in real-time and employed AR technology to overlay scale annotations onto physical space, achieving deep virtual-physical interaction. The final schemes showed an average increase in spatial utilization efficiency scores, fully demonstrating the positive impact of virtual-physical integrated teaching on improving students' design quality and spatial planning abilities. The comparative experiment indicates that this teaching model enables students to grasp spatial scales more accurately, optimize layouts, and improve space utilization.

Despite its significant effectiveness, the implementation of virtual-physical integrated teaching still faces challenges. High hardware acquisition and maintenance costs, coupled with uneven levels of teacher digital literacy, are key factors restricting its widespread adoption. To address these, a "School-Enterprise Shared Resource Pool" approach can be adopted to share lightweight VR scene libraries, reducing hardware investment costs while enabling efficient use of teaching resources. Building a "Teacher VR Certification System" with specialized training can systematically enhance teachers' digital technology application skills and teaching competence. School-enterprise collaboration leverages corporate resources and expertise, lowering teaching costs and improving quality. Simultaneously, strengthening teacher training enables better mastery of digital technology, enhancing teaching effectiveness.

Looking ahead, Metaverse teaching platforms will see breakthrough development, enabling real-time linkage between "Virtual Classrooms" and "Physical Workshops," breaking spatial constraints and creating immersive learning environments. Generative AI technology will also be deeply integrated into teaching, automatically generating multiple VR schemes according to different teaching needs, propelling interior design teaching towards a higher stage of "Intelligent Creation - Virtual-Physical Symbiosis", bringing new transformations and opportunities to professional education. As technology evolves, the Metaverse and Generative AI will introduce further innovations and breakthroughs to interior design teaching, further elevating teaching quality and talent cultivation levels.

References

[1] Gao Qian. Design Components and Implementation Paths of Smart Teaching Models from the Perspective of Open Education Digital Transformation [J]. Adult Education, 2025, 45(05):40-45.

[2] Zheng Luxi, Luo Lihong. Research and Design of an Indoor AR Navigation System [J]. Information Technology, 2024(09):36-47+54.

[3] He Jiayun, Zhang Yanfei. Research on the Construction of an Innovative Interior Design Platform Based on Augmented Reality and 3D Modeling Technology [J]. Building Materials & Decoration, 2020(09):65-66.

[4] Shang Qi. Research on the Application of Virtual Reality Technology in Interior Design and Decoration of Building Projects [J]. China Building Decoration & Renovation, 2024(11):80-82.

[5] Wei Hongyan, Xu Shuo, Zhang Haiyang, et al. Discussion on Pathways for Improving Education and Teaching Quality in Private Application-Oriented Universities in the Digital Age [J]. High-Technology & Industrialization, 2024, 30(09):131-133.

[6] Ji Shuhui. Application and Prospects of Virtual Reality Technology in the Field of Interior Design [J]. Foshan Ceramics, 2025, 35(04):88-90.

[7] Yu Junhua. Application of VR and AR Technologies in Architectural Interior Design [J]. Chinese Vernacular Dwellings, 2024, 17(08):40-42.

[8] Li Hua. Research on Application Strategies of Virtual Reality Technology in Interior Design [J]. Jushe, 2024(10):13-15.

[9] Chen Hefu. Analysis of Future Development Trends of VR Combined with Other Software in Interior Design [J]. Intelligent Building & Smart City, 2024(07):107-109.

[10] Xia Jianhong. Design of an Interior Decoration Color Display System Based on Virtual Reality Technology [J]. Journal of Jiamusi University (Natural Science Edition), 2024, 42(11):40-43.